GEOMETRIC MORPHOMETRIC ON DORSAL ASPECT OF SKULL DOES NOT ASSESS DIFFERENCES BETWEEN HORNED AND POLLED DOMESTIC GOATS

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Abstract

Few previous studies have explored caprine skulls using geometric morphometric (GM) methods, which enable the quantitative analysis and visualisation of shape changes in skeletal elements and provide an important compliment to traditional lineal analyses. The aim of this research is to determine whether GM techniques can provide insights into how the shape of the goat skull differs between horned and polled animals, focusing on the differences between the dorsal aspects of the neurocranium. Fourteen skulls (4 polled and 10 horned) skulls from adult goats belonging to different breeds were studied. From the obtained results, neither the size nor shape showed statistically significant differences between polled and horned skulls. As animal's functional capabilities are influenced by the presence of horns (if horns must function as shock absorbers, protecting the brain from blows during intraspecific combat, it would seem that some differences in shape and/or size should be detected), it seems plausible to assume that landmarks located on the dorsal aspect of the neurocranium are not useful to detect those differences between horned and polled goats.

Keywords: Capra hircus; horn; neurocranium; skull morphometry

1. Introduction

The first livestock species to be domesticated in the Fertile Crescent of the Near East was the goat (*Capra hircus*), as the wild bezoar goat (*Capra aegagrus*) was tamed at least 10,000 years ago (Mason 1984; Zeder 2006). A series of recent genetic studies based on mtDNA sequence variation has revealed a complex pattern of caprine domestication (Luikart et al. 2001; Naderi et al. 2007). Six divergent mtDNA haplogroups have been found in domestic goat populations worldwide, suggesting the incorporation of numerous genetic lineages into the domestic goat gene pool, most likely from different populations of the bezoar goat (Pereira et al., 2008). It is well known that both polled and horned goat breeds currently exist, with the size, shape and structure of the horns within the *Bovidae* characters being taxonomically distinctive (Armitage and Clutton-Brock 1976).

In horned animals, the frontal sinus excavates the horn core at the base, but does not reach so far toward the tip as in cattle. Horns of goats are placed so close to the orbit that the supply structures (blood vessels and nerves) ascend directly behind the zygomatic process (Dyce et al. 1996). Small changes in morphology can have profound effects on an animal's functional capabilities (Koehl 1996). Therefore, the purpose of this study was to assess whether horned skulls present detectable morphological changes *vs.* polled ones, using changes that are located on the neurocranium.

2. Materials and Methods
2.1. *Specimens examined*

The present analyses of sexual dimorphism and age-related variation are based on 14 adult medium-size specimens (4 polled and 10 horned) with no evidence of craniofacial deformation, and which were taken from the osteological collection of the Department of Animal Production of the University of Lleida. Specimens belonged to different breeds which were not known for all animals, so this character was not considered. As the sex of each specimen was unknown, all individuals were pooled. Skulls were considered "adults" when M^3 appeared fully erupted.

2.2. *Landmark digitizing*

The three-dimensional coordinates of 11 homologous landmarks were collected using a Microscribe 3DX portable digitiser. In geometric morphometrics, landmarks can be defined as 'biologically meaningful' points that can be consistently identified in all specimens (Richtsmeier et al. 1995; Valeri et al. 1998). Landmarks were located on the dorsal aspect of the neurocranium as either Type I or II (Bookstein 1990; Valeri et al. 1998). Type I landmarks are contact points between structures, such as the intersection of two sutures, or the midpoints of the foramina, while Type II landmarks are points at the maxima of curvature, such as points on the maxima of the tori and the minima of the sulci (Bookstein 1990; MacLeod 2001).

Landmark 1 (pf type I) was situated on the fronto-nasal suture, whereas 2 and 3 (both of type II) were on the supra-orbitary foramen. Suture fronto-lacrimal was represented by landmarks 4 and 5, and suture zygomatico-lacrimal by landmarks 6 and 7 (all of type I). The saggital section was represented by landmarks 8, 9, 10 and 11 (all of type I), with the latter on the highest point of the frontal bone. All eleven landmarks were homologous and topologically equivalent (Fig. 1). Two additional landmarks were used as a scale.

Taking landmarks directly using a stylus has an advantage over using digital images, as it is possible to reach anatomical points that can be "masked" by horns. Landmarks were standardised after removing artefactual variation due to different positions of the specimens using CoordGen6f (H. D. Sheets, www.canisius.edu/sheets). Landmarks were then converted to scaled x and y coordinates, and centroid size (CS, the square root of the sum of the squared distances among the landmarks in a configuration and their extracted centre of mass) was obtained. Size information was retained as CS.

2.3. *Testing for image-capturing precision, and landmark digitising error*

The unequal inaccuracies in landmark placement may lead to error because they may distort the apparent shape of the cranium. To assess this potential problem, eleven individuals were digitised twice by the author. The within-sample error was quantified as a percent measurement error (% ME), following Bailey and Byrnes (1990). A one-way analysis of variance (ANOVA) was performed on the Procrustes residuals to partition shape-variance into within- and between-individual components. % ME was then calculated as follows:

$$\% \text{ ME} = [(s^2_{within}) / (s^2_{within} + s^2_{among})] \times 100 \%$$

where s^2_{within} represents the within-mean square effect (or the within-specimen variance) and s^2_{among} represents the among-mean square effect (or the among-specimen variance).

2.4. *Shape variation*

In order to compare Procrustes to tangent space distances between individuals, Generalised Procrustes Analysis (GPA) superimpositions (equivalent to generalised least squares (GLS) procedure of Rohlf and Slice (1990) were performed on each data set using TPS-Small 1.20 (Rohlf 2003). The approximation of shape space by tangent space presented a high correlation (0.999). This high degree of approximation of shapes in the sample (=shape space) by the reference shape (=tangent space) allowed the accurate capture of the nature and extent of shape deformations in subsequent statistical analyses.

2.5. *Size and shape comparisons*

The Kruskal-Wallis test, a non-parametric ANOVA, was used to compare the medians of sexes for size, assessed as CS. NPMANOVA (Non-Parametric MANOVA, also known as PERMANOVA), another non-parametric test, was used to study whether there were differences in shape based on Euclidean distance measure. To investigate body-form variability between polled and horned animals, a principal component analysis on Procrustes shape coordinates for the entire sample was finally performed.

All statistical analyses were carried out in PAST- "Paleontological Statistics Software Package for Education and Data Analysis" (Hammer et al. 2001).

3. Results and analysis
3.1. *Image-capturing device precision and digitising error*

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The % ME results of the two replicates, which assessed the degree of capturing device precision, were 0.34%. Our results indicate that between-sample differences are much greater than the within-sample variances, indicating that measurement error due to image-capturing device precision and digitising error is unlikely to constrain the results of all subsequent statistical analyses in the present study. Moreover, measurement error of less than 15% is considered to be within the reliable variable range for establishing biological trends (Bailey and Byrnes 1990; Polly 2001).

3.2. *Size and shape comparison*

The Kruskal-Wallis test reflected no size differences between horned and polled animals (p=0.943). NPMANOVA also reflected no differences for shape (p=0.750). Skull-form variation between polled and horned animals using PCA of Procrustes shape coordinates is shown in Fig. 2. Because of rescaling (i.e. removal of many size effects), the first two components accounted for only 43.3% and 18.7% of the variance, respectively. There appeared to be no discontinuity, nor any clustering by the presence or absence of horns. PC I was significantly correlated with log CS (r^2 =0.520, p=0.003) and all polled animals were grouped into the wider horned group. This is probably due to shape variability, but is not associated with size differences.

4. Discussion

Phenotypic appearance of an animal's head has been reported to depend on the shape of the skull and is strongly related to breed-specific skeletal features (Kunzel et al. 2003). Morphometric studies of the skull have been documented in many domestic animals, but there is a dearth of information on morphometric studies of the skull of goats based on GM methods. Some researchers (Olopade et al. 2006; Sarma 2006; Olopade and Onwuka 2007) have published interesting articles based on classical morphometric techniques, which reflect clear regional anatomical differences between goat breeds. If the shape and appearance of the head is important for determining the character of the animal (Dyce et al. 1996), and if horns in goats must function as shock absorbers, in order to protect the brain from blows during intraspecific combat, it would seem that some differences in shape and/or size should have been detected; however, this was not the case. Although the choice of landmarks must provide valuable, discrete anatomical information, it appears that the landmarks selected in this study were not informative enough to provide information on differences between horned and polled skulls. As it is difficult to find more type I or II landmarks on the dorsal aspect of the neurocranium, a study of lateral aspects would probably reflect these expected differences. Moreover, if skulls from known breeds of different lineages were to be considered, the detection of those differences would be clearer.

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Figure 1. Landmarks recorded on the dorsal surface of skulls of domestic goats. Landmarks are marked with circles. Projection of landmark locations for all specimens, after general least square alignment. Eleven landmarks were homologous and topologically equivalent, including three paired points (2-3, 4-5 and 6-7) on each side and five on the midline.
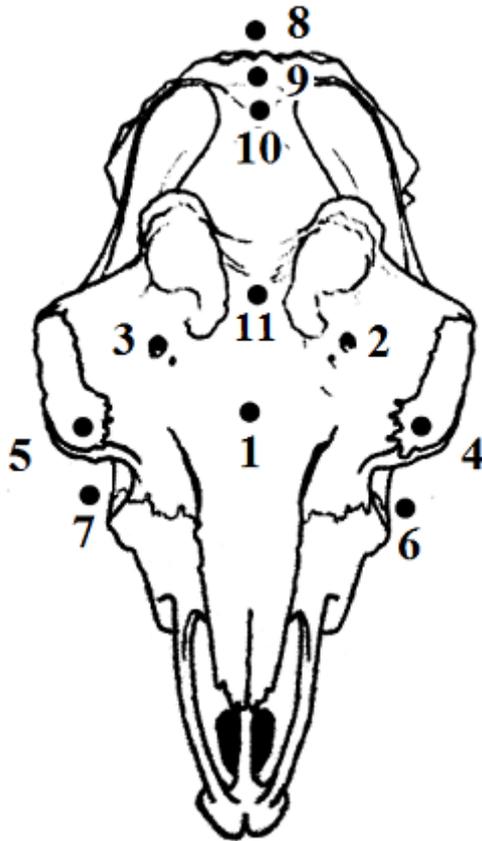
Figure 2. Principal Component Analysis of Procrustes shape coordinates for polled (empty circles, n=4) and horned (crosses, n=10) animals. The first two components account for 43.3% and 18.7% of the variance, respectively. Polled animals appear fully included into a wider horned group.