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Identifying domestic horses, donkeys and hybrids from archaeological deposits: A 3D morphological investigation on skeletons

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ABSTRACT

The first evidence for the domestication of donkeys (*Equus asinus*) dates back to at least 6000-5000 BP in Northeast Africa, and their dispersion is attributed to the ancient Romans. Latin authors described donkeys as being particularly suitable for the transport of goods and farm work. In addition, they were also bred to produce prized hybrids, particularly mules, which were perfectly adapted to the long-distance transport of people and goods. However, although the historical sources extensively describe their economic importance, both donkey and hybrid remains are surprisingly scarce in the archaeological record. This apparent contradiction is probably due to the difficulties involved in correctly identifying their bones: relatively few bones displaying morphological and metrical criteria can be used for identification, so it is often based purely on bone size. The aim of this study, therefore, is to propose solutions to identify domestic equid bones using 3D geometric morphometrics on isolated and combinations of anatomical elements. A set of 3D coordinates were registered on the 18 main skull and limb bones of 111 modern reference specimens (i.e. 42 horses, 44 donkeys and 25 hybrids). In this paper, we present the classification rate obtained on this reference sample using the k-Nearest Neighbors algorithm. The application of this method on archaeological skeletons from Roman to modern sites is also presented. The percentage of correctly classified specimens was between 77% and 95% for all 18 bones, and higher than 80% for 10 of the fragmentation patterns we defined. Using a combination of several bones enabled us to increase the rate of correct reclassification to a maximum of 97%. The application to archaeological skeletons proved the ability of this method to identify domestic horses and donkeys from archaeological samples. Correspondingly, some bones, and especially combinations of bones, provided good rates to identify hybrids. This method has proved reliable in detecting the presence of donkeys and hybrids from the archaeological samples of equid bones, and should enrich our knowledge regarding their spread across Europe.

1. Introduction

The cultural and economic importance of horses (*Equus caballus*) to past human societies is well documented in both historical sources and the archaeological record (Clutton-Brock, 1992). However, these were not the only equids used: donkeys (*Equus asinus*) and mules (*Equus asinus* x *Equus caballus*) also played a key role in civilizations worldwide. The earliest reference for the domestication of donkeys occurred in Northeast Africa, with the African wild ass (*Equus africanus*) in around 6000-5000 BP (Beja-Pereira et al., 2004; Marshall, 2007; Kimura et al., 2011). Domesticated donkeys are still used today in African pastoral societies for milking and eating, though primarily for carriage and traction (Blench, 2000; Clutton-Brock, 1992). The success of these animals lies in the fact that, contrary to cattle, they are well-adapted to arid conditions and to trekking across mountainous areas and stony terrain (Marshall, 2007; Maloiy et al., 2009). In Europe,

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domesticated donkeys were initially spread by the Greek African colonies during the second millennium BC (Bökönyi, 1974), and then widely used across the provinces of the Roman Empire (Bodson, 1985). The endurance of the donkey was commended by ancient Roman writers who described them as particularly suitable for farming activities like carrying merchandise, rotating the mill or ploughing light soil (White, 1970; Toynbee, 1973; Hyland, 1990; Peters, 1998). However, with regards to transport, the Romans seemed to have preferred the mule: the offspring of a male donkey (*Equus asinus*) and a female horse (*Equus caballus*). These mules were renowned for their vigor, which enabled them to carry heavy baggage or travel long-distances with the army or civilian population (Armitage and Chapman, 1979). In contrast, hinnies (*Equus caballus* x *Equus asinus*), the offspring of a male horse and a female donkey, are mentioned only as being of low working quality (Clutton-Brock, 1992; Loudon, 1825) and more difficult to produce (Gray, 1954; Gilbert, 1991). The use of donkeys and mules remained important during the Middle Ages (Dent, 1972) and into the modern period, especially with the increasing role of equids in agricultural works; in southern Europe, donkeys and mules were even preferred to horses (Clutton-Brock, 1992). Nevertheless, despite the fact that donkeys and hybrids seem to have been essential to the economy of past societies, the archaeological remains attributed to them are surprisingly scarce (Bökönyi, 1974; Albarella et al., 1993; Manconi, 1995; Peters, 1998; Arbogast et al., 2002). Several authors have emphasized the putative existence of a methodological bias to explain this apparent contradiction, and have questioned the reliability of the methodologies used to identify donkeys, especially hybrids, from archaeological bone material (Johnstone, 2006). Generally, donkeys and hybrids are identified based on the morphology of teeth enamel (Armitage and Chapman, 1979; Davis, 1980; Eisenmann, 1986; Payne, 1991; Uerpmann, 2002). When bones are examined, the morphological criteria concentrates on the skull (Groves and Mazák, 1967; Azzaroli, 1978; Eisenmann, 1980, 1986; Albizuri and Nadal, 1991; Kunst, 2000), although these are rarely well-preserved in the archaeological context. Some postcranial morphological criteria has been defined (Arloing, 1882; Barone, 1986; Peters, 1998; Rosselli Vilá, 1921), not all of which is considered reliable (Zeder, 1986; Albarella et al., 1993; Baxter, 1998; Putelat, 2015) and the most widely accepted by zooarchaeologists involves relatively few bones. Some quantitative methods based on linear measurements do exist (Eisenmann, 1986; Eisenmann and Beckouche, 1986; Groves, 1986; Dive and Eisenmann, 1991; Peters, 1998; Johnstone, 2004, 2006); however, bone size is generally used as the criterion to identify equid species, as horses and mules are visibly larger that donkeys. These practices are justified by the idea that large donkeys only appeared with modern breeds (Arbogast et al., 2002); therefore, small-sized specimens are often identified as donkeys (Forest, 2008) and, due to the near absence of specific criterion to identify hybrids, large bones displaying the morphological characteristics of donkeys are generally identified as hybrids. This overview of the methodologies used to identify donkeys and hybrids from archaeological deposits, highlights that each suffers from different limitations and none allows for the robust identification of hybrids. In this study, we partially solved these various issues using 3D geometric morphometrics on a large set of cranial and postcranial elements from a broad sample of modern comparative specimens, and proposed statistically challengeable identifications of archaeological equids. We applied this method to 18 skull and limb bones of a modern reference sample and compared their discriminate potential. The analyses were performed on complete bones but also on sections of bones, in order to simulate the fragmented nature of the archaeological remains and to adapt the methodology to these archaeological constraints (Owen et al., 2014; Cornette et al., 2015). Finally, analyses were carried out on combinations of bones: indeed, thanks to their particular status, equids are often found as complete or sub complete skeletons in archaeological deposits linked to funeral or ritual practices; moreover, the taboo of horsemeat consumption during Roman times and the Middle Ages, coupled with the bulkiness of a horse's body, meant that their carcasses were often deposited outside of the city confines (Arbogast et al., 2002). The purpose of our study was to provide a reliable method of identifying horses, donkeys and hybrids from archaeological sites; we demonstrated the applicability of this approach using 6 archaeological equid skeletons excavated from French archaeological sites dating from the Roman to the modern period.

2. Material and methods

2.1. Material

2.1.1. Modern comparative sample

To develop the identification methodology, data from modern reference specimens of known species were required. While it is not possible to strictly compare modern and archaeological forms, this kind of comparative approach, which enables the highlighting of phenotypic proximities between archaeological and modern specimens, is used extensively within zooarchaeology (Cucchi et al., 2011; Cornette et al., 2015; Guillaud et al., 2015). The comparative modern dataset here includes the complete or partial skeletons of 111 individuals from several European institutions (Table 1): 27 domestic horses (*Equus caballus*) of various breeds (i.e. racehorses, draft horses, Shetland ponies, Icelandic ponies, Camargue horse, Pottok, Konik); 15 Przewalski's horses (*Equus przewalskii*); 44 domestic donkeys (*Equus asinus asinus*) and wild asses (*Equus asinus africanus*); 17 mules (*Equus asinus* x *Equus caballus*) and 8 hinnies (*Equus caballus* x *Equus asinus*). All of which were adult specimens with fully fused epiphyses.

2.1.2. Archaeological material

In order to test the method's validity on an archaeological sample, we applied it to 6 archaeological equid skeletons from Roman to modern sites in northern France (Table 2). The specimens were chosen primarily because they were all complete, or almost complete, skeletons which covered a broad chronological period. Some specimens had been previously identified in published studies, the rest had been identified according to Peters' morphological criteria on the scapula, radius, metacarpal, tibia and first phalanxes (Peters, 1998).

2.2. Method

2.2.1. Acquisition of data and 3D geometric morphometrics

Geometric morphometrics (GMM) is a quantitative approach which allows for the comparison of bone shapes by providing detailed shape data, which are usable for the graphical visualization of morphological differences and statistical analyses. This methodology was previously applied to the distal of horse metapodials, to distinguish specific populations within archaeological contexts (Bignon et al., 2005).

In this study, for each complete equid skeleton, 645 3D anatomical landmarks (LMK) were placed on 18 bones: skull (110 LMK), mandible (72 LMK), scapula (27 LMK), humerus (47 LMK), radius/ulna (42 LMK), metacarpal (32 LMK), coxal (24 LMK), femur (41 LMK), tibia (41 LMK), calcaneus (20 LMK), talus (28 LMK), metatarsal (30 LMK), first, second and third phalanxes (25, 21 and 19 LMK, respectively). It has been ensured that the anatomical structures described by the most commonly used linear measurements (Eisenmann, 1986) were all covered by the defined