Structural and functional aspects of porcine placental microvasculature

Rudolf Leiser 1 and Vibeke Dantzer 2

1 Institut für Tieranatomie, Universität Bern, CH-3001 Bern
2 Department of Anatomy, Royal Veterinary and Agricultural University Copenhagen, DK-1870 Copenhagen V

Summary. The microvascular architecture of the pig placenta was studied by serial semithin histological sections for light microscopy, which were compared with scanning electron microscopy of artificially exposed materno-fetal contact surfaces as well as of vessel casts prepared from the maternal, fetal, and combined maternal and fetal sides.

The superficial reliefs from the exposed surfaces as well as from the casts are almost identical with the complementary maternal and fetal sides. In order to meet the physiological needs of materno-fetal exchange for the rapidly growing fetuses, these reliefs develop from a simple to a more complex system during pregnancy and can be described as follows: (1) The degree of interlocking increases between the fetal ridges or bulbous protrusions and maternal ridges of different orders separated by maternal troughs of variable depth, most clearly seen on vessel casts. It creates a three-dimensional notch-arrangement, giving strength to the materno-fetal contact area. (2) The structure of precapillary vessels as well as of the meshwork, and the diameter of capillaries of the maternal and fetal sides, adapt during gestation giving a good distribution of oxygenated blood into the maternal capillaries; these, with the development of large prevenous connecting capillaries on the fetal side, favour a high arterio-venous difference of fetal blood O2 pressure. (3) The vascular architecture of endometrial and fetal ridges and troughs develop into a crosscurrent to countercurrent materno-fetal blood interrelationship.

Our demonstration of the materno-fetal capillary interrelationship in the porcine placenta thus shows that the latter is a much more efficient organ for exchange than hitherto assumed.

Key words: Pig placenta – Vascularisation – Corrosion casts – Crosscurrent-countercurrent blood flow

Introduction

The microvascular architecture of the diffuse folded epitheliochorial placenta of the pig has been studied by Heuser (1927), Tsutsumi (1962) and Macdonald (1976, 1981). The latter two authors concluded from the three-dimensional arrangement of maternal and fetal vessels that the blood flow interrelationship was mainly in a concurrent way.

However, a concurrent interrelation gives, from the physiological point of view, the lowest possible placental exchange of diffusible substances between mother and fetus (reviewed by Faber and Thornburg 1983). Therefore, this model seems to be inconsistent with an expected high rate of exchange necessary for the rapidly growing fetuses of the litter during the comparatively short porcine gestation time (115 days).

To clarify this discrepancy between the proposed placental blood flow conditions and the physiological demands in the pig, as well as to elucidate the morphology of the placental vasculature in relation to its contribution to a materno-fetal anchoring effect (Heuser 1927; Wislocki and Dempsey 1946; Amoroso 1952), new techniques of materno-fetal tissue separation (Dantzer 1984) and vessel-filling with plastic for scanning electron microscopy (Leiser and Kohler 1983) were used and compared with serial semithin histological sections. Preliminary observations have been reported by Leiser and Dantzer (1987) and Dantzer et al. (1988).

Material and methods

Uteri from 7 pregnant sows at days 35, 43, 48, 65, 70, 75 and 99 were obtained at an abattoir within 4 min after slaughter. All stages except for day 35 were well known from the time of natural insemination, whereas the stage of day 35 was estimated from CR (crown-rump) length and weight (De Villiers et al. 1958; Marrable 1971).

From 4 stages, days 35, 43, 48 and 99, large pieces of placental tissue were used to prepare exposed surfaces of porcine placenta for scanning electron microscopy as earlier described (Dantzer 1984).

Placenta from all gestational stages were fixed by microperfusion. A blunt canula was inserted into a ramus cornualis (Boye 1956) from arteria uterina close to the uterine wall at the central region of an embryo. The anastomoses to each side were clamped, and perfusion fixation with 3% glutaraldehyde in 0.07 M phosphate buffer (Björkman et al. 1981) with 3% PVP (polyvinylpyrrolidone) was performed. Well-fixed areas were cut into 2 mm3 pieces, immersion-fixed in 3% glutaraldehyde in 0.1 M cacodylate buffer for an additional 3 h, rinsed in buffer, postfixed for

2 h in 1% OsO₄ in 0.1 M cacodylate buffer at 5°C, dehydrated and embedded in epon by routine methods.

From each stage of gestation serial, 2 μm thick sections, in number up to 350 to 460, were cut and stained with toluidine blue and studied by light microscopy in order to follow the fine branching of maternal and fetal arterioles and venules into their respective capillary network.

Ten placentae from two gestational stages, days 43 and 99, were used for vascular casts. From both stages maternal and fetal as well as combined materno-fetal casts were made. The uterine horns of pregnant sows are long with vaginals (Boye 1956). Therefore it was necessary to clamp vessels running into the depth between the troughs (Fig. 4), and anastomosing rami cornuales of arteria uterina towards the anastomosing rami uterini of the arteria ovarica as well as of the arteria vaginalis (Boye 1956). Therefore it was necessary to clamp arterioles on each side of the injection-site to obtain an efficient filling of the whole or 1/5 to 1/3 of the maternal part of the diffuse placenta. To obtain the fetal casts, the uterus was opened between two placentae and subsequently the nonvascular part of the allantochorion and then the amnion were opened in order to pull out the fetus. The fetal placenta was injected via the arteria umbilicalis.

For the detailed preparation of vascular casts see Leiser and Kohler (1983), Leiser (1985) and Dantzer et al. (1988). Casts made by the methylmetacrylate mixture of Batson number 17 compound® (Polysciences) and of Sevriton® and of Sevriton® show especially improved vessel filling and, because of a better electron beam resistance in the scanning electron microscope (Risco and Nopanitaya 1980), it gives a better resolution.

Results

Light microscopy

The branching of arterioles into the capillary net as well as the connection between capillaries and venules was elaborated in serial sections on the maternal and the fetal side as illustrated in Fig. 1 (from day 99).

At the maternal side the arterioles can be followed between two troughs or fossae to the top of the maternal ridges or rugae (for nomenclature see Dantzer 1984; Fig. 1a). There, at the top of the ridges the perfusion-fixed specimens show ramifications of the arterioles into capillaries with round and slightly larger lumina than the capillaries at the sides and at the bottom of the maternal troughs, where they often become "flattened" along the maternal epithelium. The capillaries also indent the maternal epithelium at the sides of maternal ridges and at the troughs, thus giving this epithelium an irregularly cuboidal to squamous shape, whereas, on the top of the maternal ridges, it is low columnar or cuboidal. The maternal venules arise from the capillary network at the bottom of the maternal troughs (Fig. 1b).

At the fetal side the arterioles can be followed to the top of the fetal ridges or, in late stages, to the top of bulbous protrusions (see below), often giving off branches to the sides of the ridges on their way (Fig. 1b). The fetal capillaries form a rich network which is intensely indented into the irregularly shaped trophoblast at the sides and at the top of the fetal ridges, whereas the vascularisation related to the high columnar trophoblast of the fetal troughs is very scarce. The fetal venules arise close to the fetal troughs at the transition between the irregular and the columnar trophoblast (Fig. 1a). It is characteristic that the fetal arterioles and capillaries very often contain erythrocytes, whereas the fetal venules appear to be almost without erythrocytes.

Scanning electron microscopy

Scanning electron microscopy of exposed surfaces of the porcine placenta shows the formation of maternal ridges and troughs complementary to the fetal troughs and ridges, as they are interlocked (Fig. 2).

Stereomicroscopic inspection of maternal and fetal vascular casts reveal almost the same general surface reliefs as the preparation of the exposed surfaces, namely primary and secondary folds provided with microscopic folds (ridges) between troughs (Fig. 3). The less well vascularized roundish areas on the maternal casts represent maternal areolae, which have not been under special focus in this research.

Scanning electron micrographs of combined maternal and fetal casts show the placental vessel architecture in overview and detail (Figs. 7-9).

On the maternal vascular cast from day 43, the branching of arteries into arterioles and venules into veins can be followed at the maternal side of the placenta. The arterioles run into the depth between the troughs (Fig. 4), and can only be followed on a cracked area (Fig. 5). Here it is revealed how the arterioles ascend to the top of maternal ridges and continue into a capillary network. This network forms the ridges and continues at the slopes of the ridges into the troughs, which gradually become subdivided by perpendicular secondary ridges, thereby transforming the troughs into rows of continuous basket-like structures (Figs. 4, 6). At the bottom of the troughs the blood is collected by maternal venules (Figs. 4, 5). The top of the ridges is broader than at the sides (Figs. 5, 6) and the capillaries here at the top are round in shape, whereas they are flattened in the troughs forming a very wide irregular capillary network with relatively narrow holes (Figs. 4–6).

Figs. 1a, b. Semithin sections of porcine placenta from day 99 showing interlocking maternal ridges (upward arrows) and fetal ridges (downward arrows). Maternal vasculature is obvious, with an arteriole (MAI) running to the top of a ridge (a) joining a capillary system arranged beneath a cuboidal to flat uterine epithelium. A maternal venule (MVI) is located near to a trough between two maternal ridges (b). Fetal arterioles (FAI) and the system of "intranthroblastic" capillaries located at the lateral and apical slopes of ridges are both typically filled with erythrocytes and meet in the upper part of fetal ridges, as visible in b. Fetal venules (FVI), showing only few erythrocytes, arise from the capillary system close to the base of a fetal ridge (*, a), where the trophoblast changes from irregular to columnar. L, lymphatic vessel. × 170

Fig. 2. Scanning electron micrograph from day 35. After partly artificial separation of the uterine tissue (lower half) from the trophoblast (above the separation line X-X), the complementary ridges or rugae and troughs or fossae (dashed double arrows) is clearly seen. The fine structure of both uterine and trophoblast surfaces is represented by the apical pattern of cells. × 220