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Shape and Surface Structure of the Human Cerebellum: Variant Anatomy

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The aim of the study was to determine the characteristics of individual variability in the shape and external structure of the human cerebellum. Cadaveric material (cerebella and adjacent brainstems of 100 people) was studied. We proposed a comprehensive method for evaluating the cerebellar shape in the morphometry of anatomical specimens, which involves measuring linear dimensions (width, length, and height) and calculating relative parameters, which describe cerebellar shape by the ratio of one dimension to the other two: *relative width of the cerebellum* (rW), *relative length of the cerebellum* (rL), and *relative height of the cerebellum* (rH). The magnitude of the relative parameter determines its contribution to the shape and surface structure of the cerebellum. The combination of relative parameters ultimately defines the characteristics of the shape and surface structure of the cerebellum, which were described in this study.

Key words: human, anatomy, cerebellum, morphometry

Introduction

One of the manifestations of individual anatomical variability of an organ is the variability of its shape. Evaluating the ratio of linear dimensions of an organ is one of the ways to determine its shape [1, 3, 4]. Modern neurovisualization research methods, including magnetic resonance imaging, allow for *in vivo* identification of morphological features of the cerebellum. However, the information about the anatomical norm of the cerebellum, upon which the criteria for the standards of neurovisualization diagnostic methods are based, does not take into account the characteristics of its individual anatomical variability. *The purpose of this study* was to determine the characteristics of individual variability in the shape and surface structure of the human cerebellum.

Materials and Methods

Materials

The study was conducted on 100 samples. Each sample included cerebellum and an adjacent brainstem. They were obtained from adult human cadavers (67 male and 33 female) who died of causes unrelated to brain pathology at the age between 20 and 92.

Measuring the cerebellum

Cerebellar width (W), length (L) and height (H) were measured. The width was measured between the most distant points of the cerebellar hemispheres lying on the surface of the superior semilunar lobules (**Fig. 1**). The length was measured between the most distant points on the surface of the inferior semilunar lobule at the back and the quadrangular lobule at the front (**Fig. 2**). The height was measured between the uppermost point on the surface of the culmen of the vermis and the straight line connecting the lowermost points of the two biventer lobules (**Fig. 3**). If there were discrepancies in the length measurements between the right and left sides, the average value was taken.

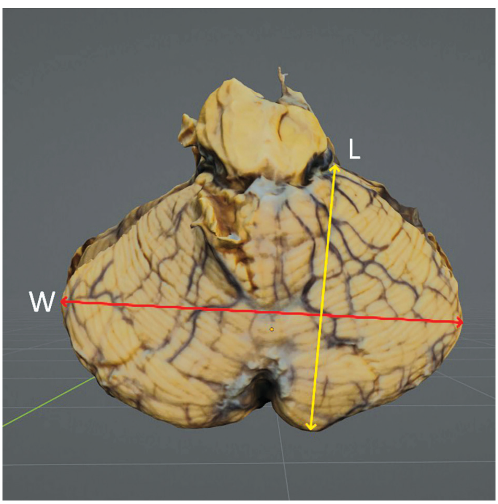

Fig. 1. Determination of the width and length of the cerebellum.

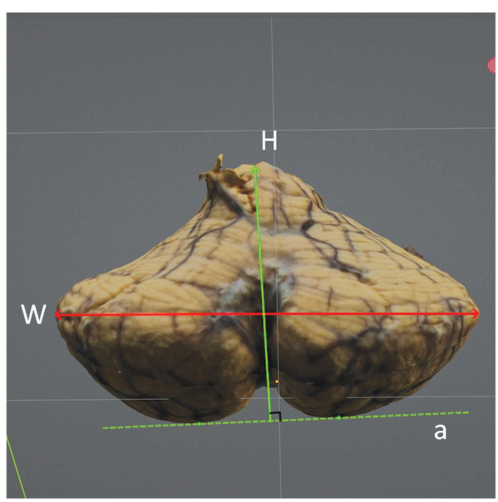

Fig. 2. Determination of the width and height of the cerebellum: a – a straight line connecting the lowermost points of the two biventer lobules.

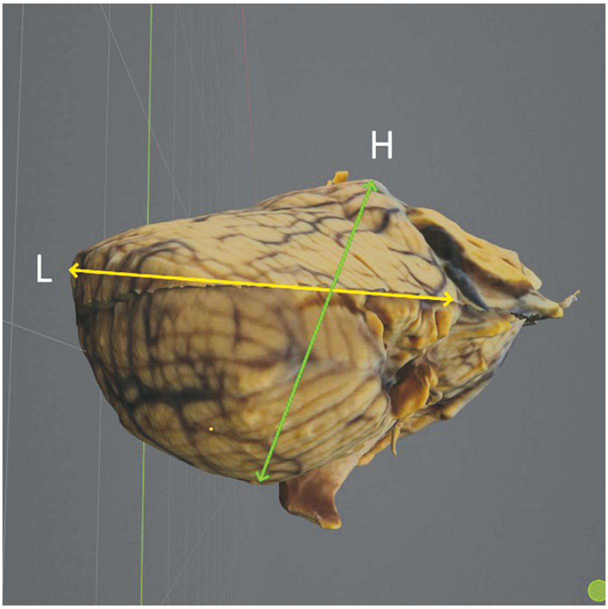

Fig. 3. Determination of the length and height of the cerebellum.

Method for determining the shape of the cerebellum

To describe cerebellar shape by the ratio of one parameter to the other two, *relative width of the cerebellum* (rW), *relative length of the cerebellum* (rL), and *relative height of the cerebellum* (rH) were proposed using the following formulas:

$$rW = W^2 / (L \times H) \quad (1)$$

$$rH = H^2 / (W \times L) \quad (2)$$

$$rL = L^2 / (H \times W) \quad (3)$$

A statistical analysis was conducted, including the calculation of the sample mean (M), standard deviation (S), coefficient of variation (Cv), and determination of the minimum and maximum values. Correlation analysis was also performed, with the calculation of the Pearson correlation coefficient (r). The values of cerebellar dimensions and their ratios were grouped based on the mean and standard deviation into three categories: small (from the minimum value to M–S), medium (M±S), and large (from M+S to the maximum value).

Results and Discussion

Variability in the linear dimensions of the cerebellum. **Table 1** presents the values for the width, length, and height of the cerebellum.

Table 1. Statistical evaluation of the distribution of cerebellar measurement values and relative parameters

Parameter	Test statistics					
	M	**m**	**S**	**CV,%**	**min**	**max**
A. Parameters						
W	104.4	0.5	5.5	5.3	90	117.3
L	60	0.3	3.4	5.7	51.4	67.7
H	50	0.4	4.3	8.6	40	62.5
B. Relative parameters						
rW	3.71	0.05	0.51	13.81	2.22	5.22
rL	0.7	0.01	0.08	11.65	0.52	0.9
rH	0.4	0.01	0.08	19.34	0.25	0.62

As evident from the data in **Table 1 (A)**, there is variability in the values of the linear dimensions of the cerebellum in the studied sample, but it is insignificant; the greatest variability is observed in height (Cv = 8.6%), which confirms previously obtained data [2].

Figures 4, 5 and 6 depict the distribution of values for paired linear dimensions of the cerebellum.

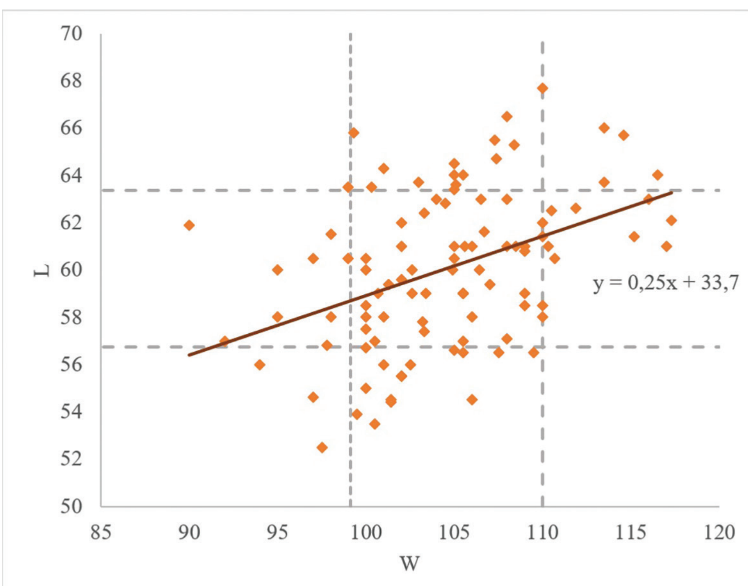

Fig. 4. Distribution of values for the width and length of the cerebellum. Note: Dashed lines correspond to the values of M–S and M+S (here and in **Figs. 5, 6**)

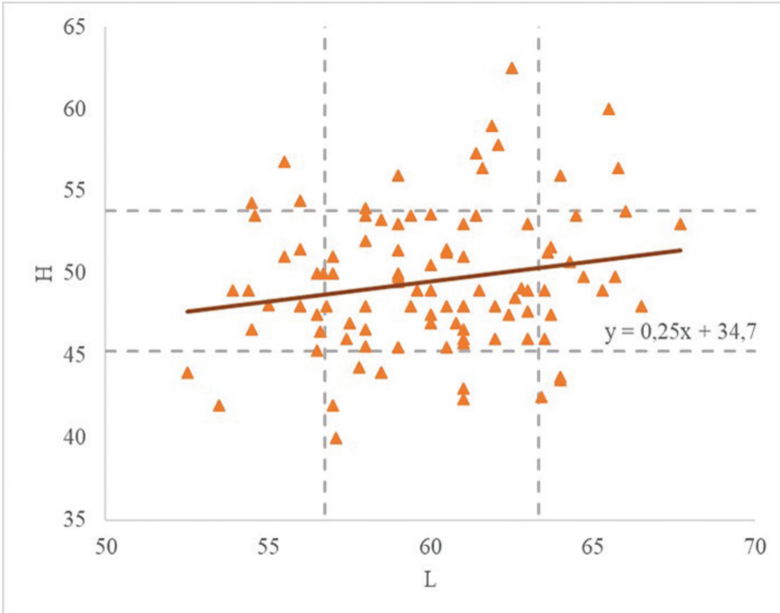

Fig. 5. Distribution of values for the length and height of the cerebellum

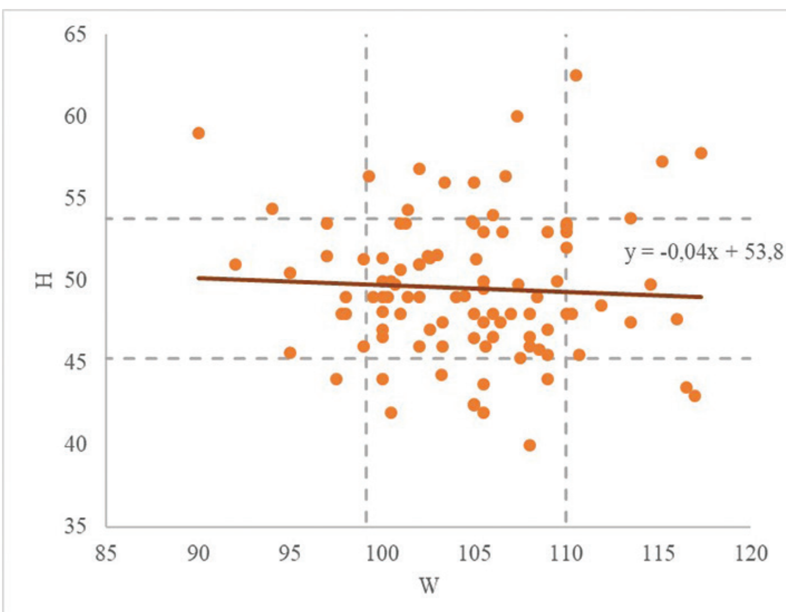

Fig. 6. Distribution of values for the width and height of the cerebellum

As evident from the data in **Figs. 4-6**, there appears to be a relative independence of variability of one linear dimension to the variability of the other two: correlation analysis showed a weak and statistically insignificant linear relationship between the values of width and height ($r = 0.07$, $p>0.05$) as well as between the values of length and height ($r = 0.16$, $p>0.05$). There is, however, a moderate and statistically significant linear relationship between the values of width and length ($r = 0.44$, $p<0.01$). The presence of a statistically significant linear relationship between width and length values has been previously established [2].

Relative parameters of the cerebellum

The data of the relative parameters of the cerebellum are presented in **Table 1 (B)**. According to these data, the overall shape of the cerebellum can be characterized by the magnitude of the relative parameter. If the values of the investigated cerebellar parameters fall within the range of mean values, such a cerebellum is described as proportional, while extreme values indicate disproportionality:

- *relatively wide*, with a large value of rW (4.27 ÷ 5.22) or conversely, *relatively narrow*, with a small value of rW (2.22 ÷ 3.2);
- *relatively long*, with a large value of rL (0.78 ÷ 0.9) or conversely, *relatively short*, with a small value of rL (0.52 ÷ 0.62);
- *relatively high*, with a large value of rH (0.48 ÷ 0.63) or conversely, *relatively low*, with a small value of rH (0.25 ÷ 0.32).

The magnitude of the relative linear dimension determines its contribution to the shape and influence on the external structure of the cerebellum.

Therefore, cerebella that are *relatively wide* tend to have a more flattened shape, a greater separation between the hemispheres and tonsils, and broad posterior and anterior notches. In contrast, *relatively narrow* cerebella appear compressed from the sides, with a narrower posterior notch compared to cerebella of other shapes, resembling a slit. The inferior vermis may not be visible, or only a single part of it is noticeable. The tonsils are closely adjacent to each other.

Relatively long cerebella exhibit a deep anterior notch, and the course of their gyri resembles parabolas. Conversely, in *relatively short* cerebella, the vermis protrudes forward relative to the anterior edge of the hemispheres, thereby reducing the depth of the anterior notch.

The hemispheres of *relatively high* cerebella are massive and form a sharp peak. In contrast, *relatively low* cerebella appear flattened, with the vermis declive protruding above the superior surface of the hemispheres.

The complexity of the three-dimensional spatial organization of the cerebellum, on one hand, and the diversity of individual anatomical variability of the cerebellum, on the other hand (in this case, the variability in its linear dimensions, specifically the relative independence of variability of one linear dimension to the other two), lead to varying combinations of relative parameters.

The combination of relative width and relative length (horizontal projection):

Proportional cerebella have a rounded, slightly convex superior surface, and the culmen of the vermis is moderately elevated above it. The lateral contour formed by the surfaces of the superior semilunar lobules has a regular, rounded shape, and the posterior corners of the cerebellum are smoothed. The gyri resemble open arcs of concentric circles. The posterior notch of the cerebellum has a slit-like shape. Through the *cerebellar valley*, the inferior surface of the vermis is partially visible.

Relatively wide and *relatively short* cerebella have a lateral contour that, unlike proportional cerebella, is oval-shaped and stretched sideways. The hemispheres appear to be spread apart from the midline. As a result, the valley of such cerebella is wide, and the lower vermis is visible along its entire length. The lateral and posterior corners, as well as the anterior and posterior notches, are more distinctly defined.

Relatively narrow and *relatively long* cerebella appear as if "compressed" from the sides and stretched from front to back, giving their lateral contour an elliptical arc shape. The lateral corners are directed more forward than in proportional cerebella, and the posterior corners are sharp. The anterior notch is deeper than in cerebella of other shapes, while the posterior notch is narrower. Due to the relative increase in length, the course of the gyri resembles parabolas rather than concentric circles, as seen in proportional cerebella. The hemispheres are compressed by their medial surfaces, the border line between them becomes uneven, and only the vermis pyramid remains visible on the inferior surface. Unlike proportional cerebella, the tonsils are of unequal size and asymmetric in their positioning.

The combination of relative width and relative height (frontal projection):

Proportional cerebella have approximately flat surfaces. When viewed from behind, the cerebellum's contour resembles an isosceles triangle with a right or obtuse angle at the vertex. The posterior notch is narrow, but as it transitions to the inferior surface, the distance between the hemispheres increases, revealing the tonsils and the lower vermis.

Relatively wide and *relatively low* cerebella have a flat, slightly flattened superior surface, and the culmen of the vermis is not pronounced. The angle at which the superior surfaces of the hemispheres converge approaches to straight. The posterior notch is large, and the posterior and lower portions of the vermis are clearly visible. The inferior surface is flat, and the cerebellar valley is the least deep and widest among all cerebella.

Relatively narrow and *relatively high* cerebella have massive hemispheres, and the culmen of the vermis is prominently elevated. The angle formed by the hemispheres is the sharpest among such cerebella. The posterior notch appears as a narrow slit. On the inferior surface of the hemispheres, they are compressed, and the cerebellar valley is the deepest and narrowest among all cerebella. The lower vermis is either not visible, or only a single portion is visible. The tonsils can be symmetric or overlap each other.

The combination of relative length and relative height (sagittal projection):Proportional cerebella. The angle formed by the superior and inferior surfaces of the hemispheres is approximately 45 degrees. The course of the gyri on the superior and inferior semilunar lobules has a horizontal direction, and the gyri of the quadrangular lobule bend downward.

Relatively long and *relatively low* cerebella. The angle between the superior and inferior surfaces of the hemispheres is acute. The declive protrudes above the superior surface because the culmen is flatter than in proportional cerebella. The gyri gradually curve downward as they move away from the vermis.

Relatively short and *relatively high* cerebella have the greatest angle between the superior and inferior surfaces of the hemispheres, approaching a right angle. The vermis is positioned more vertically, so the declive is not visible behind the hemispheres. The gyri of the superior semilunar lobule run horizontally, those of the inferior semilunar lobule turn forward and upward, and those of the quadrangular lobule turn downward.

The distribution of values for all three relative parameters by the value of the feature is compared together in **Table 2**.

Table 2. Observed variants of the cerebellar shape (based on relative parameters)

Group	rW	rL	rH	Count
1	wide	long	low	2
2	wide	medium	medium	3
3	wide	medium	low	7
4	wide	short	medium	2
5	medium	long	medium	7
6	medium	long	low	4
7	medium	medium	high	3
8	medium	medium	medium	45
9	medium	medium	low	1
10	medium	short	high	4
11	medium	short	medium	9
12	narrow	long	medium	2
13	narrow	medium	high	4
14	narrow	medium	medium	5
15	narrow	short	high	2
Total				100

As evident from the data in **Table 2**, there is a variety of combinations of cerebellar shape parameters. 45 cerebella have average values for each of the three parameters (Group 8), 28 have average values for two out of the three parameters (Groups 2, 5, 7, 9, 11, 14). In 23 cerebella, only one parameter falls within the range of average values (Groups 3, 4, 6, 10, 12, 13), and there were also 4 non-proportional cerebella (Groups 1, 15).

The combination of relative parameters ultimately determines the characteristics of the cerebellar shape and its surface structure. For instance, relatively narrow cerebella with medium length (Groups 13, 14) have symmetrically located tonsils adjacent to each other, whereas relatively narrow and relatively long cerebella (Group 2) have tightly yet asymmetrically arranged tonsils overlapping like the branches of a purse. The relative length of the cerebellum affects the depth of the anterior notch, the relative width influences its width. The relative width affects the width of the cerebellar valley, and the relative height influences its depth, and so on.

Conclusions

The proposed comprehensive method for evaluating the cerebellar shape in the morphometry of anatomical specimens involves measuring linear dimensions (*width, length,* and *height*) and calculating relative parameters (*relative width*, *length*, and *height of the cerebellum*) using specific formulas.

The magnitude of the relative parameter determines its contribution to the shape and surface structure of the cerebellum. The combination of relative parameters ultimately defines the characteristics of the shape and surface structure of the cerebellum.

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