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# Development of a new anatomic tool for the study of the occipital region in *Delphinus delphis*

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Anatomic indexes have proven to be an essential tool in the study of anatomic differences between and within species (Simoens *et al.* 1994*a*, Gapert and Last 2004, Muthukumar *et al.* 2005, Chrószcz *et al.* 2006). They are often used in descriptive studies; however, these indexes are only accurate within very narrow parameters, and thus are only useful for very specific studies. Our aim is to find and develop a new anatomic tool for the study of *Delphinus delphis* that can provide us with both greater accuracy and the possibility of using it in a wider scope of research.

Most morphometry studies employ biometrical indexes that take different values for each studied morphotype. For example, Radinsky (1967) calculated the area of the foramen magnum as: area $= \pi \times 1/4 \times W \times H$, where $W$ is the maximum width of the foramen magnum and $H$ its maximum anteroposterior diameter in the median plane (as described by Muthukumar *et al.* 2005). Gapert and Last (2004) calculated a foramen magnum index, dividing the anteroposterior diameter of the foramen magnum by the transverse diameter. Chrószcz *et al.* (2006) calculated the index of the foramen magnum using the following formula: width/height $\times$ 100. Simoens *et al.* (1994*a*) defined the foramen magnum index as the ratio between the maximal width and the total height of the foramen magnum.

The material examined (Supporting Information) consisted of 652 adult skulls of *Delphinus delphis* of both sexes from two different populations (North Atlantic Ocean and North Pacific Ocean) and two possible geographical morphotypes (Perrin *et al.* 2003). Both stranded and nonstranded specimens were included. The morphometric analyses were conducted on the part of the occipital bone that has its embryological origin in the paraxial mesoderm (Gaupp 1906, Al-Motabagani and Surendra 2006) to avoid including osseous structures with different embryological origin, which might be subject to different developmental processes.

The following anatomical measurements (Fig. 1, 2) were taken with a digital caliper to the nearest 0.01 mm: (1) maximum width of the occipital bone, (2) left width of the occipital bone, (3) right width of the occipital bone, (4) anteroposterior diameter of the foramen magnum, (5) transverse diameter of the foramen magnum, and (6) total length of dolphin's body. These measurements need not be taken in

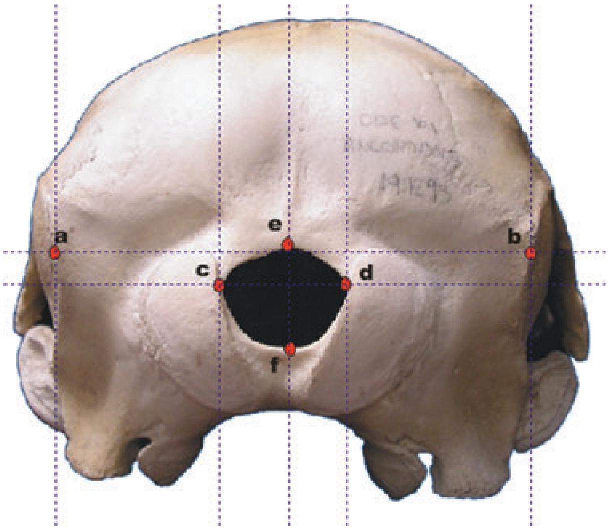


*Figure 1.* Measurements taken in the occipital bone of *Delphinus delphis* for our study in posterior view. (a,b) Maximum width of the occipital bone; (a, c) left width of the occipital bone; (b, d) right width of the occipital bone; (c, d) transversal diameter of the foramen magnum; and (e, f) anteroposterior diameter of the foramen magnum. Total dolphin's length was also measured for the relativization of variables.This figure appears in color in the online version of the article (DOI: 10.1111/j.1748-7692.2010.00382.x).

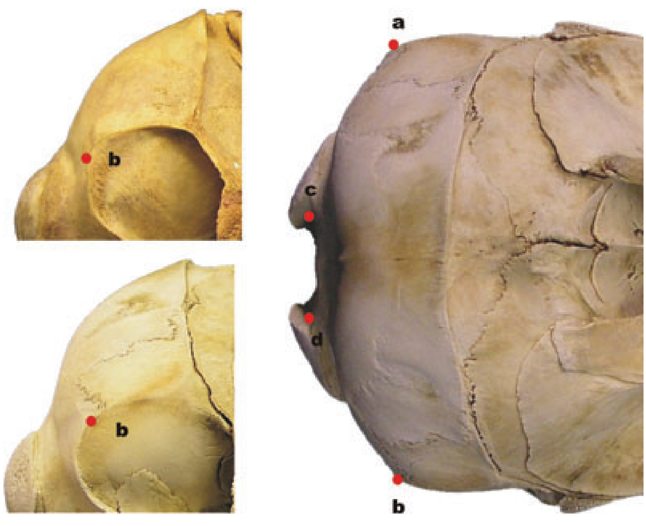


*Figure 2.* Measurements taken in the occipital bone of *Delphinus delphis* for our study in lateral and dorsal view. Where point b is at the maximum width of the occipital, at or immediately below the lambdoid suture on the parietal crest. The upper part of the occipital has a dermic embrionary origin (supraoccipital) and is narrower. This point and its left homologue (a), as well as c and d, are comparable throughout all mammals. This figure appears in color in the online version of the article (DOI: 10.1111/j.1748-7692.2010.00382.x).

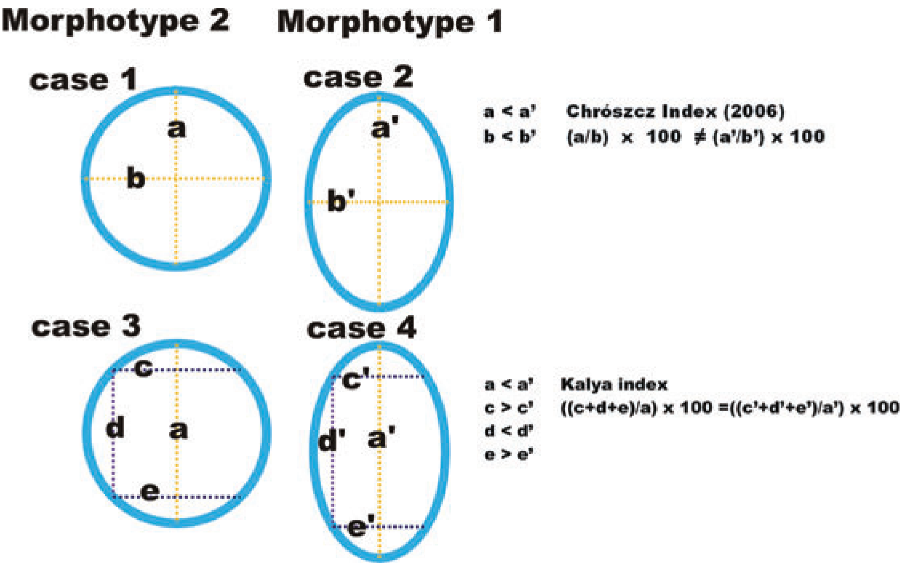


*Figure 3.* Theoretical model for the comparison of two indices applied to two different morphotypes (1 and 2) of a given osseous structure. Using the first index (cases 1 and 2), composed by two variables, different values are obtained when the values of the variables change between different morphotypes ($a/b \neq a'/b'$). However, when an index with four variables (cases 3 and 4) is applied, the final value remains stable despite the changes in the values of the variables due to a buffer effect caused by the proportions that exist between the variables $(c + d + e)/a = (c' + d' + e')/a'$. This figure appears in color in the online version of the article (DOI: 10.1111/j.1748-7692.2010.00382.x).

the same plane, because they are taken directly between points on the surface of the skull.

After the calculation of occipital bone biometrical indexes with the two variables used most commonly by other authors (width and height of foramen magnum), we observed that variations in the variables measured affected the value of the index, thus limiting its generalization for a given species due to the fact that different morphotypes would have different index values (Fig. 3, cases 1 and 2). However, we can take four interrelated variables to create a new index that keeps a stable value within the species' variability, and allows comparison between different morphotypes despite the variations in the studied variables (Fig. 2, cases 3 and 4).

The Kalya index, developed by us and named after the first author of this paper, is the percentage of the sum of the right and left widths of the occipital bone and the transverse diameter of the foramen magnum, divided by the maximum width of the occipital bone (Kalya index: $[L_{\text{right}} + L_{\text{left}} + W/ab] \times 100$).

This index does not take into account the height of the foramen magnum, because this can be an anatomical expression of the dorsal notch morphological variability (Marin-Padilla and Marin-Padilla 1977, Watson *et al.* 1989, Simoens *et al.* 1994*a*, *b*, Nishikawa *et al.* 1997, Onar *et al.* 1997, Karagoz *et al.* 2002, Nash *et al*. 2002, Chrószcz *et al.* 2006). Furthermore, to compensate for fluctuating asymmetry (Palmer and Strobeck 1986, 1992; Palmer 1994) of the occipital bone, both lateral widths

*Table 1.* Descriptive statistics and ANOVA of two of the morphotypes found in our study which show the stability of the Kalya index in the studied populations of *Delphinus delphis*. Where $w$ is the width of the foramen magnum; $ab$ is the maximum width of the occipital bone; $L_{right}$ is the right width of the occipital bone; $L_{left}$ is the left width of the occipital bone; K1 index is the Kalya index value found in morphotype 1; K2 index is the Kalya index value found in morphotype 2.

| Morphotypes | Specimens $n$ | K index components | K index | Minimum | Maximum | Mean | Typical deviation |
|---|---|---|---|---|---|---|---|
| 1 | 140 | | K1 index | 102.23 | 116.48 | 109.80 | 2.82 |
| | | $w$ | | 32.41 | 43.00 | 37.06 | 2.17 |
| | | $ab$ | | 121.54 | 154.28 | 141.91 | 5.85 |
| | | $L_{right}$ | | 49.38 | 67.33 | 60.14 | 3.19 |
| | | $L_{left}$ | | 50.44 | 65.88 | 58.56 | 2.94 |
| | | | K2 index | 102.89 | 116.12 | 109.19 | 2.75 |
| 2 | 164 | $w$ | | 26.57 | 37.74 | 32.57 | 2.05 |
| | | $ab$ | | 108.72 | 147.30 | 130.18 | 7.83 |
| | | $L_{right}$ | | 42.49 | 66.07 | 55.70 | 4.82 |
| | | $L_{left}$ | | 42.49 | 62.38 | 53.90 | 4.17 |
| 1.2 | 303 | ANOVA | | $F$ | Significance | | |
| | | | K index | 3.696 | 0.055 | | |
| | | $w$ | | 341.808 | 0.000 | | |
| | | $ab$ | | 212.357 | 0.000 | | |
| | | $L_{right}$ | | 86.050 | 0.000 | | |
| | | $L_{left}$ | | 122.729 | 0.000 | | |

of the occipital bone were taken into account. The relation between the variables taken from the occipital area of the skull of *Delphinus delphis* allows the compensation of the individual variability for each specimen, allowing the index value to remain stable, with $P > 0.05$ confirming the lack of any statistically significant differences in the index value (Table 1). This property gives our index its usefulness, because the presence of a value with very small variability between morphotypes (Fig. 4) allows us to conduct inter- and intrapopulational studies with more accuracy than with the usage of any other of the existing indexes (such as the one used by Chrószcz *et al.* 2006), due to their much greater variability (with a variance 10 times greater than that of the Kalya index) between individuals and the associated loss of statistical power (Table 2, 3; Fig. 4).

Pearson's correlation coefficient among the variables and the Kalya index are significant at the 0.01 level (bilateral) (Table 4). Total length shows a strong correlation with all the occipital bone variables. The Kalya index is constant in all the specimens of *Delphinus delphis* measured, compensating for the fluctuation of the variables used to calculate it. Because of this balancing of the variables, this index allows us to use it as a comparative base to study the other occipital bone morphotypes.

The abovementioned properties make the index a constant that could be interpreted as an example of anatomic compensation, which can be defined as the phenomenon by which the growth of some traits implies the reduction of others (Fig. 5). The Kalya index characterizes the studied species and defines the developmental

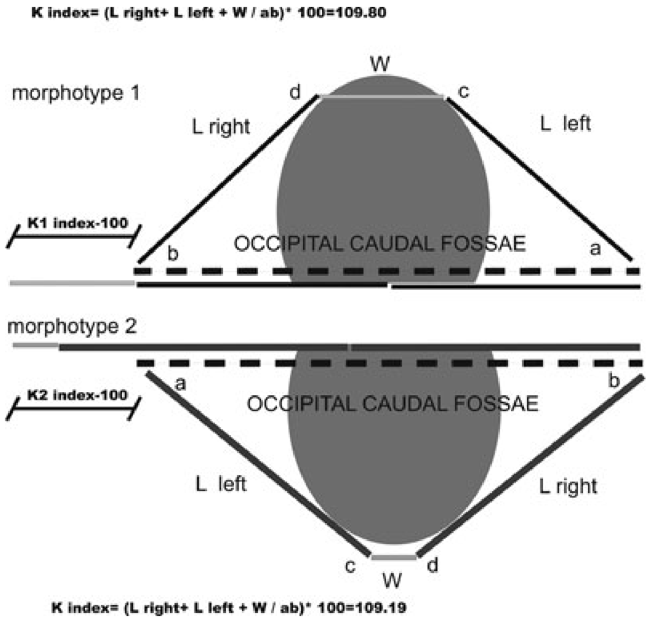


*Figure 4.* Graphical representation of two of the morphotypes found among the dolphins sampled. The black and grey lines represent the different variables as seen from a dorsal view in both morphotypes, scaled by their measured value. It can be seen that, despite the differences in the value of the variables, the value of the Kalya index remains very similar in both morphotypes.

genetic stability of the occipital bone proportions independently of the different morphotypes. We can conclude that this new index is constant in all the specimens studied and can be used as a comparative base to study the other variables involved with any osseous structures. Further, other researchers (Richards and Plourde 1995, Creed-Miles *et al*. 1996, Arsuaga *et al*. 1997, Tillier 1999) are also in the process of reevaluating the phylogenetic value of the shape of the foramen magnum.

This index could be very useful in anatomical studies. For now it has helped us with intraspecific comparison between stranded and nonstranded specimens of *Delphinus*

*Table 2.* Descriptive statistics of Kalya index and Chrószcz index.

| | *n* | Mean | SE | Variance |
|---|---|---|---|---|
| Kalya index | 619 | 109.68 | 0.128 | 10.29 |
| Chrószcz *et al*. 2006 | 621 | 107.54 | 0.403 | 101.05 |
| *n* valid | 612 | | | |

*Table 3.* Output from one-sample *t*-test between Kalya index and Chrószcz index.

| | | *n* | Correlation | Significance |
|---|---|---|---|---|
| Pair 1 | Kalya index and Chrószcz *et al*. (2006) | 612 | 0.131 | 0.001 |

*Table 4.* Pearson's correlation coefficient between the specimen's total length and (1) width of the occipital bone, (2) sum of the left and right width of the occipital bone excluding foramen magnum (S_LR_occ), (3) transverse diameter of the foramen magnum, and (4) Kalya index.

| | Statistic | Total body length |
|---|---|---|
| Width of the occipital bone | Pearson's correlation | 0.798[a] |
| | Significance (bilateral) | 0.000 |
| | *n* | 563 |
| S_LR_occ | Pearson's correlation | 0.709[a] |
| | Significance (bilateral) | 0.000 |
| | *n* | 548 |
| Transverse diameter of the foramen magnum | Pearson's correlation | 0.591[a] |
| | Significance (bilateral) | 0.000 |
| | *n* | 559 |
| Kalya index | Pearson's correlation | 0.128[a] |
| | Significance (bilateral) | 0.003 |
| | *n* | 543 |

[a]Correlation is significant at the level 0.01.

*delphis*. Some interesting studies in *Delphinus capensis* are currently underway. Also, future studies will be centered on its applicability to other species, which would lead to all kinds of studies evaluating inter- and intraspecific variability in both living and extinct odontocetes and other vertebrates.

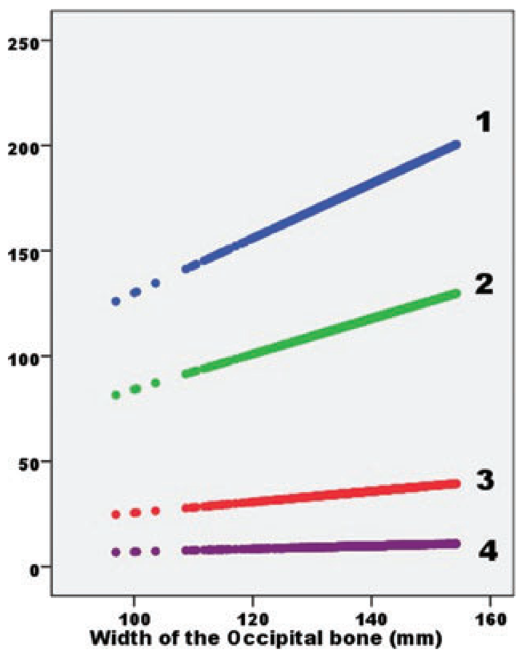


*Figure 5.* Linear correlation among the measured variables and the Kalya index. (1) Total dolphin's body length (cm). (2) Sum of right and left width of the occipital bone, excluding the FM (mm). (3) Transverse diameter of the foramen magnum (mm). (4) Kalya index. This figure appears in color in the online version of the article (DOI: 10.1111/j.1748-7692.2010.00382.x).

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## Literature Cited

Al-Motabagani, A. M., and M. Surendra. 2006. Total occipitalization of the atlas. Anatomical Science International 81:173–180.

Arsuaga, J. L., I. Martinez, A. Gracia and C. Lorenzo. 1997. The Sima de los Huesos Crania (Sierra de Atapuerca, Spain). A comparative study. Journal of Human Evolution 33:219–281.

Chrószcz, A., M. Janeczek, M. Wojnar and N. Pospieszny. 2006. Morphological analysis and morphometry of the foramen magnum of the American Staffordshire terrier breed newborns. Medycyna Weterynaryjna 62:1002–1004.

Creed-Miles, M., A. Rosas and R. Kruszynski. 1996. Issues in the identification of Neandertal derivative traits at early post-natal stages. Journal of Human Evolution 30:147–153.

Gapert, R., and J. Last. 2004. Endocranial capacity correlates with the size of the foramen magnum in human adult crania. Journal of Anatomy 205:542–543.

Gaupp, E. 1906. Ueber allgemeine und spezielle Fragen aus der Lehrevom Kopfskelett der Wirbeltiere. Verhandlungen der Anatomischen Gesellschaft 20:21–73.

Karagoz, F., N. Izgi and S. S. Kapíjcíjoğlu. 2002. Morphometric measurements of the cranium in patients with Chiari type I malformation and comparison with the normal population. Acta Neurochirurgica (Wien) 144:165–171.

Marin-Padilla, M., and T. M. Marin-Padilla. 1977. Developmental abnormalities of the occipital bone in human chondrodystrophies (achondroplasia and thanatophoric dwarfism). Birth Defects Original Article Series 13:7–23.

Muthukumar, N., R. Swaminathan, G. Venkatesh and S. P. Bhanumathy. 2005. A morphometric analysis of the foramen magnum region as it relates to the transcondylar approach. Acta Neurochirurgica 147:889–895.

Nash, J., J. S. Cheng, G. A. Meyer and B. F. Remler. 2002. Chiari type I malformation: Overview of diagnosis and treatment. Wisconsin Medical Journal 101:35–40.

Nishikawa, M., H. Sakamoto, A. Hakuba, N. Nakanishi and Y. Inoue. 1997. Pathogenesis of Chiari malformation: A morphometric study of the posterior cranial fossa. Journal of Neurosurgery 86:40–47.

Onar, V., R. Mutuş and K. O. Kahvecioğlu. 1997. Morphometric analysis of the foramen magnum in German Shepherd dogs (Alsatians). Annals of Anatomy 179:563–568.

Palmer, A. R. 1994. Fluctuating asymmetry analyses: A primer. Pages 335–364 *in* T. A. Markow, ed. Developmental instability: Its origins and evolutionary implications. Kluwer Academic Publishers, Dordrecht, The Netherlands.

Palmer, A. R., and C. Strobeck. 1986. Fluctuating asymmetry: Measurement, analysis, patterns. Annual Review of Ecology and Systematics 17:392–421.

Palmer, A. R., and C. Strobeck. 1992. Fluctuating asymmetry as a measure of developmental stability: Implications of non-normal distributions and power of statistical tests. Acta Zoologica Fennica 191:57–72.

Perrin, W. F., M. L. L. Dolar, M. Amano and A. Hayano. 2003. Cranial sexual dimorphism and geographic variation in Fraser's dolphin, *Lagenodelphis hosei*. Marine Mammal Science 19:484–501.

Radinsky, L. 1967. Relative brain size: A new measure. Science 17:836–838.

Richards, G. D., and A. M. Plourde. 1995. Reconsideration of the 'Neanderthal' infant, Amud-7. American Journal of Physical Anthropology 20:180–181.

Simoens, P., P. Poels, P. Vyt and H. Lauwers. 1994*a*. Foramen magnum variability and occipital dysplasia in the dog. Vlaams Dierengeneeskundig Tijdschrift 63:44–53.

Simoens, P., P. Poels and H. Lauwers. 1994*b*. Morphometric analysis of the foramen magnum in Pekingese dogs. American Journal of Veterinary Research 55:34–39.

Tillier, A. M. 1999. Les enfants moustériens de Qafzeh. Interprétation phylogénétique et paléoauxologique. Cahiers de Paléoanthropologie. Centre National de la Recherche Scientifique, Paris, France.

Watson, A. G., A. De Lahunta and H. E. Evans. 1989. Dorsal notch of foramen magnum due to incomplete ossification of supraoccipital bone in dogs. Journal of Small Animal Practice 30:666–673.

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## Supporting Information

The following supporting information is available for this article online:

*Appendix S1.* Sample details, anatomical measurements, and values of Kalya index and Chrószcz et al. (2006).