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A simple nonlinear model for estimating obturator foramen area in young bovines

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Abstract : The aim of this study was to produce a simple and inexpensive technique for estimating the obturator foramen area (OFA) from young calves based on the hypothesis that OFA can be extrapolated from simple linear measurements. Three linear measurements - dorsoventral height, craneocaudal width and total perimeter of obturator foramen - were obtained from 55 bovine hemicoxae. Different algorithms for determining OFA were then produced with a regression analysis (curve fitting) and statistical analysis software. The most simple equation was OFA (mm^2) = [3,150.538 + (36.111*CW)] – [147,856.033/DH] (where CW = craneocaudal width and DH = dorsoventral height, both in mm), representing a good nonlinear model with a standard deviation of error for the estimate of 232.44 and a coefficient of multiple determination of 0.846. This formula may be helpful as a repeatable and easily performed estimation of the obturator foramen area in young bovines. The area of the obturator foramen magnum can thus be estimated using this regression formula.

Keywords : biometry, hip bone, image analysis, morphometry, osteology

Introduction

The distinctive morphology of the hip bone (os coxae) and its clear sexual dimorphism in mammals make it of interest from anatomical, anthropological and forensic points of view. Those authors who have studied this bone by osteometric methods have paid attention either to features relating to its total size or to those of various components, such as its inferior border, the greater sciatic notch, the symphysial surface, the acetabulum, the obturator foramen and the arcuate line.

The obturator foramen is a large opening in the hip bone, which is bridged by the obturator membrane, except for above, where there is a communication between the pelvis and the thigh. This communication, also known as the obturator canal, is the passage through which the obturator vessels and nerves pass [6]. Shape analysis has been scarcely applied to the study of the obturator foramen, and only for human [1, 2, 4], although it is of great interest, for instance for sex determination from archaeological remains [5]. Anatomical knowledge and awareness of variations in the area associated with the obturator foramen may be of immense clinical importance to veterinary surgeons and radiologists. The obturator region has mainly been used by surgeons for sling operations and as a route for cystocele repair. Prior knowledge of the anatomy of the obturator region and its structures would ensure safe surgery in the region.

If there is a paucity of literature on humane obturator foramen, detailed studies that set out to establish the morphological pattern of the obturator foramen seem not available in the literature. It was therefore decided to undertake the present study and specifically is has been focused to obtain an easy procedure of area estimation using simple linear measurements. The lack of literature makes this study more interesting from both from an academic as from a clinical point of view.

Materials and Methods

A random sample of 55 bovine hip bones from a commercial abattoir was collected from the deboned carcasses of young bovines belonging to “Bruna dels Pirineus breed (a rustic meat breed which is native of Catalunya, Spain). The animals studied were approximately 12 months old (average = 364.7 days, range = 297~556 days) and they presented neither abnormal general appearance nor signs of clinical lameness. Twenty-nine were males and thirteen were females, whereas of thirteen sex was unregistered. All hip bones were undamaged and showed no pathological alterations that could lead to error in measurement; 30 were from the right and 25 from the left.

Image capture was performed with a digital camera (image resolution of 2,240 × 1,488 pixels, D70; Nikon, Japan)

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equipped with a telephoto lens (AF Nikkor 28-80 mm; Nikon). The focal axis of the camera was parallel to the horizontal plane of reference, and centred on the obturator foramen. For scaling purposes a ruler was concurrently photographed on each image. A computerized image analysis system was then used to measure obturator foramen area (OFA) with digital picture analysis software (ver. 3.0, UTHSCSA Image Tool software, USA) This software tool has been partially developed for this application and is therefore able to properly evaluate areas (UTHSCSA Image Tool software). The boundary of the foramen was delimitated digitally. As spatial calibration is available in UTHSCSA to indicate real linear and area dimensional measurements all the photocopies included a measuring piece to facilitate calibration by the software. Linear measurements were also taken digitally with the UTHSCSA program.

For each variable from the total sample the following measurements were obtained: craneocaudal maximal width (distance in a straight line from the end of the anterior border through the virtual centre of the obturator foramen until the end of the posterior border, parallel to a saggital plane), dorsoventral maximal height (distance in a straight line from the most dorsal plane of the obturator foramen, to the opposite end of its most ventral plane, with transverse direction to length), total perimeter (contouring the osseous ridge of the foramen) and area (area of the "hole" delimited by the osseous ridge of the foramen). The area was calculated in square millimetres by the corresponding option of the UTHSCSA software and recorded as OFA. The first author (PMPC) performed all measurements one time.

Correlations were performed to investigate relationships between the various obturator foramen measurements. To determine the most suitable regression equation for the criteria, standard deviation of error (SDE), residual sum, residual average, residual sum of squares (RSS), coefficient of multiple determination (R^2) and adjusted coefficient of multiple determination (Ra^2) observed in OFA were used to evaluate and compare different regression models. The goodness of fit of the models was assessed by examining the regressions of residuals. Each model was then assessed based on its algorithm simplicity. The data were analysed using Data Fit (ver. 9.0.59) and PAST (ver. 1.94b) [3]. Because of the limited number of cases available for study, the model could not be adjusted for the effects of sex.

The research was conducted between November 2011 and December 2011. Ethical approval was not required as all measurements were recorded post-mortem at a commercial abattoir plant.

Results

Although the distribution of age was not normal (Shapiro-Wilks' W = 0.53) the sampling was considered to be homogeneous with no sexual bias for age difference ($p = 0.887$). Analysis by Mann-Whitney test revealed no significantly differences between sides for any linear measurement ($p < 0.05$), but males and females were significantly highly different ($p < 0.01$) for Ao and Po. The obturator foramen measurement results obtained are shown in Table 1. According to coefficient of variation (CV), measured OFAs conformed a fairly uniform group (CV OFA = 16.0%). All measurement values showed a normal distribution ($W > 0.935$) so it is assumed not to have added bias when developing the formula for predicting OFA (skewness OFA = –0.869 and kurtosis OFA = 1.972). Dorsoventral height, craneocaudal width and total perimeter showed significant Pearson's correlation coefficients with the area ($t < 0.001$) (results not showed here). The high correlation coefficients between measurements suggest that either of these variables or a combination of them could provide a good estimate for predicting the OFA, but total perimeter has been excluded as it presented differences between sexes; moreover this measurement it is difficult to obtain directly on the bone (in this article, the measurement has been obtained digitally on pictures). The best fitted algorithms obtained are presented in Table 2. The equation $a + b*CW + c / DH$, where CW = craneocaudal width, DH = dorsoventral height, a = 3,150.538, b = 36.111 and c = –147,856.033, represented one of the simplest nonlinear model with a low SDE = 232.44. The high coefficient of multiple determination of this equation ($R^2 = 0.846$) indicated that it predicted differences in OFA quite well for the independent data set. Fig. 1 shows that the residual follows a straight line pattern and there are no unusual patterns or outliers. As a result, the assumption regarding the residuals was

Table 1. Some simple statistics obtained

	Craneocaudal width (mm)	Dorsoventral height (mm)	Total perimeter (mm)	Obturator foramen area (mm^2)
Average (X ± SD)	77.5 ± 8.74	65.0 ± 9.27	218.6 ± 18.46	3,628.2 ± 583.11
Min	55.7	37.4	159.5	1,789.5
Max	93.1	89.2	254.3	4,890.4
W	0.937	0.935	0.936	0.949

X: mean, Min: minimum value, Max: maximum value, W: Shapiro-Wilk normality test, Craneocaudal width: distance in a straight line from the end of the anterior border through the virtual centre of the obturator foramen until the end of the posterior border, parallel to a saggital plane, Dorsoventral height: distance in a straight line from the most dorsal plane of the obturator foramen, to the opposite end of its most ventral plane, with transverse direction to length.

Table 2. Best fitted (with lowest SDE) algorithms obtained

Rank	Model	SDE	RSS	R^2	Ra^2
1	a + b*CW + c / DH	232.443	2809561.64	0.846	0.841
2	a + b*CW + c*ln(DH)	232.487	2810622.30	0.846	0.841
3	a + b*ln(CW) + c*ln(DH)	235.793	2891115.45	0.842	0.836
4	a + b*ln(CW) + c / DH	236.559	2909944.11	0.841	0.835
5	a + b / CW + c*ln(DH)	240.285	3002334.99	0.836	0.830
6	a + b / CW + c / DH	241.511	3033036.99	0.834	0.828
7	a + b*CW + c*DH	245.860	3143269.57	0.828	0.822
8	a + b*ln(CW) + c*DH	249.162	3228270.05	0.824	0.817
9	a + b / CW + c*DH	253.975	3354179.07	0.817	0.810
10	$a*b^{CW} * DH^c$	255.679	3399337.58	0.814	0.807
11	$a*CW^b * DH^c$	257.953	3460089.37	0.811	0.804
12	$a*CW^b * c^{DH}$	279.892	4073670.78	0.778	0.769

CW: craneocaudal width, DH: dorsoventral height, SDE: standard deviation of error, RSS: residual sum of squares, R^2: coefficient of multiple determination, Ra^2: adjusted coefficient of multiple determination.

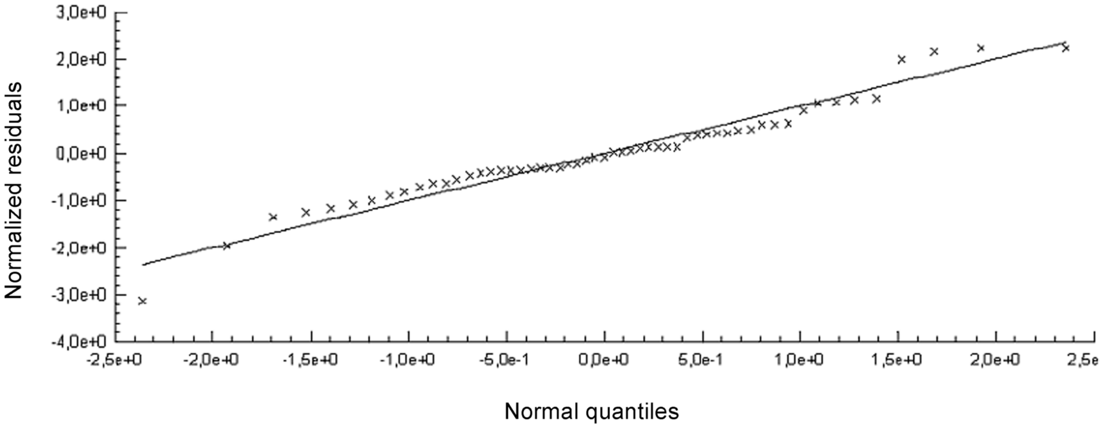

Fig. 1. Residual normal probability plot. A normal distribution is evidenced by the points roughly lying on a straight line. The plot demonstrates adequate normality of the residuals. The discrepant values have not been removed from the plot.

not violated. The correlation between the observed OFA and the residuals was very low ($r = 0.391$), indicating that the deviation between actual and predicted values did not vary across the entire validation data set.

Discussion

The equation OFA (mm^2) = [3,150.538 + (36.111*CW)] – [147,856.033 / DH] (where CW = craneocaudal width and DH = dorsoventral height, both in mm), represents a good nonlinear model and may be helpful as a repeatable and easily performed estimation of the obturator foramen area in young bovines based on two simple measurements: width and height. A model for estimating obturator foramen in bovines has not been described elsewhere. We hope that this formula will be useful to evaluate pathologies and malformations of the bovine coxae.

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