Development of the Ductus Venosus in the SD Rat

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原　　著

Development of the Ductus Venosus in the SD Rat

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Abstract We used scanning electron microscopy to observe the development of the ductus venosus in the fetal rat liver. At day 13 of gestation, the vascular system in the liver was already formed and the umbilical vein had branched many capillaries to the parenchyma of the liver and was connected to the posterior vena cava directly by one small ductus venosus. At day 14 of gestation, the umbilical vein bulged at its terminal part and bifurcated into the ductus venosus, which joined the posterior vena cava, and a branch that anastomosed with the vitelline vein. The ductus venosus had no branches and subsequently enlarged and then degenerated just before birth. The bulging part of the umbilical vein and its branches degenerated in the later stages of gestation. The vitelline vein developed to form the capillaries of the liver and the intestinal venous system. In the SD rat liver, the ductus venosus was therefore established by development of the terminal part of the umbilical vein, which anastomosed directly with the posterior vena cava.

Key words : ductus venosus, rat, SEM

Introduction

The ductus venosus (DV) is a bypass that connects the umbilical vein (UV) with the posterior vena cava (PVC) during fetal life in mammals. According to textbook of embryology, this duct is formed by the gathering of capillaries that branch in the liver as a result of excess blood flow[1]. In the rat, however, the mechanism by which this direct channel to the PVC is constructed remains obscure. Our study was designed to observe the development and, in particular, construction of the DV in the SD rat by scanning electron microscopy.

Materials and methods

All procedures were done in accordance with the "Guiding principles for the care and use of animals in the field of physiological sciences" of the Physiological Society of Japan. Female SD rats, 12-13 weeks old at the time of mating, were used in the present study. The females were placed with males overnight and examined for the presence of sperm in vaginal smears in the next morning. The day on which sperm were found was designated as day 0 of gestation and the pregnant females were caged individually from then on. They were sacrificed under ether anesthesia on days 13 through 22 of gestation and their fetuses were obtained by the caesarian section. We used the 4 fetuses on 13 day of gestation, 5 fetuses on 14 day of gestation, 5 fetuses on 15 day of gestation, 5 fetuses on 16 day of gestation, 3 fetuses on 18 day of gestation, 7 fetuses of 20 day of gestation and 6 fetuses

on 22 day of gestation. An injection needle was inserted into the UV of each fetus to perfuse the vessels in the liver with saline. Immediately after the blood was drained off, a casting resin mixture (Mercox, Dainippon Ink and Chemicals Incorporated, Tokyo, Japan) was injected into the UV through the same needle. After complete polymerization of the injected resin, the fetus was immersed in NaOH solution at 60 (C. The concentration of NaOH varied from 0.3 % to 1.0 % and the duration of immersion varied from overnight to longer, according to the age and size of each fetus. Following maceration of the soft tissues, the specimen was washed gently in running water. The resultant cast was air-dried and the liver and surrounding tissues were dissected out with a sharp needle under a binocular dissecting microscope (SFZ-10 Nikon, Japan). The cast was then sputter-coated with gold in a vacuum chamber (E-1030 Hitachi, Japan) and observed under a scanning electron microscope (S-4100 Hitachi, Japan).

Results

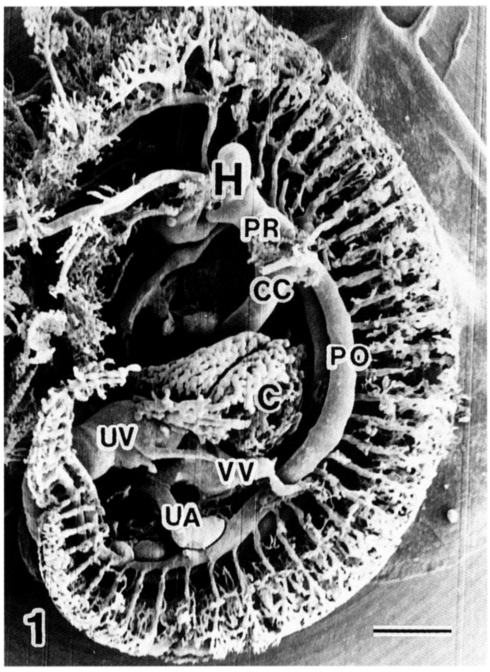
Day 13 of gestation. The postcardinal vein and the common cardinal vein were anastomosed and entered the immature heart. The hepatocardiac channel of the PVC was connected to the common cardinal vein. The precardinal vein entered the heart directly. The vascular system of the liver was already formed (Fig. 1). The left UV entered the liver, distributing some branches in the liver parenchyma and connecting directly with the PVC by a small vein (Fig. 2). The vitelline vein (VV) also sent out some capillaries in the liver. The two umbilical arteries fused into one before leaving the body.

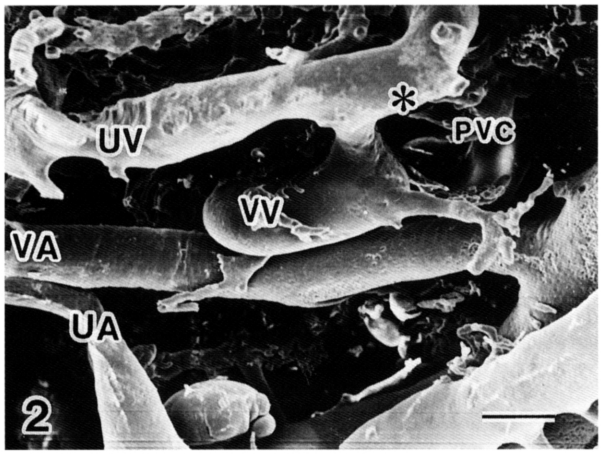
Day 14 of gestation: Two VVs accompanied by one vitelline artery ran along the right side of the UV in confluence with each other (Fig. 3). The terminal part of the UV with which the VV anastomosed was bulged to some degree, sprouting small branches into the parenchyma of the liver (Figs. 3, 4). This bulging part (BP) was bifurcated at its apex. One branch was the DV, which was small and short and joined the anterior part (hepatocardiac channel) of the PVC, and the other was the branch that joined the VV. Although the hepatocardiac channel of the PVC had no branches, the posterior part of the PVC had many branches that were afferent veins from the liver parenchyma (hepatic veins, Fig. 4).

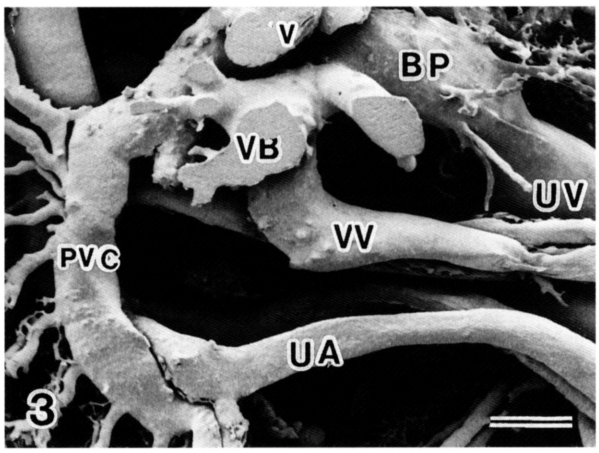
Day 15 of gestation: The PVC was gradually developing further. The diameter of the BP (about 0.8 mm) was two to three times greater than that of the DV (about 0.3 mm), making it easy to distinguish them (Fig. 5). The distal part (placental side) of the VV had partly degenerated. From the BP, many branches coursed to various parts of the hepatic parenchyma. The hepatic veins were well developed (Fig. 6).

Day 16 of gestation: We observed a single VV that was beginning to degenerate. Branches sprouting from the terminal part of the VV had developed further. One of these branches was particularly well developed and coursed to the caudal part of the liver as a mesenteric branch. The DV was longer than on day 15. The branches from the BP itself were also more developed (Fig. 7).

Day 18 of gestation: Many well developed hepatic veins entered the PVC (Fig. 8). With the regression of the yolk sac, the VV had become progressively smaller but the mesenteric branch persisted as the portal vein. From the terminal part of the VV, many well developed branches extended in







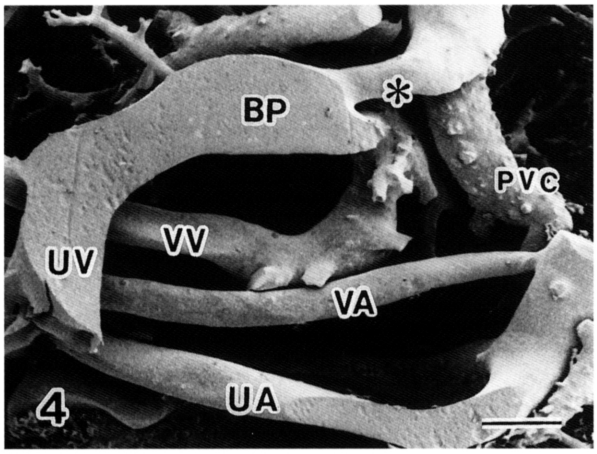
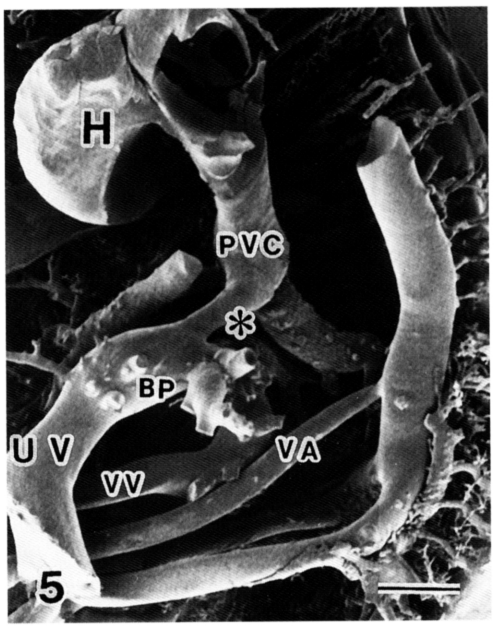


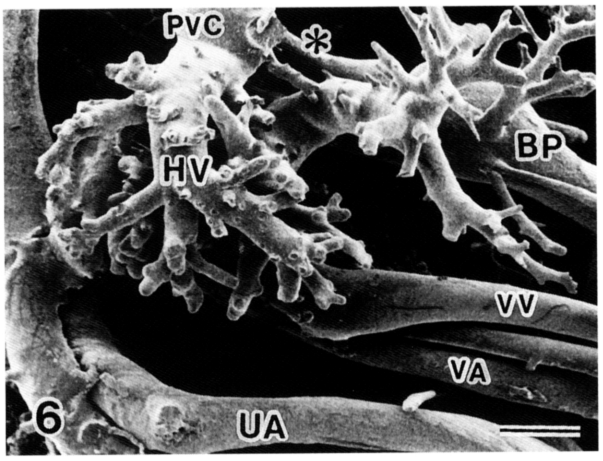
Fig. 1 Resin cast of the cardio vascular system of the rat fetal body (left side) on day 13 of gestation. The cardio vascular system of the liver is already formed and the precardinal and postcardinal veins are still evident. Bar = 600 μm
C : capillaries of the liver ; CC : common cardinal vein ; H : heart ; PO : postcardinal vein ; PR : precardinal vein ; UA : umbilical artery ; UV : umbilical vein ; VV : vitelline vein.

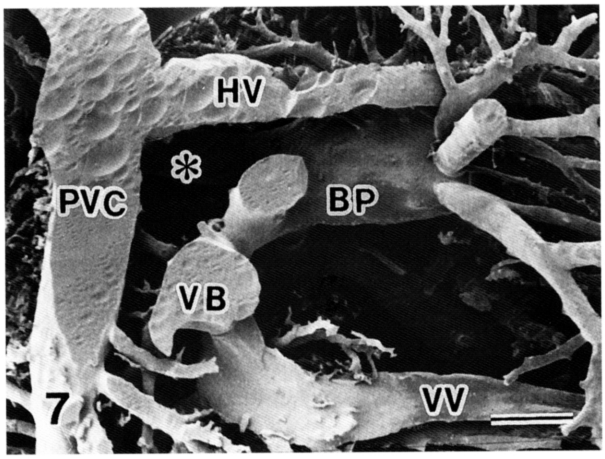
Fig. 2 Resin cast of the cardio vascular system around the fetal rat liver (left side) on day 13 of gestation. Almost all the capillaries in the liver parenchyma are removed by the needle and forceps. The UV anastomoses directly with the hepatocardiac channel of the PVC. The VV has branches and connects with the UV. Bar = 180 μm
asterisk : immature ductus venosus ; PVC : posterior vena cava ; UA : umbilical artery ; UV : umbilical vein ; VV : vitelline vein, VA : vitelline artery

Fig. 3 Cast of the cardio vascular system around the fetal rat liver (right side) on day 14 of gestation. Two vitelline veins run confluent with each other just before anastomosing with the hepatic circulation. The PVC receives some efferent branches as hepatic veins from the liver. The terminal part of the UV, with which the VV anastomoses, bulges to some degree. The VV has some branches in the liver. Bar = 570 μm
BP : bulging part of the umbilical vein ; HV : hepatic vein ; PVC : posterior vena cava ; UA : umbilical artery ; UV : umbilical vein ; VV : vitelline vein ; VB : branch of the vitelline vein.

Fig. 4 Cast of the cardio vascular system of the fetal rat liver (left side) on day 14 of gestation. The surface of the UV is sliced. The DV (asterisk) is clearly distinguishable from the BP. The PVC receives some efferent branches as hepatic veins from the liver. Bar = 570 μm
asterisk : ductus venosus ; BP : bulging part of the umbilical vein ; PVC : posterior vena cava ; UA : umbilical artery ; UV : umbilical vein ; VA : vitelline artery ; VV : vitelline vein.







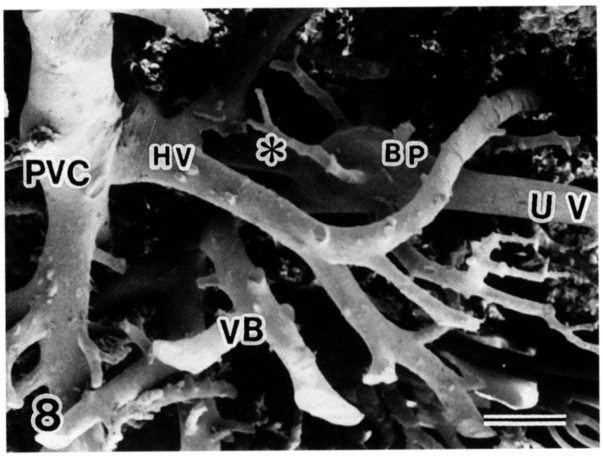


Fig. 5 Resin cast of the cardio vascular system of the fetal rat body (left side) on day 15 of gestation. The diameter of the BP is larger than that of the DV. The terminal part of the VV has some small branches. Bar = 570 μm
asterisk : ductus venosus ; BP : bulging part of the umbilical vein ; H : heat ; PVC : posterior vena cava ; UV : umbilical vein ; VA : vitelline artery ; VV : vitelline vein.

Fig. 6 Cast of the cardio vascular system of the fetal rat liver (right side) on day 15 of gestation. The PVC is gradually developing well. The hepatic vein, branches sprouting from the BP, and the VV are well developed. Bar = 400 μm
asterisk : ductus venosus ; BP : bulging part of the umbilical vein ; HV : hepatic vein ; PVC : posterior vena cava ; UA : umbilical artery ; VA : vitelline artery ; VV : vitelline vein.

Fig. 7 Cast of the cardio vascular system of the fetal rat liver (right side) on day 16 of gestation. The surface of the PVC is sliced. Hepatic veins are developed. As in Fig. 6 the branches from the BP and the VV are well developed. The distal part of the VV has partly degenerated. Bar = 435 μm
asterisk : ductus venosus ; BP : bulging part of the umbilical vein ; HV : hepatic vein ; PVC : posterior vena cava ; VB : branch of the vitelline vein ; VV : vitelline vein.

Fig. 8 Cast of the cardio vascular system of the fetal rat liver (right side) on day 18 of gestation. Branches from the VV extend in various directions in the liver. The branches from the BP have degenerated. Bar = 590 μm
asterisk : ductus venosus ; BP : bulging part of the umbilical vein ; HV : hepatic vein ; PVC : posterior vena cava ; UV : umbilical vein ; VB : branch of the vitelline vein.

various directions in the liver. With the development of the intestines, one branch coursing to the caudal part of the liver had developed well to become an excurrent vein of the intestine, concomitantly with the increasing length and thickness of the intestinal tract. The DV was markedly increased in length. Afferent vessels from the BP had begun to degenerate and become smaller.

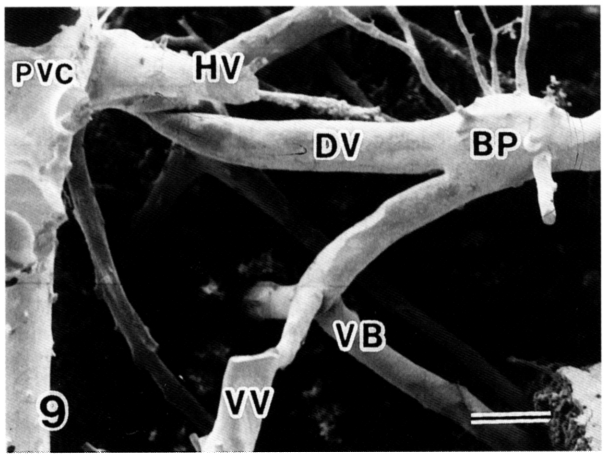
Day 20 of gestation: Many branches from the liver (hepatic vein) now entered the PVC. Branches from the BP had degenerated and decreased in number (Fig. 9). The DV had enlarged further (to about 3.8 mm long and 0.6 mm in diameter) but it had no branches. At this period, the VV sent off many capillaries into the parenchyma of the liver as a portal vein. At the connection of the DV with the PVC, some hepatic veins from the left lobe of the liver opened into the PVC.

Day 22 of gestation: The UV coursed anteriorly on the ventral surface of the liver and entered the liver, where it passed between the right and left medial lobes toward the PVC. At this period the BP was less remarkable and had few branches and the DV had degenerated slightly. The terminal part of the VV had degenerated and gave out many vessels that coursed to almost all parts of the parenchyma (Fig. 10). Its connection to the BP still remained. The excurrent veins from the intestine to the VV (portal vein) had developed and branched.

Discussion

During the fetal period, the DV enables blood to flow from the posterior systemic circulation, the portal circulation and the placental circulation into the heart together. Following the closure of the DV after birth, the portal vein leads blood flow from the gut to the hepatic sinusoids[2].

The terminal part of the UV bulged and gave out two vessels: at 14 day of gestation, one was the DV which connected with the PVC, and the other anastomosed with the VV. This anastomosis itself is called the "portal sinus"[3)4)]; many afferent vessels



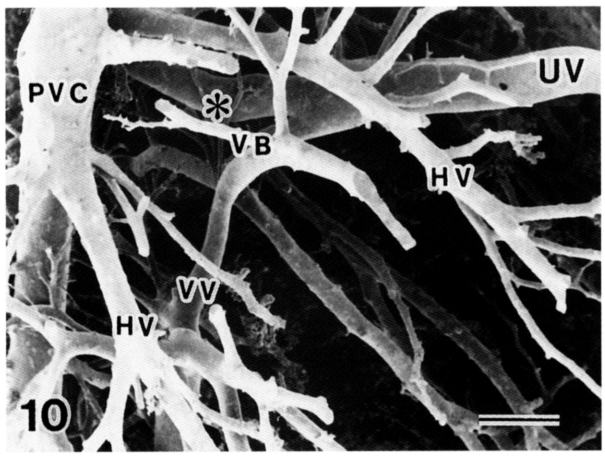


Fig. 9 Cast of the cardio vascular system of the fetal rat liver (right side) on day 20 of gestation The DV has further enlarged. The branches from the BP have degenerated, but the branches of the VV and the hepatic veins have developed further in the parenchyma. Bar = 830 μm
BP: bulging part of the umbilical vein; DV: ductus venosus; HV: hepatic vein; PVC: posterior vena cava; VB: branch of the vitelline vein; VV: vitelline vein.

Fig. 10 Cast of the cardio vascular system of the fetal rat liver (right side) on day 22 of gestation. The UV has degenerated and the BP is indistinct. Many hepatic veins from the parenchyma enter the PVC. Bar = 1000 μm
asterisk: ductus venosus; HV: hepatic vein; PVC: posterior vena cava; UV: umbilical vein; VB: branch of the vitelline vein; VV: vitelline vein.

arose from it, and one of them developed further to bring the blood from the intestines as the portal vein. At a later stage, with the disappearance of the yoke stalk, the distal tributaries of the VV eventually disappeared. The BP of the terminal part of the UV is called the "umbilical recess"[5], the "recessus umbilicalis"[6], or even the "portal sinus"[7][8], where the sphincter muscle is observed[9]. Despite these previous reports, our study revealed that the BP existed in all the fetal rats observed, and that the afferent vessels arose only from the BP, not from the anastomosis between the UV and the VV.

In the present study on day 13 of gestation, the left UV alone entered the liver to make a meshwork of vessels together with the VV. At this stage, the UV opened directly into the developing PVC by way of the DV. The resin could cast all of the arteries, veins and capillaries of the organs. We could not find any other capillaries that took part in making this DV without the terminal part of the UV. On day 14, although very short and small, the DV was clearly distinguishable from the PVC, between the BP and the anterior part (hepatocardiac channel) of the PVC, which is called the hepatic vein by Gasser[2]. After this stage, the DV developed further to become clearly distinguishable from other vessels. It has been said that the DV forms by excavation of the main channel running through the substance of the liver as the volume of sinusoids increases[5][6][10]. If this is the case, the DV should have some different branches as shown by Williams and Warwick[1]. In fact, Gasser[2] showed that the DV has some afferent vessels and passes through the liver to open directly into the right hepatocardiac vein. However, in our rats the DV was too short to have spaces from which any vessels could arise and to excavate a main channel through the liver. After this stage, we failed to reveal any afferent vessels from the DV, a result similar to that of Lind and Wegelius[11]. It appeared to us that afferent vessels to the hepatic parenchyma arose only from the BP.

It has been said that the DV becomes confluent with the hepatic veins (efferent veins from the hepatic sinusoids) just after leaving the liver[10] and opens into the PVC. In almost all of our rats, however, the DV entered the PVC directly without any confluence with the hepatic veins. The subcardinal veins and the capillaries of the right VV are said to be anastomosed, and they move to the dorsum of the liver to become the middle part of the PVC, into which the hepatic veins open; the middle part is called "hepatic part" of the PVC[5][12]. In our study it is appeared that the DV did not enter this middle part, but instead entered the hepatocardinal vein (named by Gasser[2] in 1976).

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(和文抄録)

ラット静脈管の発生分化

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那 須 哲 夫[1]，有 嶋 和 義[2]

ラットの肝臓内静脈管の発生分化を走査型電子顕微鏡で観察を行った．胎齢13日では肝臓内毛細血管はすでに形成されており，臍静脈は肝臓実質内に毛細血管を分枝し，細い静脈管を介して後大静脈に合流していた．胎齢14日では，臍静脈終末部は膨大し，この膨大部は二分岐し，1本は後大静脈に連絡する静脈管で，他の枝は卵黄嚢静脈に連絡する吻合枝であった．静脈管は胎齢20日頃までは成長し，分娩直前になると退化を始めていた．また，静脈管から分枝する毛細血管は認められなかった．臍静脈終末部の膨大部は胎齢後期になると退化していた．卵黄嚢静脈は腸管の静脈を形成し，肝臓内では多くの毛細血管に分枝していた．ラットの肝臓では，後大静脈に直接吻合する1本の臍静脈終末部から静脈管が分化すると考えられる．