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ORIGINAL ARTICLE

Elliptical Fourier descriptors of outline and morphological analysis in caudal view of foramen magnum of the tropical raccoon (*Procyon cancrivorus*) (Linnaeus, 1758)



Descripteurs elliptiques de Fourier du contour et de la morphologie en vue caudale du foramen magnum du raton-laveur tropical (Procyon cancrivorus) (Linnaeus, 1758)

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Foramen analysis;
Morphology;
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Summary

Objectives. – To evaluate sexual-size dimorphism and attempt at categorization of inter-individual shapes of foramen magnum outlines using Fourier descriptors which allow for shape outline evaluations with a resultant specimen character definition.

Materials and methods. – Individual characterization and quantification of foramen magnum shapes in direct caudal view based on elliptical Fourier technique was applied to 46 tropical raccoon skulls (26 females, 20 males).

Results. – Incremental number of harmonics demonstrates morphological contributions of such descriptors with their relations to specific anatomical constructions established. The initial harmonics (1st to 3rd) described the general foramen shapes while the second (4th to 12th) demonstrated fine morphological details. Sexual-size dimorphism was observed in females (87.1%) and 91.7% in males, normalization of size produces 75% in females and 83% in males. With respect to foramen magnum dimorphism analysis, the result obtained through elliptic Fourier analysis was comparatively better in detail information of outline contours than earlier classical methods. The first four effective principal components defined 70.63% of its shape properties while the rest (22.51%) constituted fine details of morphology.

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Conclusion. – Both size and shape seems important in sexual dimorphisms in this species, this investigation suggest clinical implications, taxonomic and anthropologic perspectives in foramen characterization magnum characterization and further postulates an increased possibility of volume reduction cerebellar protrusion, ontogenic magnum shape irregularities in the sample population with neurologic consequences especially among females.

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Résumé Ce travail vise à évaluer le dimorphisme sexuel de taille et à tenter de catégoriser les formes inter-individuelles du contour du foramen magnum en utilisant des descripteurs de Fourier qui permettent des évaluations des contours de forme avec une définition de caractère de l'échantillon résultant. La caractérisation et quantification individuelles des formes du foramen magnum en vue caudale directe basée sur la technique elliptique de Fourier ont été appliquées à 46 cranes de rats-laveurs tropicaux (26 femelles, 20 mâles). Le nombre croissant d'harmoniques démontre les contributions morphologiques respectives de ces descripteurs et leurs relations avec des caractères anatomiques spécifiques. Les harmoniques initiaux (4^e à 3^e) ont décrit les formes générales tandis que les suivants (4^e à 12^e) ont démontré des détails morphologiques fins. Le dimorphisme sexuel de taille a été observé chez les femelles (87,1 %) et chez les mâles (91,7 %) ; la normalisation de la taille amène à 75 % chez les femelles et à 83 % chez les mâles. En ce qui concerne l'analyse du dimorphisme du foramen magnum, le résultat obtenu grâce à l'analyse de Fourier elliptique s'est avéré comparativement meilleur dans la caractérisation détaillée des contours que les méthodes classiques antérieures. Les quatre premiers composants principaux efficaces ont défini 70,63 % des caractéristiques de forme, tandis que le reste (22,51 %) offrait et révélait de nombreux détails de morphologie. La taille et la forme semblent importantes dans le cadre du dimorphisme sexuel de cette espèce. Nos résultats suggèrent des perspectives taxonomiques et anthropologiques dans l'analyse de la forme du foramen magnum et suggère la possibilité accrue de réduction de volume de la protubérance cérébelleuse, des irrégularités de forme d'origine ontogénétique, avec des conséquences neurologiques possibles, en particulier chez les femelles.

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Introduction

The foramen magnum by its diverse morphology presents some peculiar challenges in attempts at its characterization, the caudal view shape of the foramen is important in both neurological and anthropological studies [1,2]. Classical metric quantification methods in assessment of the foramen magnum scarcely applied with reference to limited and subjective available information for cephalometric evaluations [3]. Difficulties in precise homologous point location for repeatability and biological shape pattern recognition and discrimination interpretations could explain this difficulty. In anthropological investigations, accurate description of individuals is necessary for forensic studies on species from different ecological populations, skeletal remains, taxonomic and in evolutionary processes investigations [4–7].

Size, shape and architecture of foramen magnum present important race and individual variations [2] and as seen in raccoons (*Procyon cancrivorus*); indices among subspecies peak within juveniles' age group especially in the smaller subspecies [8]. Morphology of the foramen outline in the present species remains poorly described. The most caudoventral portion morphology of this structure also offers variations, which may be of further relevance in classification of the family [9].

Females, in this regard have about 15% attenuated size development of the skull bones as was confirmed by Watson et al. [10]. As in canids, the possibility of cerebellar

protrusion occasioned by volume reduction of the posterior fossa, syringomyelia and neurological disorders [7,9] remains potent with observation of open dorsal notches, which has been frequently reported associated with captive breeding and domestication attempts [11].

Advances in morphometry especially through computational biology introduced approaches in which homology of landmark points are not important while details of shape outlines can be explained geometrically, Elliptical Fourier method has been utilized by Dixon et al. [12] and Urbanová [13] after being initiated by Kuhl and Giardina [14] in the description of complex outlines but the methodology still remains largely unknown [15,16].

The purpose of this study is to morphologically analyze the elliptical Fourier descriptors of the foramen magnum outlines using variation–covariation by stepwise reconstruction in separate gender classes with contributions of the principal components of the coefficients as developed by Iwata and Ukai [17] to assign quantities, compare inter-individual variability and evaluate dimorphisms.

Materials and methods

Osteological materials generation and categorization

This in vitro experiments involved 46 adult tropical raccoons (*P. cancrivorus*) comprising of 26 females and 20 males

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