



Dilemma in the diversity of foramen magnum dimensions

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ABSTRACT

Foramen magnum, which is an opening for the passage of spinal cord is highly variable in its dimensions, the reasons for which are not known. In this report we examined a few skulls from different species and performed selective morphometric analysis (Condyle ratio, Nuchal ratio and radius) to derive possible explanations for variations in size of foramen magnum. We propose possible influence of variations in dimension of foramen magnum on a few physio-anatomical traits, which necessitates further research.

Key words: Foramen magnum, body balance, speed physiology

ANATOMICAL DESCRIPTION OF FORAMEN MAGNUM

The foramen magnum is a large round or oval opening found within the occipital bone (Figure 1 and 2), which forms the caudal boundary of the skull in non-primate species. In primates, the occipital bone is positioned in a more ventral location. The components of the occipital bone, namely the squamous, basilar and paired lateral parts, develop around the foramen magnum, which marks the junction between the spinal cord and the medulla oblongata. Structures associated with the spinal cord that pass through the foramen magnum include the meninges, the spinal branch of the accessory nerve (cranial nerve XI), the vertebral venous sinuses and the basilar artery.^{1,2}

The foramen magnum is bordered on its lateral and ventral aspects by the paired occipital condyles, convex structures that articulate with the first cervical vertebra, the atlas (Figure 1 and 2). The intercondyloid notch forms the ventral edge of the foramen magnum and lies between the occipital condyles, which contribute to the formation of the notch. The curved dorsal border of the foramen is made up of the squamous part of the occipital bone, also known as the supraoccipital bone. A median ridge, the external occipital crest, is prominent in some skulls and extends the length of the supraoccipital bone.

The long axis of the foramen magnum has a horizontal orientation and is oval in shape. The dorsal border often contains a median notch, especially in brachycephalic breeds of dog (Figure 1).² The anatomical diversity of foramen magnum and its associated structures in some selected species is summarized in (Table 1).

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Species variance in dimension of foramen magnum

Morphometric analysis of variations in the foramen magnum is routinely used to differentiate closely related species.¹ This is specifically useful in understanding the evolution of hominids wherein the anatomical differences in the location of foramen magnum is linked to the ability to maintain straight posture^{1,5} and consequently the development of physiological capabilities of enhanced locomotion. Interestingly the morphometry of the foramen magnum is also highly variable across different species as well and it is not clear if this variation has any physiological relevance in addition to its contribution to body posture and locomotion. To address this we examined skulls of different species (Figure 3-5) and performed morphometric analysis of the foramen magnum using the following three matrix:

1. Condyle ratio (Horizontal ratio): which is the ratio of horizontal distance between the two occipital condyles to the horizontal diameter of foramen magnum.
2. Nuchal ratio (Vertical ratio): which is the ratio of distance between pharyngeal tubercle and external occipital protuberance to that of vertical diameter of foramen magnum.
3. Radius: The radius of foramen magnum was calculated using the ratio of area (πr^2) and perimeter ($2\pi r$) of foramen magnum and multiplying the resulting value by 2.

We analysed 17 different species for which we had clear images of the skull and foramen magnum. Morphometric data was assessed using ImageJ software. The species variation in all the three matrixes estimated was clearly evident (Figure 3-5). Accounting the nature of variance we set one level of threshold for the condyle (Figure 3) and nuchal (Figure 4) ratio, while we set two levels of threshold based on the foramen magnum radius (Figure 5). It was interesting to note that chimpanzee, dog, hyena, lion horse and cattle had condyle ratio above the threshold, while the rest of the species studied had similar condyle ratio. The nuchal ratio was observed to be above the threshold in hyena with all other species studied having uniform nuchal ratio. In contrast we observed a wide degree of variation in the radius of foramen magnum, which we have classified into high, medium and low foramen magnum radius species (Figure 5). The high foramen

Table 1: Comparative features of the occipital bone among selected species.					
Species	External occipital protuberance	Squamous part (supraoccipital)	External occipital crest	Occipital condyles	Foramen magnum
Dog	Prominent	Usually fused with interparietal bone	Often faint	Oblique, wider dorsally	Large, often has dorsal notch
Horse	Prominent	Quadrilateral shape	Prominent	Oblique, wider dorsally	Large, almost circular
Cow	Prominent	Fuses with parietal bone	Prominent	Oblique, far apart	Wide
Grey Seal	Not evident	Large	Not evident	Oblique, far apart	Very large
Birds	Not evident	Triangular, smooth	Not evident	Single, ventral to foramen magnum	Variable in orientation
Human	Prominent	Convex external surface	Faint	Angled rostro-medially	Oval, wider posteriorly

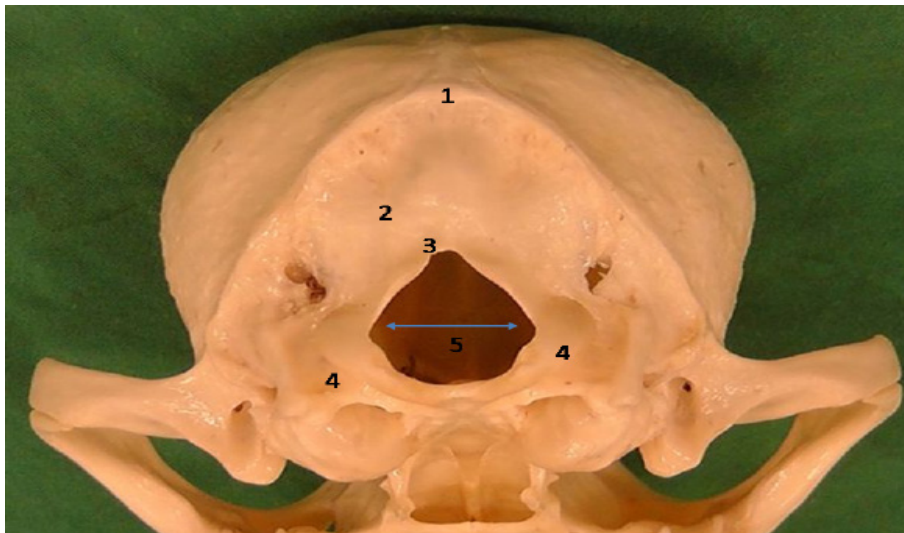


Figure 1: Caudal view of skull of Chihuahua dog.

1= External occipital protuberance ; 2= Squamous part of occipital bone(supraoccipital) ; 3= External occipital crest ; 4= Occipital condyles ; 5= Foramen magnum

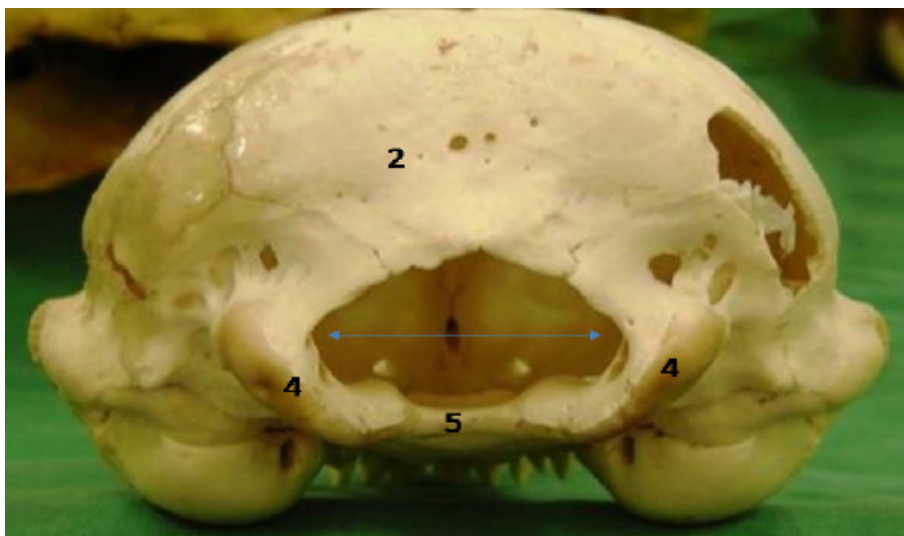


Figure 2: Caudal view of Grey seal skull.

2= Squamous part of occipital bone(supraoccipital) ; 4= Occipital condyles ; 5= Foramen magnum

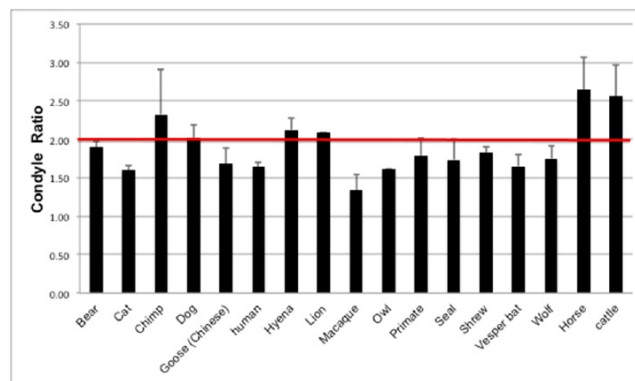


Figure 3: Condyle ratio of various species. Data is represented as Mean \pm SD.

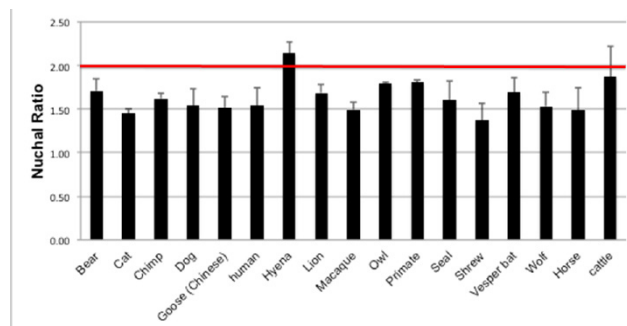


Figure 4: Nuchal ratio of various species. Data is represented as Mean \pm SD.

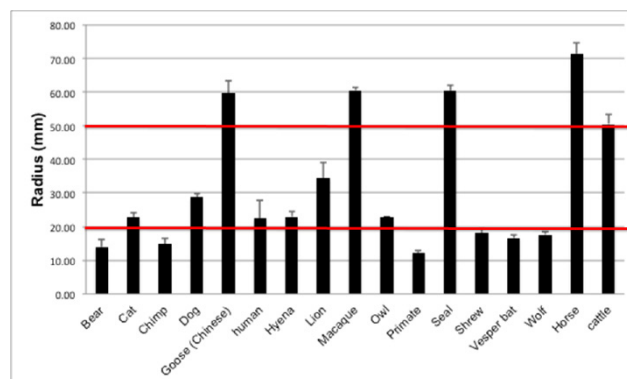


Figure 5: Foramen magnum radius of various species. Data is represented as Mean \pm SD.

magnum radius group consisted of seal, macaque, horse, cattle and goose, while the medium foramen magnum radius group consisted of cat, human, hyena, lion and owl and the rest of the species analysed were in the low foramen magnum radius group. We believe among the three matrix used in our analysis, the radius estimation based on area to perimeter ratio analysis is most reliable and appropriate in segregating species difference. However further studies to include several other species with more replicates for each species will be necessary to validate this approach. Nevertheless our preliminary study provides a proof of concept to understand the physio-anatomical dilemma in the morphometric variations of foramen magnum.

Hypothesis on foramen magnum diversity

Although our study is very preliminary to make any concrete conclusion on the reasons for diversity in the dimensions on foramen magnum. However we would like to suggest some hypothesis based on our current understanding on variations in dimension of foramen magnum and the morphometric analysis shown in this report. We

are limiting our focus to the physiological relevance of variations in dimensions of foramen magnum as the pathological consideration is beyond the scope of this article.

The most widely explained concept is positioning of the foramen magnum in relation to the skull, which is believed to be vital in developing upright body positioning during evolution of humans. It is obvious to suggest that upright body positioning has led to advantages with locomotion and body balance. Similar advantages may also be evident among aquatic and land animals and avian species with alignment of foramen magnum with long axis of the body or head to body ratio, which necessitates further research. We provide here a few insights into this dilemma in the diversity of foramen magnum dimensions and its possible physio-anatomical implications.

In addition to species differentiation, several reports have highlighted the utility of foramen magnum diameter is differentiation of gender within the species,^{3,4,9,10} which is of high significance in forensic investigations. In general females tend to have lower foramen magnum diameter compared to males.^{3,4,9,10} However most data

reported to date are based on analysis of skull samples. Since foramen magnum diameter can be non-invasively measured by imaging (CT, MRI or Ultrasound), larger multicentre and multi-geographic studies are necessary to further understand the implication of variations in diameter of foramen magnum.

Non-invasive determination of foramen magnum diameter may also have utility in prediction of individuals prone for herniation of the cerebellum, especially in species, which are predisposed to this condition. For instance Cavalier King Charles Spaniels have high predisposition to herniation of the cerebellum into the foramen magnum.^{7,9} Hence it will be interesting to evaluate if radius analysis of foramen magnum diameter and its symmetry would be of help to identify individual dogs prone for herniation of the cerebellum.

Interestingly in addition to intra species variations in foramen magnum diameter, variations in its shape are also reported. The following different shapes of foramen magnum with their relative occurrence are reported in humans: round (19 cases; 18.8%), 2 semi-circles (18; 17.8%), egg-shaped (15; 14.9%), hexagonal (14; 13.9%), tetragonal (11; 10.9%), oval (11; 10.9%), pentagonal (9; 8.9%), and irregular (4; 4%).³ However it's not clear if this variation in foramen magnum shape offers any physiological or anatomical impact. Indeed such shape variances in foramen magnum is also reported in camels¹² and it remains to be seen if novel approaches for classification of species or breeds can be developed based on foramen magnum shape and dimensions.

Interestingly body weight was highly correlated with the area of the foramen magnum in some group of birds (passerines and non-passerines).¹¹ We suggest that the predictive potential of foramen magnum size in body weight gain in avian species specifically the broiler industry can result in significant economic advantage and hence should be researched. Also, architectural analysis of the avian neurocranium suggested that expansion of the avian brain in some species of birds (hummingbirds, raptors and passerine species) has led to the foramen magnum assuming a more ventral position, similar to primates⁶ and it will be fascinating to know if this correlates with higher cognitive functions. In most other avian species, the foramen magnum has a more caudal location, which is the typical arrangement like in most other animals. In the former group, the expansion of the brain relative to the cranial base is linked to greater flight activity and a skull that is more

easily manoeuvred. Indeed in our analysis we observed a higher foramen magnum diameter among Chinese goose (Figure 5).

Based on our initial analysis, we propose an interesting hypothesis that "foramen magnum diameter and its symmetry can give an individual an athletic advantage by influencing the speed and body balance and coordination". The non-invasive determination of foramen magnum matrix should allow prediction of these improved physiological traits which can be very valuable in several species and specifically in humans, equines and canines to predetermine their athletic advantage. For instance it will be interesting to know if higher foramen magnum radius among seals and goose gives them physiological advantage of swimming and navigation skills. Likewise the possibility of attributing higher speed in human, equine and canine species. We think research looking into these concepts are necessary and will be promising and rewarding.

Indeed diving marine mammals are characterised by a large foramen magnum in addition to other skull adaptations,⁸ including large venous sinuses for drainage of cerebral blood. Many of these large sinuses are extradural in position, thereby requiring substantially more space than in terrestrial mammals. The large foramen magnum in the seal would permit the passage of these sinuses and associated vasculature into the cranium, whereas a small occipital opening would severely limit perfusion of the brain. Given the large intra-species variation in foramen magnum size in domestic animals, perhaps a morphometric study of this foramen in humans would be worthwhile to determine if a narrow foramen magnum predisposes to problems with cerebral blood flow. Alternatively it will interest to test if humans with larger foramen magnum are more resistant to development of stroke and its associated complications.

CONCLUSION

In this report we have attempted to give our insight into the possible influence of variations in dimension of foramen magnum on various physio-anatomical traits. Specifically among them are the influences of foramen magnum size on higher cognitive ability in different species, swimming and navigation skills among aquatic and avian species, athletic advantage among humans, equines and canines and body weight gain in broiler breeds in addition to offering protections against developing some clinical conditions, all of which necessitates further research.

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