Assessment of Growth Dynamics of Human Cranium Middle Fossa in Foetal Period


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A – research concept and design; B – collection and/or assembly of data; C – data analysis and interpretation; D – writing the article; E – critical revision of the article; F – final approval of article; G – other

Abstract

Background. Available literature analysis demonstrated smallness of studies of cranial base.

Objectives. The goal of the study was to analyse the medial fossa of the human cranium in the foetal period against other fossae.

Material and Methods. Survey material consisted of 110 human foetuses at a morphological age of 16–28 weeks of foetal life, CRL 98–220 mm. Anthropological, preparation method, reverse method and statistical analysis were utilized. The survey incorporated the following computer programmes: Renishaw, TraceSurf, AutoCAD, CATIA. The reverse method seems especially interesting (impression with polysiloxane (silicone elastomer of high adhesive power used in dentistry) with 18 D 4823 activator. Elicited impression accurately reflected complex shape of cranial base.

Results. On assessing the relative rate of cranium medial fossa, the rate was found to be stable (linear model) for the whole of the analysed period and is 0.19%/week, which stands for the gradual and steady growth of the middle fossa in relation to the whole of the cranium base. At the same time, from the 16th till 28th week of foetal life, relative volume of the cranium middle fossa increases more intensively than cranium anterior fossa, whereas the cranium middle fossa volume as compared with the cranial posterior fossa is definitely slower. In the analysed period, the growth rate of the cranium base middle fossa was bigger in the 4th and 5th weeks than in the 6th and 7th weeks of foetal life. The investigations revealed cranium base asymmetry of the left side. Furthermore, the anterior fossae volume on the left side is significantly bigger than the one of the fossae on the right side.

Conclusions. Volume growth rate is more intensive in the 4th and 5th than in the 6th and 7th weeks of foetal life. In the examined period, the relative growth rate of cranium base middle fossa is 0.19%/week and it is stable – linear model. The study revealed correlations in the form of mathematical models, which enabled foetuses age assessment (Adv Clin Exp Med 2014, 23, 3, 327–342).

Key words: middle fossa, cranium base, volume, human foetus.
Enlow’s [10] principles of skeletal growth (superstructure and resorption), which cause cortex drifting and replacement processes. The author states that cranium base growth process is hard to define and evaluate as these two phenomena may take place simultaneously in two opposite directions.

Width increase results from the replacement in petroocipital articulation and posterior mastoid suture. Fossa length increase is favoured by anterior and posterior intraocpittal articulations with sphenoid petrosquamous articulations and Björk’s [3] posterior mastoid suture. Cranium middle fossa length increases in the sphenoid and petrosquamous sutures. As indicated by Björk [3], posterior dislocation proceeding towards frontal bones in the main direction of temporal bones growth. Cranium middle fossa growth takes place after cranium anterior fossa increase completion and lasts several years. Ford [11] found that cranium base anterior (prechordal) part increases six-sevenfold (linearly) against the posterior (chordal) one which grows only four-fivefold. In order to compensate this slow growth, cranium base angles between cranium prechordal and chordal bases get flattened. Sikora [38] stated that a foetal head width-length index increases gradually until the 3rd month of foetal life (head width increases faster), from the 3rd till the 6th month, the index decreases (head length increases faster) and from the 6th month until the moment of birth, the index is constant (head width and length increases are equal). In his paper, the author points at the index estimative character. Malinowski’s survey [26] performed on 150 foetuses deals with the same problem. In his study, Malinowski made width and length traditional measurements defining foetal head indices. His observations revealed that the biggest gains of the foetal cranium width and length happened in the 4th, 5th and 9th months of pregnancy.

Levin et al. [25] detected the progressive growth of the cranium anterior base length in comparison with its posterior part. He also observed a general tendency of cranium base angle, which appeared more and more obtuse along with foetal age. In accordance with his observations, the biggest rate of examined structures growth was indicated in the 4th and 5th months of foetal life. Kvinnsland [21] found that the cranium anterior base development is more active than that of the cranium posterior base. Sagittal and occipital element of the cranium base revealed stability during the foetal period, whereas the sagittal and ethmoidal part of cranium base angles increased in this period. Kędzia [18], in her paper, demonstrated a strict connection between the dura mater processes and brain and cranium base development. Lee et al. [23] proved that the cranium anterior fossa grows anteriorly. They demonstrated proportional growth of cranium all fossae based on angles with S angular point (sella center). Anterior fossa angle was relatively stable and amounted to 107.4–112.5°. Middle fossa angle increased, whereas posterior fossa angle decreased. In the authors’ opinion, cranium base particular fossae angles are keys to normal development assessment of the cranium base.

Derkowski [9] pointed to the irregular growth of cranium anterior fossa. In his opinion, anterior fossa angle decreases and middle fossa angle increases. Progressive growth observed in the 2nd trimester is gradual and the anterior fossa angle changes slightly. What is important, from the 4th till the 7th month of foetal life, the cranium base increases preserving the symmetry in regard to the body median plane. Kędzia et al. [19] demonstrated the sexual dimorphism in the area of cranium anterior fossa on the basis of: anterior fossa angle-bigger in male foetuses as well as ethmoid bone crista galli height – bigger in female foetuses. Slawinski [37] examined the growth parameters of the foetal temporal bone in relation to age. Pyramid length increased with age, and its length growth dynamics dominated width increase. In turn, temporal bone pyramid angle enclosed between long axis and squama decreased with foetal age. The author did not find any other statistically significant differences in regard to side or sex.

Roelfsema et al. [31] pointed at a statistically significant increase of cranium anterior and posterior fossae lengths at cranium base angle slight but visible flexion by 6°. In their survey, they observed a bigger increase of foetal cranium posterior fossa length in relation to the cranium base anterior angle. In the authors’ opinion, the more distinct increase of cranium posterior fossa length in relation to the anterior fossa length resulted from the influence of brain development process. Jeffery [17], on the basis of high resolution MRI, observed a two-fold higher rate of cranium anterior fossa growth than cranium posterior fossa increase as well as posterior fossa width exceeding its length. In our own surveys, preliminary metrological analysis of cranium base fossae (2009) revealed that cranium middle fossae volume was significantly bigger than the volume of other fossae. Besides, no statistically significant asymmetry was found in relation to all sizes of middle and anterior fossae on the left and right sides or any significant sexual dimorphism of cranium base sizes. Ultrasound examinations are the most popular diagnostic and measurement method presented in literature: Biasio et al. [2], Chitkara et al. [7], Campbell [6], Hata et al. 1989 [14], Hoftbauer et al. [15]. However, not very many papers describe cranium base geometry; usually, the evaluation concentrates on cranium base.
fossae contents as well as foetus external parameters or long bones. Ultrasound examination usually evaluates: biparietal size, v-tub length, femoral bone length, foetus abdominal circumference, thorax and cerebellum transverse size.

Roelfsema et al. [31] described foetal cranium base increase with the use of a three-dimensional ultrasound examination. Measurement results proved successful in 69–94% of cases. MRI enables intra cranial structures evaluation and foetal brain development disturbances evaluation (Adamsbaum et al. [1], D’Ecrole et al. [8] Levine et al. [24]).

Mall et al. [27, 28], while constructing biomechanical model of adult cranium with the use of finite-element method, paid special attention to cranium base complex. Elicited model was exposed to virtual forces action and the results were compared with real injury effects.

Frątczak et al. [12] elaborated a foetal cranium computer measurement with the use of finite-elements method. They constructed foetal cranium virtual model on the basis of sectional material embedded in resin samples and exposed to cutting methods. The survey effect was prompt and accurate simulation of foetal cranium stress and recognition of processes leading to perinatal injuries.

Recently, large progress has been observed in medicine which enables early diagnosis and treatment of developmental abnormalities during the foetal period. Present prenatal screening is able both to reveal structural defects and to define their character. In the case of foetal abnormalities, reparatory operations are limited. Prenatal surgery is a comparatively new domain and it deals mainly with: hydrocephalus treatment or myalomeningocele closure. Operations are performed either with uterus opening or endoscopically Wysocka [39]. Serlo et al. [34] performed a prenatal assessment of hydrocephalus in 38 foetuses. Foetal hydrocephalus proved to have differentiated aetiology and in 84% of cases, it was connected with other developmental abnormalities. Severe forms of foetal hydrocephalus may be detected with the use of modern ultrasound techniques before the 20th week of pregnancy. In the authors’ opinion, the majority of hydrocephalus cases develop slowly in the foetal period. After ultrasound control examinations, hydrocephalus treatment initiated immediately after delivery gives a good or moderate prognosis. Only a minority of foetuses may be potential candidates for intrauterine interventions. Contemporary intrauterine treatment of foetal hydrocephalus is based on ventriculoamniotic valve placement (a shunt serving as a connexion between foetal brain widened ventricles and amniotic cavity) draining the excess of cerebrospinal fluid to amniotic sac.

**Material**

The study was carried out on 110 foetuses at a morphologic age of 16–28 weeks of foetal life, in v-tub range 98–220 mm. There were 58 female and 52 male foetuses.

Foetal material originated from the collection of Normal Anatomy Department of Wroclaw Medical University. Foetuses were preserved in formaldehyde solution (concentration hard to define due to the fluid etherial qualities) and in constant concentrations of ethanol and glycerol to minimize formalin toxicity. Scamon’s and Calkins [32] tables were used to assess foetuses morphological age with the use of the dependence:

\[
\text{age} = 2.23 + \frac{\text{v-tub}}{7.56} + \left(\frac{\text{v-tub}}{18.49}\right)^2,
\]

when: v-tub – crown-rump length (mm), age (weeks).

**Table 1.** Quantitative division of foetuses in respect of sex

<table>
<thead>
<tr>
<th>Age (month)</th>
<th>Sex</th>
<th>Number of foetuses</th>
</tr>
</thead>
<tbody>
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</tr>
<tr>
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<td>total</td>
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</tr>
<tr>
<td></td>
<td>male</td>
<td>52</td>
</tr>
<tr>
<td></td>
<td>total</td>
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</tr>
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</table>

**Methods**

The following methods were used: antropological and preparational methods, reverse (impression) method, image computer analysis with the use of Irfan View programme and Scion Image for Windows [33]. Subsequently, the results were subjected to statistical analysis with STATISTICA v. 9 programme. Reverses were made with polysiloxane (silicone elastomer of big adhesiveness used in
Fig. 1. Material prepared to elicit reverse of female foetus cranial base: 5th month of foetal period, v-tub length 145 mm, down hill projection 1 – front (frontal pole), 2 – back (occipital pole), 3 – right side, 4 – left side, 5 – right anterior fossa of cranial base, 6 – right middle fossa of cranial base, 7 – posterior fossa of cranial base (unpaired), 8 – left anterior fossa of cranial base, 9 – left middle fossa of cranial base. Red line demarcates approximate boundaries of cranial base fossae.

Fig. 2. Reverse of male foetus cranial base, 4th month of foetal life, v-tub length 198 mm 1 – front (frontal pole), 2 – back (occipital pole), 3 – right side, 4 – left side, 5 – reverse of cranial right anterior fossa, 6 – reverse of cranial right middle fossa, 8 – reverse of cranial left anterior fossa, 9 – reverse of cranial left middle fossa, 7 – reverse of cranial posterior fossa (unpaired). Red line demarcates reverses approximate boundaries of cranial base particular fossae.

Fig. 3. Reverse of male foetus cranial base, 4th month of foetal life, v-tub length 193 mm 1 – front (frontal pole), 2 – back (occipital pole), 3 – the lowest point of cranial base right anterior fossa, 4 – the lowest point of cranial base right middle fossa, 5 – the lowest point of cranial base posterior fossa g-op – reverse basic plane (reverse base) based on points g and op.
dentistry) with 18 D 4823 activator which provided adequate accuracy.

Elicited reverses were placed in a self-constructed tripod and photographed in five planes with a Canon Power Shot A630 camera with a millimetre scale in the background. JPG format images were rolled in the computer. Particular fossae volumes were defined with triple measurement of liquid extruded by reverses to within ± 1 mL. Reverse sizes of 18 cranium base fossae were turned into a digital representation in the form of a cloud of dots with the use of Cyclone II system – 3D scanner in Institute of Machines Design and Operation, Technical University of Wrocław [22].

Renishaw CYCLONE 2 scanning system is equipped with Wolf&Beck non-contact laser probe enabling the digitalization of geometric data of physical objects as well as the elaboration of computer geometrical models of real objects. They may be used in the reconstruction or modification of objects which do not possess technical documentation in the form of drawings or 3D models. The Cyclone 2 system enables the transformation of geometry of any digital form into a cloud of dots. Renishaw TraceSurf provides further transformation of elicited data. It is used to prepare CAD surface model, which, due to neutral formats record system (DXF, STEP, IGES), enables data export to external software e.g. CAD, FEM. This way available data was processed with Renishaw Tracesurf, which enabled data export to external software (e.g. AutoCAD, CATIA) due to neutral formats record system (DXF, STEP, IGES).

After entering the data into AutoCAD programme, impressions of dimensional digital models were formed. Then, using the programme...
capacities, the total volume $V_C$ of the cranial base fossae was calculated as well as the left anterior fossae volume $V_{CAL}$, and the right anterior fossae volume $V_{CAR}$, left middle fossae volume $V_{CM}$, right middle fossae volume $V_{CMR}$ as well as posterior fossae volume $V_{CP}$.

Based on digital models, volumes of 18 impressions were evaluated and compared with volumes defined for the same specimens on the basis of extruded liquid measurements and impression mass weighing with the use of electronic scale. A very strong positive correlation was observed ($r > +0.99$) between these results, which allowed us to abandon the more accurate, but time consuming, digital method. The method of weighing the mass of impression was applied. In order to do this, particular fossae were marked in the cranial base impression. Volume measurement based on extruded liquid measurements proved to be the least precise (small repeatability of results, impression mass and extruded liquid volume correlation index $r = 0.998$ against correlation index of the volume assessed on the basis digital model measurement and impression mass which amounted to $r = 0.9999$).

Regarding the remaining 92 impressions, the middle fossae volume was assessed on the basis of the elicited formula (Fig. 7) which represented the correlation between: volume $V_C$ [cm$^3$] calculated on the basis of 3D model, extruded liquid volume $V_C$ [mL] and reverse mass $m$ [g].

Presuming the constant density of all reverses, the following formula was elicited:

$$V_C = 0.6542 \times m$$

$V_C$ - fossa volume [cm$^3$];

$m$ - reverse (impression) mass [g].

### Survey Examination

#### Cranium Middle Fossa $V_{FCM}$

Middle fossae volume on the left ($6033 \pm 3995$) is bigger than the one on the right ($5602 \pm 3629$) by an average of $431$ mm$^3$. The difference is statistically significant ($p < 0.001$) (Fig. 8).

Taking into consideration non-significantly different width and length for both sides of the foetal cranial middle fossae, the significance of middle fossae volume seems to be mainly determined by their depth. The elicited dependence was described with the following formulas:
Growth Dynamics of Human Cranium Middle Fossa

\[ V_{FCMR} = -4672 + 534.6 \times (G2-MP) \]

\[ V_{FCML} = -5260 + 564.3 \times (G2-ML) \]

\( V_{FCMR} \) – volume of right middle fossa [mm³]
\( V_{FCML} \) – volume of left middle fossa [mm³]
\( (G2-MP) \) – depth of right middle fossa [mm]
\( (G2-ML) \) – depth of left middle fossa [mm]

Relative Rate of Cranium Middle Fossa Volume Increase

The development of geometric sizes in the foetal period were analysed in monthly intervals (4th – 7th month) due to small numerosness in the 16th, 27th and 28th month. On comparing the increases of analysed sizes, Scheffe’s contrasts test was used with \( b_{x1} \) feature-age regression coefficient.

Recognition of the total volume of (left-right) cranium middle fossa \( V_{CM} \) and the remaining (anterior and posterior) fossae allowed us to determine undimensional indices, which reveal the relative rate of cranium middle fossa increase in relation both to cranium base growth and other fossae increase – hence the name: relative rate of the growth of middle fossa.

\[ w_1 [%] = \frac{V_{CM}}{V_{c}} \times 100 \]

- index of middle fossa total volume part in cranium base fossae total volume

\[ w_2 = \frac{V_{CM}}{V_{CP}} \times 100 \]

- index of middle fossa total volume part in anterior fossa total volume

\[ w_3 = \frac{V_{CM}}{V_{CP}} \times 100 \]

- index of middle fossa total volume part in posterior fossa total

The part of middle fossa total volume in cranium base fossae total volume amounts to 32.0% in the 16th week and 34.2% in 28th week. The growth rate is 0.19%/week on average. Due to the big differentiation of results, the growth rate may be regarded as constant value (linear model) in the whole analysed period (Fig. 9).

In the period from the 16th–28th week of foetal life, total volume of the middle fossa increases more intensively than anterior fossa total volume. The growth rate of \( w_3 \) index is stable and amounts to 1.02%/week (Fig. 10).

\( W_3 \) index poorly correlates with foetal age \((p > 0.05)\). Middle fossa total volume – posterior fossa volume ratio decreases, which means that the

<table>
<thead>
<tr>
<th>Table 2. Basic statistics of cranium middle fossa ( V_{FCM} ) volume on the left (L) and right (R)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Age</strong></td>
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<tr>
<td>IV</td>
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<tr>
<td>V</td>
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<tr>
<td>VII</td>
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<tr>
<td></td>
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<tr>
<td>Σ</td>
</tr>
<tr>
<td></td>
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<tr>
<td></td>
</tr>
</tbody>
</table>

\( N \) – numerical amount; \( \bar{x} \) – attribute arithmetical mean; \( SD \) – standard deviation.
increase of the middle fossa volume is slower in comparison with the increase of the posterior fossa volume (Fig. 11).

Values of $w_1$, $w_2$, and $w_3$ indices do not depend on age (Fig. 12).

![Fig. 9. Correlation diagram of $w_1$ index (middle fossa volume part in cranium base fossae total volume) with foetal age as well as mathematical model](image9.png)

![Fig. 10. Correlation diagram of $w_1$ index (medial fossa volume part in anterior fossa volume) with age as well as mathematical model](image10.png)

![Fig. 11. Correlation diagram of $w_1$ index middle fossa volume part in posterior fossa volume) with foetal age](image11.png)

**Anterior Cranial Fossa Volume $V_{FCA}$ [mm$^3$]**

Anterior fossae volume on the left is significantly bigger than the fossae volume on the right ($p < 0.0001$, Fig. 13).

Non-significantly different cranium anterior fossae length and depth on both sides suggest that this is the length which determines the significance of the anterior fossae difference.

Elicited dependence may be represented by the following formula: $V_{FCA} = 485.5 \times \exp \left[ 0.1202 \times (D1-T) \right]$

$V_{FCA}^L = 514.7 \times \exp \left[ 0.1166 \times (L1-T) \right]$

$V_{FCA}^L$ – right anterior fossa volume [mm$^3$],
$V_{FCA}^L$ – left anterior fossa volume [mm$^3$],
$(D1-T)$ – right anterior fossa length [mm],
$(L1-T)$ – left anterior fossa length [mm],
exp – exponent symbol, record of exponential function with $e$ base being natural log.

![Fig. 12. Comparison of $w_1$ index of male and female foetuses as well as t-Student test result for non related variables](image12.png)

![Fig. 13. Comparison of left anterior fossa volume ($V_{FCA}^L$) and right anterior fossa volume ($V_{FCA}^R$) [mm$^3$] of examined female and male foetuses and t-Student test result for related variables](image13.png)
Conclusions from Statistical Analysis of Middle Fossa Volume in Respect of Other Fossae

The table beneath presents the conclusions from a statistical analysis of the growth rate measurement of the selected parameters of the cranium base middle fossae in respect to other fossae. Conclusions are collected in tabular, textual and figurative forms. Mathematical dependence is applied in the form of a formula.

Volume of Cranium Base Right Middle Fossa $V_{FCMR}$ [mm$^3$]

In the 4th and 5th months, the right middle fossa volume growth rate is bigger than in the 6th and 7th months. It is confirmed by the values of linear regression ratios $b_{x}$, presented in Table 4 (volume monthly increases) as well as the shape of mathematical model fitting curve (Fig. 14).

Fig. 14. Volume of cranium base right middle fossa in age monthly classes and adjusted logarithmic model

Volume of Cranium Base Left Middle Fossa $V_{FCML}$ [mm$^3$]

In the 4th and 5th months, the growth rate of left middle fossa volume is bigger in the 6th and 7th months. This is confirmed by the values of linear regression ratios $b_{x}$ in Table 5 (volume monthly increases) as well as the shape of fitted mathematical model curve (Fig. 15).
Table 4. Basic statistics of foetal age (t) and X size: V_{FCMR} in four age classes as well as linear correlation indices and parameters of regression straight line \( Y = a + b \times X \)

<table>
<thead>
<tr>
<th>Class</th>
<th>Sex</th>
<th>N</th>
<th>( \bar{t} )</th>
<th>( S_t )</th>
<th>( \bar{x} )</th>
<th>( x_{\text{min}} )</th>
<th>( x_{\text{max}} )</th>
<th>( S_x )</th>
<th>( r_{X,t} )</th>
<th>( b_{X,t} )</th>
<th>( a_{X,t} )</th>
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\( N \) – numerosness; \( \bar{t} \) – foetus mean age (day); \( S_t \) – foetal age standard deviation; \( \bar{x} \) – character arithmetic mean; \( S_x \) – character standard deviation; \( x_{\text{min}} \) – character minimum value; \( x_{\text{max}} \) – character maximum value; \( r_{X,t} \) - character and foetal age (day) correlation index; \( b_{X,t} \) – character and foetal age (day) regression index; \( a_{X,t} \) – abscissa in regression model

Fig. 15. Volume of cranium base left middle fossa in monthly age classes and fitted logarithmic model

Fig. 16. Volume of cranium base right fossa in monthly age classes and fitted log model

**Volume of Cranium Base Right Anterior Fossa** \( V_{FCAR} \) [mm³]

In the 4th and 5th months, the growth rate of right anterior fossa volume is bigger than in 6th and 7th months. This is proved by the values of linear regression \( b_{X,t} \) ratios values in Table 6 (volume monthly gains) as well as fitted mathematical model curve shape (Fig. 16).

**Volume of Cranium Base Left Fossa** \( V_{FCAL} \) [mm³]

In the 4th and 5th months, the volume growth rate of the anterior middle fossa was bigger than in the 6th and 7th months. This is confirmed by the values of linear regression ratios \( b_{X,t} \) presented in Table 7 (volume monthly increases) as well as the shape of the fitted mathematical model curve (Fig. 17).
Table 5. Basic statistics of foetal age (t) and X size: $V_{FCML}$ in four age classes as well as linear correlation ratios and regression straight line parameters $Y = a + b \times X$

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Table 6. Basic statistics of foetal age (t) and X size: $V_{FCAR}$ in four age classes as well as linear correlation ratios and parameters of regression line $Y = a + b \times X$

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Fig. 17. Volume of cranium base left anterior fossa in age monthly classes and fitted logarithmic model
Volume of Cranium Base Posterior Fossa $V_{FCP}$ [mm$^3$]

In the 4th and 5th months, the increase rate of the posterior fossa volume is bigger than in the 6th and 7th months. This is confirmed by the ratio values of linear regression $b_X$ in Table 8 (volume monthly increases) as well as the shape of the curve of the fitted mathematical model (Fig. 18).

Surveys Results Resumption

In the area of central fossa symmetry in respect to other fossae:

- central fossae volume on the left is bigger than the one on the right by 431 mm$^3$ on average. The difference is statistically significant at the level $p < 0.001$;
- anterior fossae volume on the left side was statistically bigger than the anterior fossae volume on the right side at the level $p < 0.0001$.

As for middle fossa volume growth rate against other fossae:

- In 4th and 5th months, the volume growth rate of particular right and left middle fossae was more intensive than in the 6th and 7th months.
- The growth rate of the relative volume of the middle fossa against the total volume of the cranial base is on average 0.19%/week and is constant (linear model) in the whole of the analysed period:
- In the period the 16th–28th week of foetal life, relative volume of cranial fossa increases more intensively than the total volume of the anterior fossa:
- The growth rate of the relative volume of the middle fossa against the growth of the posterior fossa in the analysed period is slower:
- In the 4th and 5th months, the growth rate of the anterior left and right fossae is bigger than in the 6th and 7th months.
- In the 4th and 5th months, the growth rate of posterior fossa volume is bigger than in the 6th and 7th months.

With reference to elicited correlations:

During the survey, some important correlations with foetal somatic measures were elicited.
They may be of diagnostic (medical visualisation equipment), prognostic or evaluation (morphometric preparation of operative field) importance. Relationships presented below might prove useful in criminology.

- middle fossae volumes (in the range the 4th–7th month):

\[ V_{FCMR} = -4672 + 534.6 \times (G^2 - MP) \]

\[ V_{FCML} = -5260 + 564.3 \times (G^2 - ML) \]

- anterior fossae volume (in the range 4th–7th month):

\[ V_{FCAP} = 485.5 \times \exp \left[ 0.1202 \times (D1 - T) \right] \]

\[ V_{FCAL} = 514.7 \times \exp \left[ 0.1166 \times (L1 - T) \right] \]

- posterior fossa volume (in the range 4th–7th month):

\[ V_{FCP} = 2234 + 12920 \times \log (age) \]

\[ age = 0.672 \times \exp \left( 0.0002 \times V_{FCP} \right) \]

- undimensional ratios presenting relative rate of middle fossa growth with reference to both cranial base and other fossae (4th–7th month)

\[ w_i = \frac{V_{CM_i}}{V_{C}} \times 100 \]  

- index of the part of middle fossa total volume in cranial base fossae total volume:

\[ w_1 = \frac{V_{CM_i}}{V_{CP}} \times 100 \]  

- index of the part of middle fossa total volume in anterior fossa total volume:

\[ w_2 = \frac{V_{CM_i}}{V_{CA}} \times 100 \]  

- index of the part of middle fossa total volume in posterior fossa volume

### Discussion

The available literature does not provide any materials concerning the middle fossa of the base of foetal cranium. Examined material comprised the group of 110 pairs of middle fossae belonging to the collection of Normal Anatomy Department of Wroclaw Medical University aged 4–7 months of foetal life. The survey incorporated many methods characteristic for medicine, dentistry, mathematics and computer science. The available literature concerning cranial base at the particular foetal age does not include any information of such methodological combinations. The reverse (impression) method seems innovatory, as it has not been applied in neuroanatomical studies. The method presents complicated shape of the examined object with dental accuracy. Besides, reverse method is strictly connected with the possibility of measurement of such a complicated structure like cranium middle fossa or cranium base.
Apart from new methods of investigations, traditional ones were incorporated: preparational method, anthropologic method (taking foetal somatic features sizes) as well as the statistical method used to analyse the results statistically. Earlier investigative techniques of the foetal cranial base region were based on observations, autopsial examinations and traditional linear and angular measurements – Ford [11], Lee SK et al. [23]. Wysocki [40] made measurements of cranial cavity with lead shot and sand, whereas Modrzewska [29] defined the neurocranium volume with millet and rape seeds. However, these methods were characteristic for small accuracy of the measurement. During the development of the human organism, differences in the internal structure appear and the problem of body asymmetry arises. Literature discusses the foetal period touches on the problem of symmetry; however, only some papers concentrate on the cranial base. In 2008, Kędzia et al. [20] assessed the symmetry of cranial base in 77 foetuses aged 10–27 weeks of foetal period. The authors observed a high degree of symmetry maintenance in respect of the body median plane during the development of the human organism, differences in the internal structure appear and the problem of body asymmetry arises. Literature discussing the foetal period touches on the problem of symmetry; however, only some papers concentrate on the cranial base. In 2008, Kędzia et al. [20] assessed the symmetry of cranial base in 77 foetuses aged 10–27 weeks of foetal period. The authors observed a high degree of symmetry maintenance in respect of the body median plane during the developmental period. Slawiński [37] noticed that the height and length of temporal squama in human foetuses did not reveal significant differences in respect to the examined body side and sex. Derkowski [9] observed that in the period from the 4th till 7th month, the cranial base grows preserving symmetry towards the body median plane. While building a mathematical model of the human cranium base fosseae in 13 foetuses, Skomra et al. [36] did not describe any asymmetry though they observed a significant difference between the linear sizes of middle fosseae on the left and right during the formation of a mathematical model of fosseae volume increase in human cranium base. The present data concentrating on the period between the 4th and 7th month of foetal life, middle fossa volume on the left was significantly bigger. It seems that asymmetry is more characteristic for the adult age, whereas symmetry is more characteristic for foetal period. However, at some stage, lateralization of the cranium base parameters takes place. Modrzewska [29] who examined the changes that took place with age in the volume of 214 human skulls defined their pertinence on the basis of detailed inspection. Besides, while measuring their volume, she found a significant difference between females and males in favour of the latter. Regarding adults, Piontek et al. [30], with the use of Manouvier’s formula, revealed a significant sexual dimorphism in female and male average volumes of male and female skulls surveyed in Polish population. Malinowski [26], analysing the length and width of 150 foetal crania from the age of 2 months of foetal life till birth, demonstrated the biggest growth of both parameters in the 4th, 5th and 9th month of the foetal period. In 1996, Lee SK et al. assessed X-ray images of foetal crania bases (18th–40th weeks) and observed that the angle of the cranium middle fossa based on pituitary gland (point S) with its arms designated by zygomatic bone ossification points and temporal bone pyramid ridge increases at the expense of the angle of posterior fossa. Furthermore, the authors established that the anterior fossa angle was relatively stable and the cranium anterior fossa grew centrifugally forwards. In 1997 Blaszczzyk [5] observed the biggest dynamics of foetal cranium base posterior fossa growth between the 4th and 5th or between the 5th and 6th month. Later, the development rate slowed down. In Derkowski’s opinion [9], foetal cranium middle fossa angle increases at the expense of anterior fossa decreasing angle. The author also pointed to a two and half fold greater depth of cranium middle fossa in the analysed period from the 8th till 27th week. Initially, the irregular increase of the anterior fossa in the 1st trimester becomes steadier in the 2nd trimester. Our results proved that in the 4th and 5th months, the increase rate of particular right and left middle fossae is bigger than in the 6th and 7th months. Furthermore, the relative dynamics of the cranium middle fossa total volume (right + left) growth in reference to the cranium base total volume amounts to 0.19%/week and it is stable in the whole analysed period. It evidences steady growth of the middle fossa in relation to the cranial base. The elicited volume ratios ($w_1$, $w_2$, $w_3$) suggest that in the period from the 16th till 28th week of foetal life, the total volume of the cranium base middle fossa grows faster than volume of the anterior fossa. The growth rate is stable and it correlates with age, whereas the cranium middle fossa volume increase in proportion to the posterior fossa volume growth is less intensive in the analysed period and poorly correlates with age. The survey effects are inclinations of clinical (diagnostic) importance, which may be useful in the assessment of potential operative field in the area of middle fossa. Elicited correlations may be also used in programming medical diagnostic equipment (USG, CT, MR). During the study, in the form of mathematical formulas, the cranium base middle fossae volume was related to its depth. Additionally, cranium base anterior fossae volume depends mainly on their length. Mathematical relations of estimative character were established in the period from the 4th till 7th month. Foetal age assessment is of great importance in neonatology, radiology, obstetrics, neurosurgery, anthropology or crime detection. Elicited results are of cognitive value and may be used in forensic medicine for dead foetus age assessment even if only a cranium fragment is available, e.g. middle fossa. Though
imaging equipment is increasingly more advanced, doctors still elicit false data about foetal age. In our earlier studies [35], there were very promising correlations assessing cranium base fossae volume only on the basis of head mass and length up to the formula:

\[ V = -15.2 + 0.025 \cdot \text{mass} + 0.594 \cdot (g - op) \]

The authors concluded that in the analyzed foetal period, there is asymmetry of cranium base middle fossa in favour of the left side. Volume growth rate in the 4th and 5th months of foetal life is bigger than in the 6th or 7th months. In the observed period, the so-called growth relative rate of cranium base middle fossa is 0.19%/week and it is stable in forming a linear model. Middle fossa growth dynamics is of in-between character among anterior fossa, which grows more slowly, and the posterior fossa, which grows faster. The survey revealed a correlation in the form of mathematical formulas enabling foetal age assessment.

References


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