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Differential diagnosis of vertebral spinous process deviations in archaeological and modern domestic dogs

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ABSTRACT

Paleopathological study of domestic animal remains can elucidate human-domesticate relationships, when all reasonable differential diagnoses are considered. Deviated spinous processes found on ancient domesticated dog vertebrae have been assumed to result from pack burdens, although consideration of diagnostic alternatives has been unclear. To more thoroughly assess the potential significance of these features, we first generated an extensive differential diagnosis of potential causes. Broad causal categories included: (i) morphological; (ii) infectious; (iii) taphonomic; (iv) life history (*in utero* to death), with numerous subcategories that sometimes overlap. We then evaluated these possibilities through an observational and radiology study of 15 ancient deliberate domestic dog burials (191 vertebrae) from the midwestern USA, dating between 10,130 and 200 years ago. Archaeological specimens from the UK were included to evaluate for geographic uniqueness of our observations. We characterized deviations of spinous processes of cervical (n = 74), thoracic (n = 51), lumbar (n = 60), and sacral (n = 6) vertebrae. Affected spinous processes were found in 34% of cervical vertebrae, 63% of thoracic vertebrae, 78% of lumbar vertebrae, and 50% of sacral vertebrae. Four types of spinous process deviations were observed: (a) lateral leaning from the base but not otherwise deviated; (b) lateral curving at some point above the base; (c) bowing because of multiple curves; and (d) torsion along the vertical axis. Computed tomography and micro-computed tomography were essential tools for establishing differential diagnoses.

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1. Introduction

Ancient animal bones offer a unique biological record that informs about the health of animals associated with human cultures, and indirectly addresses relationships between humans and their domesticates (Baker and Brothwell, 1980; Davies et al., 2005; Bartosiewicz and Gal, 2013). Although there is a long history of paleopathological study in archaeology (Moodie, 1923), advanced imaging technology (Chhem and Brothwell, 2008), an expanding knowledge base, and increasing academic interest (Davies et al., 2005; Miklíková and Thomas, 2008), demand clarified interpretations.

Dogs and humans have maintained a domestic relationship for at least 12,000 years. Although the exact origins of this relationship remain somewhat obscure (Miklósi, 2007; Larson et al., 2012), the close association of dogs and humans in cultural contexts lend special significance to dog evolution and behavior (Morey, 2006, 2010). Paleopathological studies can contribute new understanding of the nature of human-dog relationships through analyses of behaviorally-influenced damage to bones and joints, or diseases and injuries sustained through life activities (Snyder, 1995; Tourigny et al., 2015). Dog paleopathology specifically has the potential to inform about subsistence or mobility strategies among human groups (Warren, 2004; Lawler et al., 2015).

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Previous paleopathological studies of domestic dogs have focused on opportunistic observations of gross pathologies (Warren, 2004; Walker et al., 2005; Ware, 2006). Only rarely (Tourigny et al., 2015) have such studies incorporated medical imaging (radiology and tomography) or rigorous differential diagnosis, despite example work in human paleopathology (Miller et al., 1996; Ortner, 2003; Lynnerup, 2010) and forensics (Jalalzadeh et al., 2015).

Deviated spinous processes of domestic dog vertebrae have been observed with inter-vertebral osteoarthritis, presumed compression fractures of epiphyseal endplates, and scapular modification (Snyder, 1995; Warren, 2004). However, arguments that deviated spinous processes suggest use as a pack animal were made in the absence of observing associated pathologies (Warren, 2000; Darwent and Gililand, 2001; Walker et al., 2005) or providing for differential diagnosis. Thus, the interpretation became perpetuated in literature when in fact the early diagnoses actually were speculative and in need of further study. We found no additional studies in literature that included a differential diagnosis process.

We present a differential diagnosis of deviated vertebral spinous processes in archaeological domestic dogs. We include archaeological dog remains from Great Britain for comparative evaluation for geographical uniqueness of our observations, and have used computed tomography and digital radiography in selected instances. Although we narrow the range of diagnostic possibilities, limitations inherent in archaeological materials often preclude definitive diagnosis.

2. Materials and methods

Most vertebral remains that are described in this report are curated at the Illinois State Museum Research and Collections Center, Springfield IL USA. The specimens represent both deliberate burials and isolated vertebrae recovered from nine archaeological sites in Illinois and Missouri (Fig. 1) (Fowler, 1959; Griffin and Morse, 1961; Wray and MacNeish, 1961; Parmalee et al., 1972; McMillan, 1976; Morey and Wiant, 1992). These assemblages span the Archaic to late Mississippian periods, from 10,130–200 cal BP (Table 1). Vertebrae from a Roman (mid-2nd to mid-3rd century CE) dog recovered from Alchester, Oxfordshire UK, were included to evaluate similar morphologies from a geographically, taphonomically, and temporally distant context.

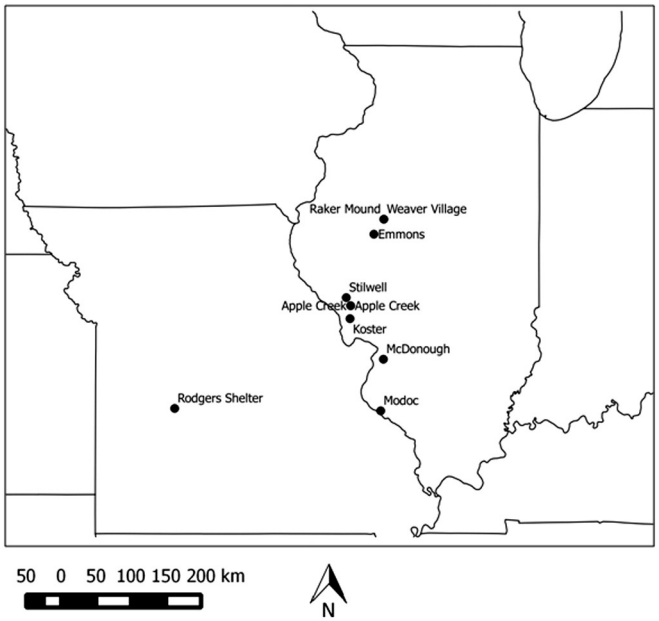

Fig. 1. Map of sites included in this study.

2.1. Zooarchaeological and taphonomic observations

2.1.1. Biological factors

Zooarchaeological observations of buried dogs were focused partly on establishing age and sex of individuals. A detailed scheme for aging *Canis lupus lupus* based on tooth wear (Nowak et al., 2000) was not used because our age categories were too coarse to account for uncertainties of diet and lifestyle influences.

We assessed age on a relative scale, considering degree of epiphyseal union of major long bones, along with dental eruption and attrition. Individuals <2 years of age were assigned to general age classes based on long bone epiphyseal closure (Newton and Nunamaker, 1985). Age estimates of individuals >2 years were assessed primarily based on dental attrition.

Shoulder height, a relative measure of body size, was calculated based on humeral length, using standard linear regression equations (Harcourt, 1974). Burials from the Stilwell and Apple Creek (Burial 3) sites lacked humeri, so shoulder height was calculated using radius and femur, respectively.

A baculum (os penis) indicated burial of a male. However, absence of a baculum did not necessarily indicate a female, considering the possibilities of non-preservation, non-recovery, or removal. Thus, burials without a baculum were categorized as female/indeterminate.

We did not assess age, sex, or body-size characteristics of disarticulated, isolated specimens, due to the possibility of mixing elements from different individuals.

2.1.2. Taphonomic factors

A number of post-mortem taphonomic processes can affect bone integrity and appearance (Lyman, 1994; Haglund and Sorg, 1997), causing partial-to-total destruction. Physical examples of these processes include modification by scavenging animals and sub-aerial weathering that often remove osteological materials from the sedimentary record.

Chemical changes may alter bone morphology *in situ*. Low soil pH can completely remove organic materials. In moist-to-saturated depositional contexts, low pH can affect bone rigidity by promoting decalcification (Brothwell and Gill-Robinson, 2001) and predisposing bones to deformation by sedimentary forces. Carcass decomposition itself promotes a low pH environment (Gill-King, 1997), and drying creates stress on muscle and ligament attachments (Weigelt, 1989). The result can be minor warping of skeletal elements.

To evaluate these taphonomic possibilities, all specimens were examined microscopically (low power magnification) for indicators of a low pH depositional history that include exterior solution pitting and erosion (Johnson et al., 1997), gastric polish (Andrews, 1990), and root etching (Morlan, 1984).

2.2. Gross morphology

Spinous processes were recorded as normal or deviated, with the latter categorized into four types: (a) lateral leaning from the base but otherwise not malformed (Fig. 2a); (b) lateral curving at some point above the spinous base (Fig. 2b); (c) bowing because of multiple curves (Fig. 2c); (d) torsion along the longitudinal axis (Fig. 2d). Data were recorded by spinal region, deviation category and direction, and qualitative severity of pathology. All affected vertebrae were photographed and described. Vertebrae were not measured because the large size variability among ancient dogs, just as among modern dogs, precludes useful biological interpretation.

Statistical analyses (Fisher's exact test) were limited to relationships among leaning, lateral curving, and bowing, for frequency, severity, and right-left direction. Statistical analyses included only data from the Illinois sites and Rodgers Shelter MO. Additional statistical evaluations were not conducted because the data are too sparse for further sub-categorization, especially considering that they are non-independent, and that a valid negative control population cannot be identified.

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