ORIGINAL ARTICLE

VIA MEDICA

Arterial supply and venous drainage of the choroid plexus of the human lateral ventricle in the prenatal period as revealed by vascular corrosion casts and SEM

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The topography of the arterial supply and venous drainage was visualised by corrosion casting and scanning electron microscopy in the human foetal (20 weeks) choroid plexus of the lateral ventricle. Although secondary villi were not yet present at that developmental stage, the topography of the large arteries and veins almost fully corresponded to that described in adult individuals. The only major difference observed was a lack of the typical tortuosity of the lateral branch of the anterior choroidal artery and of the superior choroidal vein, which probably develops during further expansion of the vascular system associated with the formation of secondary villi. (Folia Morphol 2008; 67: 209–213)

Key words: choroid plexus, blood vessels, human foetus, corrosion casting, scanning electron microscope (SEM)

INTRODUCTION

In the human brain the first ependymal buds of the choroid plexuses appear, at the telencephalic level, between the sixth and eighth weeks of embryonic development. After this period the necessary nutrients are supplied to the developing brain parenchyma, at this time by diffusion, from both the ependymal and peripheral meningeal vascular plexus surfaces. This phase, also called the "choroidal stage," is significant because the metabolic demands of the choroid plexuses determine the initial morphological pattern of the brain-supplying arterial tree, which afterwards remains essentially unchanged. Slightly later the peripheral meningeal vascular plexus sends off new vessels, which penetrate the telencephalic parenchyma and, step by step, create an adequate source of blood, nourishing the intensely developing neural tissue by perfusion. The venous channels draining the meninges as well as the choroid plexuses develop and acquire their morphological pattern progressively throughout foetal and early extrauterine life [3, 8, 9, 17, 18].

The vascular system of the choroid plexuses at the telencephalo-diencephalic level incorporates the already developed supplying arteries, which form a ring on each side, running around the stalks of the developing hemispheres. The anterior portion of this ring becomes the future anterior cerebral artery, whilst the posterior portion becomes the future anterior choroidal artery, both arteries belonging to the rostral division (cranial cerebral ramus) of the internal carotid artery. It is worth noting that at

this time the future anterior cerebral artery should be functionally regarded as a choroidal one, because together with the future anterior choroidal artery it participates in supplying the choroid plexus. The future anterior cerebral artery gives off a separate branch, the future posterosuperior choroidal artery running around the developing corpus callosum towards the choroid plexuses of the third ventricle and the rostral end (only) of the lateral ventricle. These arteries anastomose close to the interventricular foramen, thus forming the aforementioned arterial ring. Very soon after unification of the caudal branch of the internal carotid artery (posterior communicating artery) with the rostral portion of the basilar artery (posterior cerebral artery), the latter gives off separate branches, the posterior, medial and lateral choroidal arteries, which mainly supply the choroid plexus of the lateral ventricle [2, 6, 12].

With the progressive development of the corpus callosum and the especially intense further growth of the choroid plexus, the choroidal branches of the anterior cerebral artery are practically replaced in their function by the posterior choroidal arteries, which have developed as a result of partial acquisition of the diencephalic artery. All these arteries, which anastomose close to the foramen of Monro, constitute distant and indirect links between the carotid and vertebro-basal systems [3].

The vasculature of the choroid plexus has been investigated mainly in injected and cleared preparations [6, 13, 17–19, 21], allowing the two-dimensional concept of this special vascular bed to be studied. The introduction in the 1970s of a technique employing vascular corrosion casts examined by scanning electron microscope (SEM) provided improved resolution and attractive quasi three-dimensional images of the vascular networks studied [1, 11]. This technique has been used for visualisation in detail of the complex vasculature of the mammalian lateral ventricle choroid plexus [5, 14, 22], although only a single study is available concerning the adult human plexus [16].

This has prompted us to use the corrosion casting technique and SEM in order to investigate the architecture of the large blood vessels supplying and draining the human lateral ventricle choroid plexus in the foetal period.

MATERIAL AND METHODS

Foetuses

The investigations were carried out on two foetuses, both male and aged 20 gestational weeks, with a crown-rump length ranging from 190 to 193 mm.

These belonged to material collected for vascular corrosion cast studies in the period 1990–1994 in accordance with institutional requirements for the use of human material. The foetuses were obtained after spontaneous abortions from the Department of Obstetrics of the Jagiellonian University Medical College, Cracow. The abortions were due to maternal disorders and upon macroscopic inspection no developmental malformations or vascular anomalies were found in the foetuses.

Corrosion casting and scanning electron microscopy

The vascular system of the foetuses were perfused via a cannula inserted into the ascending aorta by a sequence of solutions, with outflow occurring via the umbilical vessels and additionally incised posterior tibial veins.

The foetuses were first perfused with prewarmed (37°C) heparinised saline (12.5 I.U./mL) containing 3% Dextran, M.W. 70 000, and 0.025% Lidocain (Lignocain, Polfa). Perfusion fixation was then carried out with 200 mL of 0.08% glutaraldehyde in 0.2 M cacocylate buffer, pH 7.4, at 37°C. Finally, 60 mL of a mixture was injected containing 8 mL Mercox CL-2R (Vilene Comp, Tokyo, Japan) and 2 mL methylmethacrylate (Fluca) containing 0.2 g MA initiator per 10 mL of the casting medium. Following the injection, the foetuses were kept overnight in a water bath at 55°C in order to facilitate polymerisation of the resin [15].

After resin curing, the brain was exposed in a saline bath and the meninges were carefully removed. Following a wash in distilled water, the specimens were macerated at 37°C in 10% potassium hydroxide for 5–7 days with gentle washes of hot tap water and distilled water alternately. The resulting vascular casts were cleaned in 2% formic acid, followed by washing in distilled water for a few days. Then, under a dissection microscope, the lumina of the lateral ventricles were opened from the dorsal, medial and lateral sides. In this way the choroid plexuses of both lateral ventricles were exposed *in situ*. The casts thus obtained, containing choroid plexuses as well as telencephalic, diencephalic and brain stem structures, were freeze-dried. Afterwards they were mounted with colloidal silver and conductive bridges [10] onto specially prepared specimen holders, enabling them to be tilted or rotated, and were coated with gold and examined in a Jeol JSM-35-CF scanning electron microscope at 20––25 kV. After preliminary examination and documentation the casts were microdissected under an operation microscope to remove the surrounding structures

and to fully expose the choroid plexuses, again coated with gold, and used for further scanning electron microscopic observations.

RESULTS

The choroid plexus of the lateral ventricle, suspended on the tela choroidea, a vascular invagination of pia mater, extends caudally along a C-shaped course from the posterior wall of the interventricular foramen, around the floor and throughout the body of the ventricle nearly to the tip of the inferior horn. In the trigone area of the ventricle the plexus forms an ovoidal swelling, the glomus. In the dorsal view, the vascular networks of both plexuses, which narrow along their whole length anteriorly, form an obtuse angle with its apex directed rostrally. The plexuses exhibit frond-like capillary processes on both surfaces, located along the attached and free margins of the plexus. On the basis of plexus shape and vascular patterns, several regions could be distinguished, corresponding to the particular parts of the mature plexus: the anterior part, the glomus, the posterior part, the villous fringe and the free margin. In fact, apart from underdeveloped villous processes, the general morphology of the foetal plexus examined in this study corresponds to that described for the mature plexus.

The major arteries and veins of the choroid plexus, although partially masked by the capillary networks, are relatively well seen in the corrosion casts and have been presented in illustrations prepared as mounts of several scanning electron micrographs (Fig. 1, 2) showing the entire choroid plexus area.

The arterial supply and venous drainage of the mature human telencephalic choroid plexus and tela choroidea have been presented in detail by Millen and Woollam [13], Hudson [6] and Wolfram-Gabel et al. [23], and therefore we have limited our description to the basic data. The terminology we have used has been adopted from the description of vasculature presented by the last of these authors. In the following text the bold numbers in round brackets refer to the vessels marked in Figures 1 and 2.

Arterial supply

The arterial supply of the lateral ventricle choroid plexuses is provided by choroidal arteries, which originate from the internal carotid artery. The anterior choroidal artery enters the choroid fissure and passes into the inferior horn of the lateral ventricle. As a rule it gives off two branches, medial and lateral. The former (10) courses along the attached margin of the plexus, whilst the latter (11), after

Figure 1. Total vascular cast of the right lateral ventricle plexus viewed from the dorsal aspect. Note the vascular structures located along the left part of micrograph, which occupy the bottom of the interhemispheric fissure as well as the plexus on the right side of the micrograph. The vascular fringes, mostly built of capillary networks, run along both plexus surfaces, the medial facing the interhemispheric fissure and the lateral running in close apposition to the thalamus. In the glomus area (marked by a dotted line), several stems of draining veins and their smaller tributaries not fully injected with the resin are visible. SEM, bar = 1000 μm. In Figures 1 and 2, the numbers indicate the particular blood vessels and vascular structures: 1 — internal cerebral vein; 2 — anterior vein of the septum pellucidum; 3 — anterior terminal vein; 4 — superior thalamostriate vein; 5 — superior choroidal vein; 6 — vein of the caudate nucleus; 7 — thalamic vein; 8 — branch of the posteromedial choroidal artery; 9 — inferior choroidal vein; 10 — medial branch of the anterior choroidal artery; 11 — lateral branch of the anterior choroidal artery; 12 — great cerebral vein; 13 — posterior ventricular vein; 14 — choroid plexus of the 3rd ventricle; 15 — suprapineal recess; 16 — pineal gland; 17 — posterosuperior choroidal artery; 18 — superior posterolateral choroidal artery; 19 — lateral pineal vein; 20 — dorsal vein of the corpus callosum; 21 — branch of the thalamic artery; 22 — medial choroidal veins; 23 — epithalamic vein; 24 — basal cerebral vein.

giving off several braches supplying the glomus region, runs along the free margin of the plexus. The two branches exhibit a partially parallel course and

Figure 2. Total vascular cast of the left lateral ventricle plexus viewed from the lateral and slightly dorso-anterior aspect. The anterior end of the plexus occupies the lower left corner of the micrograph (between 3 and 5) and the posterior part is located in the lower right area (marked by 10 and 11). The lateral vascular fringe built of extensive capillary networks and the glomus with chaotic capillary systems (upper right area of the micrograph) can be distinguished. Note vascular structures located within the interhemispheric fissure (upper left area), as well as the vascular system of the plexus anterior pole. The superior choroidal vein shows incomplete filling (for identification of the particular blood vessels and vascular structures consult explanations in the legend to Fig. 1). SEM, bar = 1000 μm.

in the region close to the interventricular foramen can form anastomoses with branches of the posterior choroidal arteries. The anterior cerebral artery gives off a posterosuperior choroidal artery (17). This, however, is an inconstant branch, supplying the tela choroidea of the third ventricle as well as the rostral end of the lateral ventricle plexus and often participating in the aforementioned anastomoses.

The posterior choroidal arteries arise from the posterior cerebral artery, either separately or via a common stem. However, they are variable in number:

essentially they always include the two most constant arteries, the posteromedial choroidal artery (giving off the medial and lateral branch) (8), and the posterolateral choroidal artery (dividing into superior and inferior branches) (18). The former, via its medial and lateral branches, supplies the choroid plexuses of the third ventricle and lateral ventricle, respectively. The latter, via its two branches, supplies the lateral ventricle plexus in the inferior horn area and the glomus region at the trigone level respectively.

Venous drainage

The choroid plexuses and the tela choroidea are drained by venules and small veins, distant tributaries of the deep cerebral veins. These reach the deep cerebral venous system via:

— a single, large superior choroidal vein (5) arising from numerous smaller tributaries in the glomus region and, after running along the free margin of each lateral plexus, escaping directly into the internal cerebral vein (1);

— several medially arranged medial choroidal veins, which discharge directly and also indirectly via the posterior ventricular vein (13) into the internal cerebral vein;

— the inferior choroidal vein (9), which joins the posterior ventricular vein (13), a tributary of the internal cerebral vein;

— the inferior choroidoventricular vein running on the basal brain surface (not shown) and draining into the basal cerebral vein (24), which finally escapes into the great cerebral vein (12).

In the corrosion casts the large veins were in some places incompletely filled with the resin, presenting partially interrupted or uneven contours.

DISCUSSION

The foetal period investigated (20 gestational weeks) corresponds to stage 3 in the development of the choroid plexus (17–28 gestational weeks). In this period, the choroid plexus shows the presence of simple primary villi, while true, elongated and tortuous villi are not yet developed [4, 9, 20]. The microvascular pattern observed in our material remains in accordance with that developmental stage and relatively simple capillary plexuses seem to represent the vascular systems of the primary villi.

On the other hand, the choroid plexus already displays the division into parts described in adult individuals: the anterior part, the glomus, the posterior part, the villous fringe and the free margin, manifested by different microvascular patterns.

Accordingly, the general architecture of the large blood vessels seems generally to correspond to that described in the human mature choroid plexus of the lateral ventricle [6, 13, 23].

The differences in topography and course between the foetal arteries and veins investigated in this study and the adult large vessels supplying and draining the choroid plexus described in the literature are quite subtle, with the exception of the appearance of the two vessels running along the free margin of the plexus: the lateral branch of the anterior choroidal artery and the superior choroidal vein.

In descriptions of these vessels in the mature human choroid plexus, authors have emphasised their extremely tortuous course, especially in the glomus region [13, 23]. In the 20-week foetuses investigated in this study, both vessels ran smoothly without showing any tortuosity. It seems that the forthcoming extensive angiogenesis and expansion of the vasculature in the later developmental phase, leading to formation of an elaborate system of secondary villi, includes excessive growth of these large peripheral vessels, ultimately resulting in their tortuosity.

Other differences include slight deviations in the topography of the vessels, although these can be regarded as manifestations of individual variability and, especially in the case of the veins, as a transitional state before the final stages of vascular remodelling, since arteries are formed earlier than veins in the development of the telencephalic angioarchitecture [7] and venous system remodelling in the choroid plexus can proceed even beyond birth [6].

Finally, it is worth noting that the vascular anatomy of the territory of the lateral ventricle choroid plexuses is important because these structures, by receiving a blood supply from many different sources, excluding only the medial cerebral artery, are frequently areas of developmental vascular anomalies and subsequent brain malformations.

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