Original article

Folia Neuropathologica

Architecture of cerebellomedullary cistern structures during foetal period

Alicja Kędzia[1], Marek Rybaczuk[2], Ryszard Andrzejak[3], Wojciech Kędzia[3]

[1]Department of Anatomy, Wrocław Medical University; [2]Institute of Materials Science and Applied Mechanics, Wrocław University of Technology; [3]Department of Internal and Occupational Diseases and Hypertension, Wrocław Medical University, Wrocław, Poland

Folia Neuropathol 2010; 48 (2): 123-128

Abstract

Structures of arachnoid in posterior cranial fossa have been examined during prenatal period. 100 foetuses were examined within IV up to VII month with CRL from 130 mm to 220 mm. Cuts were performed with especially constructed device what enabled ideal cross-section without disturbing of structures of arachnoid of dura mater. Image acquisition was done with the help of digital camera. The very fine structures spanned between posterior cranial fossa and cerebellum and brain stem were made visible. They are characteristics for prenatal period solely. This construction enables light weight elasticity and probably it increases strength as well as stability of circulation. Cross-section of observed structures has geometry of tangent circles with different diameters. Described structure fills entirely space situated outside of holes of posterior cranial fossa. It has the form of lattice with longitudinal meshes. Such structures were formed for foetuses with CRL – 140 mm and this was maintained up to VII month with CRL – 230 mm. Geometry of observed structures resembles Apollonian circles. There are many variations due to individual differences of foetuses. In turn power exponent for Applonian circles seems to be much more general.

Key words: *posterior cranial fossa, foetal period, Apollonian circles.*

Introduction

During foetal period there are continuous changes in the area of posterior cranial fossa. This problem is interesting for anatomists, embryologists and neurophysiologists. The analysis of changes in the posterior cranial fossa structures is very important for neuropathological evaluation of malformational disturbances occurring in above mentioned localization, especially in the cerebellum [12,16].

Evolution of posterior cranial fossa was examined mainly with USG techniques [5,11,13,18] and during recent years with the ultra fast MR. Cerebellum develops during long period beginning from early embryonic stage up to first years of life.

Kushnir *et al*. described evolution of vermis cerebelli beginning from the end of 16 week of foetal life [11]. These observations were based on ultrasonic studies. Bromley *et al.* also making use of USG observed that during 14, 15 and 16 weeks of pregnancy vermis was opened in 56%, 23% and 13% [5].

Ben-Ami under transvaginal sonography found the vermis inferior communicated with cerebellomedullary cistern in normal foetuses between 14 and 16 week of pregnancy [2].

Communicating author:

prof. Alicja Kędzia, Department of Anatomy, Wrocław University of Medicine, ul. Chałubińskiego 6a, 50-139 Wrocław, Poland, phone +48 71 784 13 31, fax +48 71 784 00 79, e-mail: sekapr@anpraw.am.wroc.pl

Zalel and co-workers examined under USG fetal evolution of vermis for 256 foetuses between 18 and 38 week of pregnancy. Values of width and height of vermis were correlated with age of foetus and biparietal dimensions. Between 18 and 20 week of pregnancy width of vermis amounted 5 mm and height equalled 5.88 mm, between 37-38 week of pregnancy width of vermis approached 15.4 mm and height increased to 15.3 mm [18].

Kushnir determined long axis of cerebellum during first trimester of pregnancy. It amounted 0.80 cm, transverse axis length equalled 0.40 cm but during 14 week long axis approached 1.23 cm and transverse one increased to 0.44 cm [11].

Ultra fast MR appeared especially effective in investigation of foetal brain. Girard *et al*. observed the brain growth and melanisation process for 33 patients between 21 and 38 week of pregnancy. Between 21 and 25 week lateral ventricles are large and they correspond to relative hydrocephalus. They observed melanisation in basal ganglia during 21 week in cerebral cortex between 23 and 28 weeks what corresponded to migration processes in dorsalis brain stem appearing in 23 week [8].

Chong *et al.* examined 26 foetuses between 9 and 24 week making use of MR, they observed evolution of cerebellum during 10 week [6]. Visualization of choroid plexus was possible in 14 week. Primary sulci of vermis were visible in 16 week of foetal life. Triulzi and co-workers [17] stated that Magendi foramen becomes formed between 12 and 20 week but according to Chong [6] it appeared in 13 week. They think that evolution of sulci cerebelli runs simultaneously to evolution of cerebellum volume. Triulzi state that transverse size of cerebellum increases by 180%, but front-back size 208-220% [17]. Adamsbaum *et al.* observed evolution of sulci cerebelli [1]. Primary sulci appear between 25 and 26 week of pregnancy, it separates lobus posterior from lobus anterior. Sulcus prepramidal become formed after 32 week and they differentiate themselves up to the end of 29 week of foetal life, in cerebellar penducles in 32 week.

Myelin around dentate nucleus together with white matter of hemispheres around vermis appeared in 38 week of foetal life. Height of vermis amounted 20 mm in 30 week of foetal life. Rybaczuk [15] analyzed changes of fractal dimension which, between 15 and 25 week, increased from 2.12 to 2.26. The growth was allometric, volume increased initially, next surface grew, finally both sizes changed steadily. Chong stated that evolution of sulci is parallel to growth of cerebellum volume [6].

Błaszczyk [4] carried out research for 114 foetuses (57 female and 57 male ones). Examinations were performed with use of new measurement techniques ELF v. 4.62. Author found that up to the six month, the posterior cranial fossa increased most rapidly in forward-back direction. Vermis cerebelli developed in fastest way and the space below vermis decreased. Vermis cerebelli and pons have the greatest dynamic of growth between fourth and seventh month. Development of fourth ventricle consisted of increase of its length especially between fifth and sixth month of foetal life. Błaszczyk observed elongation of distance between flexura medulla oblongata and foramen occipital magnum what corresponded to increase of size of anterior-posterior diameter. Flexura medulla oblongata, initially, up to fifth month was situated at latitude of foramen occipital magnum, and during sixth and seventh month it was far away from foramen occipital magnum. Author determined index cisterna magna, which constituted the distance between the lowest point of vermis cerebellum and the margo posterior of foramen occipital magnum [4].

Characteristic distribution of sinus transversus, joint according to acute angle with superior sagittal sinus increases strength with respect to torsion.

Subarachnoid space appears after the medial foramen of Magendie. Trabeculae appear as a link between arachnoid layer and pia mater [13].

Błaszczyk noticed (during foetal period) elements stabilizing structures of posterior cranial fossa and she claimed that they play the role of enforcement [4].

Material and methods

Making use of special cutting device (depicted in Fig. 1) for preparation of anatomic preparations (subjected to patent application P 385506), 100 sagittal and frontal preparations of heads within the period from IV to VII month of foetal life. Age of foetuses was determined according to CRL dimension referring to Scamon and Calkins tables. Cuts were ideally smooth what allowed especially precise examinations of structures observed in posterior cranial fossa during foetal period.

Cutting with the help of ordinary tools was difficult. The ossificating skull including bone fragments, somewhere gristle cartilage, dura mater which has the form of tangled veins with different orientation

Fig. 1. Cutting device used to made preparations.

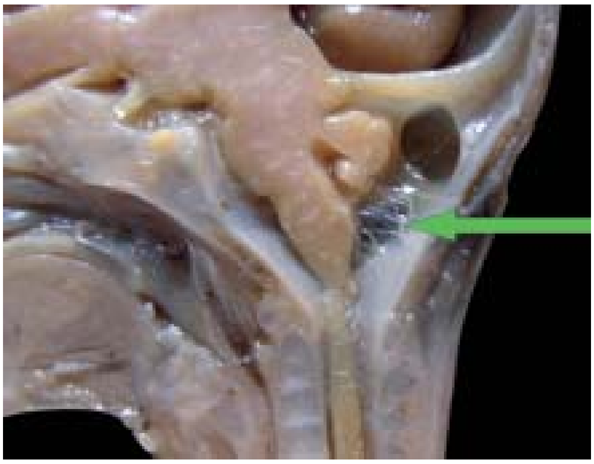

Fig. 2. Sagittal cross-section, CRL – 140 mm, 130 days, 19 weeks, V month, arrow indicates the fine structure modelled in terms of Apollonian circles.

and especially (90%) hydrated cerebellum with consistence of gelatine. These requirements were easier to fulfil if the cutting process is mechanised and the person making preparation has large freedom during cut, especially when it is deformed due to storage – conservation. The parallel shift of of object with respect to cutting surfaces is helpful.

Results

Posterior cranial fossa changes continuously. Precise cuts allowed visualisation of structures of posterior cranial fossa.

Circular, very fine structures spanned between wall posterior fossa of posterior cranial fossa and cerebellum and brain stem attracted special attention. They are characteristic for foetal period solely. Such construction ensures light weight, elasticity, also strength and supports stability of flow of cerebrospinal fluid. Sagittal and frontal cross-sections have form of mutually tangent circles with various diameters (Figs. 2-4). The structure described above exactly fills space situated behind of structures of posterior cranial fossa.

Known for long time the classical construction of Apollonian circles [3,7] is frequently applied in modelling of granular matter consisting of grains with variety of diameters. The Fig. 5 presents an example of such construction. The triangular area limited by arcs of three tangent circles is filled with smaller mutually tangent circles. The construction can be per-

Fig. 3. Sagittal cross-section, CRL – 170 mm, 141 days, 21 weeks, VI month, arrow indicates the fine structure modelled in terms of Apollonian circles.

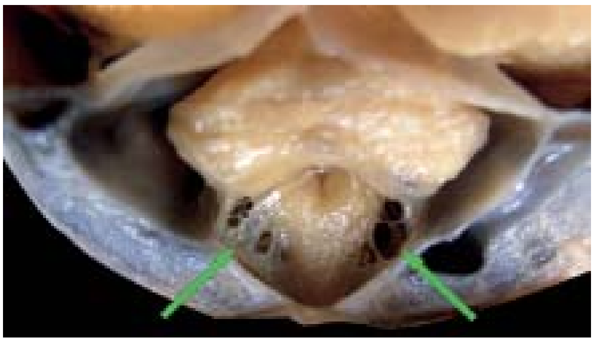

Fig. 4. Frontal cross-section, CRL – 160 mm, 143 days, 21 weeks, VI month, arrows indicates the fine structure modelled in terms of Apollonian circles.

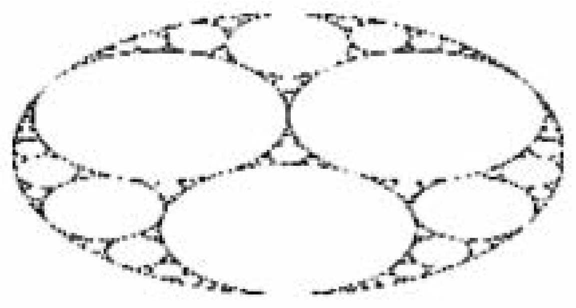

Fig. 5. Exemplary construction of Apollonian circles.

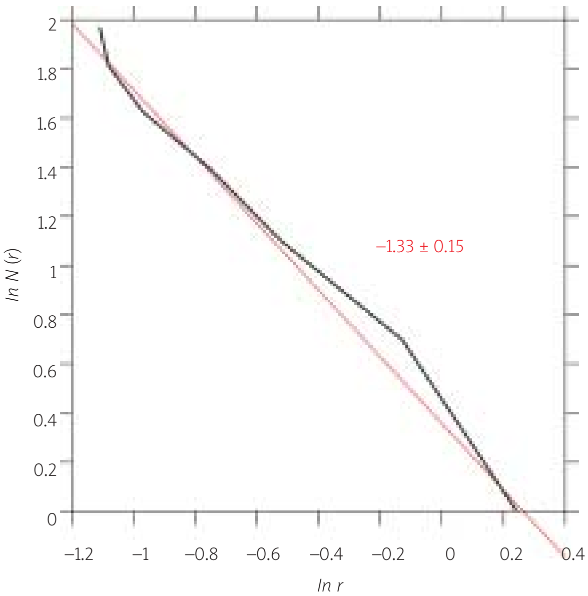

Fig. 6. Exemplary estimation of power exponent in (1) done for the structure presented in Fig. 4.

formed in recurrent way. At the first step we draw the central circle, next the smaller circles appear. Apollonian circles will be obtained after infinite number of recurrence steps. There are many generalizations of this construction. Circles can be replaced by ovals what corresponds to scaling along axes. Instead of circles one may construct infinite number of mutually tangent spheres in three dimensional spaces. Sometimes only the fragment of above construction constitutes a model of real system.

According to mathematics Apollonian circles are the infinite family of mutually tangent circles filling some fixed area in plane. There are also generalizations of this relatively simple construction. Instead of circles one may use ovals or even more complicated geometrical manifolds. Increasing dimension of enveloping space to 3 we arrive to families of mutually tangent balls or other manifolds filling volumes. The name Apollonian circles is frequently applied also for these three dimensional structures. The essential mathematical characteristic of Apollonian circles is based on scaling principles. In the classical, simplest case we involve the function $N(r)$ describing the number of circles with radius greater then r [14]. It has been proved that for sufficiently small radius r (asymptotic for r tending to) the function $N(r)$ has the form of power dependence

$$N(r) \sim r^{-D}, \qquad (1)$$

where the power exponent D is named the packing exponent. In the classical case the numerical calculations give the value D close to 1.3. Exemplary estimation of power exponent is shown in Fig. 6. However till now power exponents are calculated in numerical way solely since we do not know any exactly solvable problem of such type. In similar way as the basic construction, the involved power exponent has been generalized onto more complicated Apollonian like structures. For example, instead of numbers of circles we may describe the total area (or volume in the three dimensional case) of ovals with linear size exceeding r. In every case such dependencies are some power functions and are fixed by power exponents (most frequently all these exponent are named packing exponents). In general, power exponents depict in what way the number of smaller elements (filling some given geometrical set) grows. In every mathematical construction the number of elements is infinite, what cannot happen in real world (sizes of fragment must exceed atomic scale). Therefore Apollonian circles are some idealization of observations and they constitute some kind of approximation of physical system. On the other hand the mathematical model allows theoretical description and calculations of essential physical characteristics.

It appears the proposed Apollonian circles describe well the observed structure. Of course the real structure is three dimensional; however the available preparations are always two dimensional cross-sections. In this way we nearly achieve the classical case with single exception. It is clearly visible that instead of circles we have ovals. However the power exponent estimated for linear sizes of ellipse nearly coincides with classical result. Unfortunately mechanical properties of material, the observed structure is made of are unknown. It is too fine and so far every attempt to measure mechanical characteristics failed. Once mechanical parameters become known we may calculate strength of visible structures and an effect onto flow. Without direct measurements the proposed model and calculated exponent remains the geometrical characteristic solely.

Structures of cisterna magna have morphology of Apollonian circles. Current literature does not include description of similar structures in foetuses as well as in adults. According to own material it follows that they are mostly developed during V month of foetal life, in subsequent they slowly disappear. This connects to changes taking place in posterior cranial fossa up to the last months.

Discussion

Form of posterior cranial fossa changes. Initially it is similar to cone and being deeper it entails development of cerebellum. Rybaczuk with co-workers [15] and Triulzi [17] noticed that between 19 and 37 week the transverse size of cerebellum increases for 180%. According to results of Rybaczuk, due to performed fractal analysis, initially volume grows, next surface, finally both structures evolve simultaneously. Our observations confirm results of Błaszczyk [4], who thought that cerebellar vermis increases in fastest way between fourth and seventh month, what reduced subarachnoid space under vermis.

Own research devoted to brain vein system and sinuses of dura mater indicate multi stage development, elongation of structures in posterior cranial fossa up to the last months of growth, movement of tent and sinuses. All structures situated in the way of growing brain and cerebellum changes place and make turn. This explains the fact that complex examinations allow understanding these transformations, disappearance of some structures and appearance of others. Large material was systematically examined with the help of variety of cuts and preparation techniques.

Performed cuts made visible presence of particular structures in subarachnoid space below of vermis cerebellum. Earlier observations suggested similarities to sandwich constructions. Geometry of these bands was repeatable in various foetuses. They have numerous small holes, they appeared similar to lattice with elongated eyes. Our observations indicated that geometry is similar to so-called Apollonian circles. Initial observations were already published [9,10].

It is noticeable that there is no information about these structures in literature, especially in papers making use of ultra fast MR in living foetus examinations as well as during sections [1,17]. Anatomic literature is poor and structures were not noticed as well.

Made series of variety of cuts in both planes allowed visualization of morphology and it has valor of ideal cut due to especially constructed device. The achieved quality was very high what makes possible to exclude artefacts. The role of observed structures is still unclear and it will be a subject for future research.

References

1. Adamsbaum C, Moutard M, Andre Ch, Merzoug V, Quere M, Lewin F, Falet-Bianco C. MRI of the fetal posterior fossa. Pediatr Radiol 2005; 35: 124-140.
2. Ben-Ami M, Perlitz Y, Peleg D. Transvaginal sonographic appearance of cerebellar vermis at 14-16 weeks' gestation. Ultrasound Obstet Gynecol 2002; 19: 208-209.
3. Berger M. Geometrie. CEDIC/Nathan, Paris 1977.
4. Błaszczyk E. Analysis of morphology of posterior cranial fossa during fetal period. Wrocław University of Medicine, Wrocław 1977 [in Polish].
5. Bromley B, Nadel AS, Pauker S, Estroff JA, Benacerraf BR. Closure of the cerebellar vermis, evaluation with second trimester US. Radiology 1994; 193: 761-763.
6. Chong B, Babocook C, Pang D, Ellis W. A magnetic resonance template for normal cerebellar development in the human fetus. Neurosugery 1997; 41: 924-928.
7. Coxeter SM. Introduction to geometry. John Wiley & Sons, New York, London 1961.
8. Girard N, Raybaud Ch, Poncet M. In vivo study of brain maturation in normal fetuses. AJNR 1995; 16: 407-413.
9. Kędzia A, Rybaczuk M, Andrzejak R. Model of apollonian circles of reinforcements in posterior cranial fossa during fetal period. In: XIII Computer aided scientific research, pages 253-258, Wrocław 2006. Wrocław Scientific Research Society [in Polish].
10. Kędzia A, Rybaczuk M, Andrzejak R. A role of apollonian cicrles in posterior cranial fossa. In: XIV Computer aided scientific research, pages 253-258, Wrocław 2007. Wrocław Scientific Research Society [in Polish].
11. Kushnir U, Shavlev J, Bronstein M, Bider D, Lipitz S, Nebel L, Mashiash S, Ben-Rafael Z. Fetal intracranial anatomy in the first trimester of pregnancy, transvaginal ultrasonographic evaluation. Neuroradiology 1989; 31: 222-225.
12. Laure-Kamionowska M, Taraszewska A, Maslinska D, Raczkowska B. Faulty position of cerebellar cortical neurons as a sequel of disturbed neuronal migration. Folia Neuropathol 2006; 44: 327-332.
13. Lemire RJ, Leech RW. Normal and abnormal development of the human nervous system. Harper & Row, Hagerstown 1975.

14. Mandelbrot BB. Fractal geometry of nature. Freeman, New York 1982.
15. Rybaczuk M, Kędzia A, Błaszczyk E. Fractal description of cerebellum surface during fetal period. Folia Morphol 1996; 4: 434-436.
16. Schmidt-Sidor B, Obersztyn E, Szymanska K, Wychowski J, Mierzewska H, Wierzba-Bobrowicz T, Stępień T. Brain and cerebellar hemidysplasia in a case with ipsilateral body dysplasia and suspicion of CHILD syndrome. Folia Neuropathol 2008; 46: 232-237.
17. Triulzi F, Parrazini C, Righini A. MRI of fetal and neonatal cerebellar development. Sem Fetal Neonatal Med 2005; 10: 411-420.
18. Zalel Y, Seidman DS, Brandt N, Lipitz S, Achiron R. The development of the fetal vermis an in utero sonographic evaluation. Ultrasound Obstet Gynecol 2002; 19: 136-139.