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TECHNICAL NOTE

A geometric morphometric approach to the study of variation of shovel-shaped incisors

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Abstract

Objectives: The scoring and analysis of dental nonmetric traits are predominantly accomplished by using the Arizona State University Dental Anthropology System (ASUDAS), a standard protocol based on strict definitions and three-dimensional dental plaques. However, visual scoring, even when controlled by strict definitions of features, visual reference, and the experience of the observer, includes an unavoidable part of subjectivity. In this methodological contribution, we propose a new quantitative geometric morphometric approach to quickly and efficiently assess the variation of shoveling in modern human maxillary central incisors (UI1).

Materials and methods: We analyzed 87 modern human UI1s by means of virtual imaging and the ASU-UI1 dental plaque grades using geometric morphometrics by placing semilandmarks on the labial crown aspect. The modern human sample was composed of individuals from Europe, Africa, and Asia and included representatives of all seven grades defined by the ASUDAS method.

Results: Our results highlighted some limitations in the use of the current UI1 ASUDAS plaque, indicating that it did not necessarily represent an objective gradient of expression of a nonmetric

tooth feature. Rating of shoveling tended to be more prone to intra- and interobserver bias for the highest grades. In addition, our analyses suggest that the observers were strongly influenced by the depth of the lingual crown aspect when assessing the shoveling.

Discussion: In this context, our results provide a reliable and reproducible framework reinforced by statistical results supporting the fact that open scale numerical measurements can complement the ASUDAS method.

KEYWORDS

ASUDAS, Procrustes and non-Procrustes superimpositions, shovel-shape incisors, virtual anthropology

1 | INTRODUCTION

Teeth display morphological variations of the crown and roots that differ substantially among modern human and fossil groups, some dental characteristics being predominant in certain groups or populations (Turner, Nichol, & Scott, 1991). As stated by Hillson, "human eyes and brain are unsurpassed in discerning tiny differences between objects compared side by side, but it is much more difficult to define a scheme for recording size and shape in such a way that comparisons can be made between hundreds of such objects" (Hillson, 1996, pp. 68). For this reason, since the 19th century, several attempts have been made to classify and assess differences between fossil and extant human populations, at first using detailed descriptive approaches and later elaborating scoring systems (reviewed in Irish & Scott, 2016).

Following the influential early works of Hrdlička (1920) and Dahlberg (1956), who standardized a four-grade classification plaque for upper incisor shoveling, some researchers tried to reduce the visual subjectivity by measuring the depth of the lingual fossa. However, they had little success because of issues with the precision of the method (Carbonell, 1963; Dahlberg & Mikkelsen, 1947; Goaz & Miller, 1966; Hanihara, 1969). Later Scott (1973) developed an eight degree scale that was then adapted and integrated by Turner et al. (1991) into a formal system for scoring nonmetric aspects of dental morphology: the Arizona State University Dental Anthropology System (ASUDAS) (Scott, 1973; Scott & Turner, 1997; Turner et al., 1991). This widely-used standard protocol is based on reference plaster plaques representing the casts of selected teeth showing a gradient of expression of a particular trait (Scott & Turner, 1997; Scott, Turner, Townsend, & Martinón-Torres, 2018; Turner et al., 1991). Since their initial publication, the number of traits and plaques have increased and some of them have been adapted to the range of variation expressed by fossil hominins (Bailey & Hublin, 2013; Bailey & Wood, 2007; Irish, Guatelli-Steinberg, Legge, Ruiter, & Berger, 2013; Irish & Scott, 2016).The scoring and analysis of dental nonmetric traits currently represents a common diagnostic procedure to highlight ancestry/genetic affinities and investigate human variation in anthropological, paleoanthropological and forensic studies (Bailey & Hublin, 2013; Irish, 1998, 2014; Irish & Guatelli-Steinberg, 2003; Irish & Scott, 2016; Scott & Turner, 1997; Turner et al., 1991; Zanolli, 2013; Zanolli et al., 2014). If the observer has been trained by an expert, the ASUDAS approach to morphological characters is easy, fast and reliable, and remains the gold standard technique today (Scott et al., 2018; Scott & Irish, 2017). However, visual scoring, even when controlled by strict definitions of features and the experience of the observer, includes an unavoidable part of subjectivity. In fact, the assessment of shoveling defined by the ASUDAS method has some major limitations inherent to its definition. The specimens selected to develop the reference grades on the plaque were chosen by qualitative appreciation, which does not necessarily represent the morphological variation in a linear way. This can lead to minimal visual difference between some grades of expression and so to the difficulty experienced by users in classifying the analyzed specimens with regard to the ASUDAS (especially for beginners). In brief, both the selection of the reference teeth when creating the ASUDAS method and the comparison of the dental specimens with the ASUDAS plaques are dependent on observations/palpations and the experience of the observer (i.e., dependent on operator subjectivity). Nichol and Turner II (1986) have shown that the intraobserver error when assessing the expression of incisor shoveling is small: 4.1% for more than one grade difference and only 2% for presence/absence differences. However, as mentioned by Scott and Turner (1997), "it will probably never be possible to attain 100% concordance in replicated observations of tooth crown and root traits, either by single observers or between observers. The reference plaques developed by Dahlberg, K. Hanihara, Turner, and others have enhanced observational precision but they have not been a panacea for the reasons noted above (i.e., threshold expressions, post-eruptive modifications, surficial noise, varying levels of experience, etc.)" (Scott & Turner, 1997, pp. 72).

Incisor shoveling is one of the nonmetric features that has received the most attention from anthropologists as an indicator of relationships among populations and it is frequently used for its taxonomic and phylogenetic relevance (e.g., Bailey & Hublin, 2013; Carter, Worthington, & Smith, 2014; Irish et al., 2013; Irish, Guatelli-Steinberg, Legge, Ruiter, & Berger, 2014; Scott & Turner, 1997). This feature can be defined as the degree of elevation of the mesial and distal lingual marginal ridges on the lingual surface of the maxillary incisors, canines and mandibular incisors, with more pronounced forms enclosing a fossa (Dahlberg, 1956; Hrdlička, 1920; Scott & Turner, 1997; Turner et al., 1991). Shoveling is more marked and variable in the

primates (Pilbrow, 2003) and fossil hominins (Bailey & Hublin, 2013; Bailey & Wood, 2007; Crummett, 1994; Irish et al., 2013; Martinón-Torres et al., 2007; Mizogushi, 1985)—in part because, once the grades are scored, they are dichotomized into presence/absence to help reduce observer error and because of the current dichotomous biological distance statistics available (e.g., MMD). There has been a previous attempt to link morphology and measurements for the UI1 shoveling trait, notably by considering the depth of the lingual fossa with respect to ASUDAS grades (Hanihara, 2008). However, this method only considers the maximum depth at the center of the lingual fossa and does not quantify the shape of this fossa. Thus, it is still possible to develop innovative, complementary methods. The recent development of quick and efficient methods for acquiring 3D models of an object (e.g., photogrammetry, laser scanner), together with the advent of powerful quantitative techniques to assess shape variation (geometric morphometrics), has opened up new ways to test the reliability (precision and accuracy) of the ASUDAS method. These methods represent an opportunity to provide objective protocols to investigate nonmetric dental variation. In this preliminary study, we have compared the classical plaque-based visual scoring assessment with a new 3D geometric morphometric approach. We propose here a simple, fast method based on geometric morphometrics to characterize a sample of modern human UI1s using a continuous scale of morphological variation of shoveling. The intraobserver error related to the visual scoring is very low, as previously demonstrated for ASUDAS plaques (Nichol & Turner II, 1986; Scott, 2008; Scott & Irish, 2017; Scott & Turner, 1997). As anticipated, our results highlight some limitations of the use of the current ASUDAS plaque, indicating that it did not necessarily represent an objective gradient of expression of a nonmetric tooth feature (Figures 3, 4, and 6). Our results also agree with the currently recognized ASUDAS breakpoint between the recorded absence (grades 0–1) and presence (grades 2–7) of shoveling (Scott et al., 2018; Scott & Irish, 2017). This method can also distinguish between the French and South African groups (expressing low degrees of shoveling) and the Chinese sample (being more variable but mostly showing well-defined shovel-shaped incisors). This is in agreement with the vast literature on the topic (e.g., Irish & Scott, 2016; Scott et al., 2018; Scott & Irish, 2017; Scott & Turner, 1997) and demonstrates that our method, while confirming the ASUDAS results, opens a path toward more advanced quantitatively-based assessment for the distinction of fossil and extant human populations. This modest sample was only used here to test the method, but by increasing it and incorporating larger chronogeographic groups, including fossil hominins, there is a high potential to better understand the evolution of shovel-shaped incisors. For example, Neanderthals are well-known for their markedly shovel-shaped incisors and, given the increasing availability of 3D virtual data on their teeth, paleogenetics techniques, and molecular data on tooth morphology (Zanolli, Hourset, Esclassan, & Mollereau, 2017), this new quantitative method is perfectly suited to the investigation of the evolution of UI1 shoveling.

Our protocol integrates the analysis of two different but complementary aspects: the depth of the lingual surface with respect to the marginal ridges and the shape of the lingual aspect. This is an important point as our analyses have revealed that visual rating of shoveling tends to be more prone to intra- and inter-observer bias for the highest grades (even starting at grade 2). In addition, even when the observers are well trained and follow the definition of the UI1 shoveling trait (Supporting Information Table 2), when dealing with numerous specimens, they tend to create a mental image of the ASUDAS categories and then make their judgments, resulting in a mental scale that is linearly dependent on the maximum depth of the palatal aspect, while the ASUDAS grades are not distributed linearly for this parameter. This results in the visually assigned ratings being correlated with the maximum depth rather than with predicted ASUDAS categories. In this context, our results provide a reliable, reproducible framework reinforced by statistical results supporting the fact that open scale numerical measurements can complement the ASUDAS method and provide new information. Of course, similar methods complementing the classic ASUDAS method still need to be developed for other nonmetric dental traits. There are also other possibilities for the quantitative study of shape variation, with or without landmarks. For example, a surface deformation-based approach considering a 3D portion of the crown surface (such as the lingual aspect in the case of UI1 shoveling) could be used to assess the degree of deformation from one tooth to another and quantify shape variations of the complete set of dental traits (Durrleman et al., 2012; Durrleman et al., 2014). Thus, although the ASUDAS is a reliable and efficient tool, it is still possible to complement it with alternative methods.

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