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A morphometric analysis of prognathism and evaluation of the gnathic index in modern humans

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ABSTRACT

Subnasal prognathism is a morphological feature often described in studies of paleoanthropology, bioarchaeology, and forensic anthropology. This trait is commonly quantified using the gnathic index, which compares *basion–prosthion* and *basion–nasion* lengths. This study used geometric morphometrics to assess whether the gnathic index is a reliable indicator of subnasal prognathism and to explore the effects of sex, population, and allometry on this trait. Nineteen craniofacial landmarks were collected from three-dimensional cranial surface scans of 192 individuals across five population groups. Generalized Procrustes analysis and principal components analysis were employed to identify shape components related to changes in subnasal prognathism, comparing component scores to gnathic index values. M/ANOVAs were used to determine the effects of sex and population on prognathism, and linear regression served to assess static allometry. The gnathic index was significantly correlated with PCs 1 and 3, which appeared to capture prognathic shape change, but also with PCs 2 and 6, which reflected other craniofacial shape changes. Population differences in levels of prognathism were identified, but no significant effects of sex or allometry were found. The results show that, although the gnathic index correlates with prognathic shape variation, it is also influenced by other variables, such as the relative position of *basion*. In this sense,

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the gnathic index serves to illustrate the shortcomings of linear measurement analysis as compared to landmark configurations. Further, the results demonstrate that subnasal prognathism is a complex feature in need of redefinition.

Introduction

When discussing prognathism, it is important to distinguish it from midfacial projection (Hanihara, 2000; Lieberman et al., 2000; Lieberman, 2011). Midfacial, or facial, projection has been defined as the "degree to which [the] face projects in front of [the] cranial base" (Lieberman et al., 2000:118). In contrast, prognathism, which may be referred to as lower facial, subnasal, or maxillary alveolar prognathism, is defined as the anterior projection of the lower face relative to the upper face (Lieberman, 2011; Neaux et al., 2013). This is also distinct from mandibular prognathism, which may be referred to as basal prognathism, and is more often discussed in clinical literature (Björk, 1950; Chang et al., 2006). For the purposes of this paper, "prognathism" will refer strictly to subnasal maxillary alveolar projection (i.e., *subnasal prognathism*).

Prognathism is frequently invoked to characterize and distinguish hominin taxa and human populations, at the paleontological, bioarchaeological, and forensic levels (Bass, 1987; Brooks et al., 1990; Brown and Maeda, 2004; Gonzalez-Jose et al., 2007; Kennedy and Possehl, 2012; Lieberman, 2011; Martínez-Abadías et al., 2006; Ousley et al., 2009; Quatrehomme et al., 2007; Spoor et al., 2005; Weisensee and Jantz, 2011). Varying degrees of prognathism have been identified as distinguishing features between both temporally and geographically distinct human populations (e.g., Brown and Maeda, 2004; Gonzalez-Jose et al., 2007) and as an indicator of gene flow between populations (Gonzalez-Jose et al., 2007; Martínez-Abadías et al., 2006). Among modern humans, populations of African ancestries are generally characterized as displaying a high-degree of subnasal prognathism (i.e., *prognathic*), in contrast with those of European, Asian, and Native American ancestries, who are generally described as having little to no prognathism (i.e., *orthognathic*) (Bass, 1987; Gill and Rhine, 1990).

Subnasal prognathism and associated nasal and palate morphology have also been described as sexually dimorphic characteristics (Bigoni et al., 2010; Franklin et al., 2006). In addition, differences in subnasal prognathism have been argued to be driven, in part, by variation in overall size (Franklin et al., 2006; Weisensee and Jantz, 2011). However, despite recurrent mentions in studies of overall craniofacial morphology, few studies have focused on the specific morphology contributing to subnasal prognathism. This may in part be due to difficulties with objectively evaluating this trait and a lack of understanding regarding the developmental processes involved in the expression of prognathism.

Throughout paleoanthropology, bioarcheology, and forensic anthropology, subnasal prognathism is commonly described qualitatively, as a relative degree of prognathism (e.g., high, moderate, low, or lacking) compared to a reference group or groups (e.g., Gill and Rhine, 1990). However, such qualitative descriptions are highly subjective, with high intra- and inter-observer error rates (L'Abbé et al., 2011), and are hard to validate statistically. There have been several attempts in the past to quantify subnasal prognathism metrically. Huxley (1863) suggested using the craniofacial, or sphenomaxillary, angle as a measure of prognathism. This angle was calculated from lines connecting *prosthion* (the most anterior point on the maxilla), *sellion* (the most anterior point on the sphenoid), and *basion* (the most anterior point on the foramen magnum). The use of *sellion*, however, requires endocranial access or a lateral radiographic examination, thereby making this method difficult to apply to intact crania. To overcome this issue, the use of the "gnathic index" was proposed, using three ectocranial landmarks: *basion*, *nasion*, and *prosthion* (Martin, 1957; Martin and Knussmann, 1988).

The gnathic index is calculated as a ratio of *basion–prosthion* length to *basion–nasion* length (Fig. 1) and has continued to be used among bioarchaeologists, skeletal biomechanists, forensic anthropologists, and paleoanthropologists to document and analyze subnasal prognathism (Brooks et al., 1990;