AN ANALYSIS OF FACTORS AFFECTING THE DEVELOPMENT OF AN EQUID CRANIAL ENTHESOPATHY

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Summary. This article presents methodology for use in analysing archaeological horse remains. The aim of the methodology is to improve understanding of the use of horses in the past. One of the problems in the interpretation of horse use from archaeological bone assemblages is that there is only limited understanding of some of the observable changes to equid skeletons, in terms of the factors that cause these manifestations such as age, sex, genes, and work. This article explores the variation in size and shape of an enthesopathy located on the back of equid skulls and considers factors effecting its development. To this end it analyses this phenomenon in collections of equids with known life histories.

This article proposes a new method for analysing the variation in size and shape of an enthesopathy located on the back of horse skulls. The method uses a scoring system for the musculoskeletal stress marker (MSM) located at the attachment site of the nuchal ligament located on the external occipital protuberance. The principle behind the method is that differences in osteon remodelling at the ligament attachment site will be affected by differences in muscle activity, and therefore possibly reflect the uses of the animal. Analysis of MSM expression in skeletal collections of equids with known life histories suggests that it is to a large degree age-related, and may also be more developed in highly trained racehorses.

Key words: horse use; enthesopathy; equid skulls, work-related changes, age-related changes.

VEIKSNIŲ, SĄLYGOJANČIŲ ARKLIŲ KAUKOLIŲ ENTEZOPATIJĄ, ANALIZĖ

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Santrauka. Straipsnyje siūlomas naujas entezopatijos arklių kaukolių užpakalinėje dalyje dydžio ir formos analizės metodas. Metodo esmė – kaulų ir raumenų sistemos streso rodiklio (KSR), esančio sprando raiščio prisitvirtinimo vietoje ties išoriniu pakaušio gumburu, įvertinimas balais. Metodas pagrįstas tokiu principu: osteonų persitvarkymo raiščio prisitvirtinimo vietoje skirtumus lemia raumenų darbo intensyvumas, rodantis gyvulio panaudojimą. KSR analizė, atlikta naudojant arklių kaukolių su žinoma gyvenimo istorija kolekcijas, leidžia manyti, kad entezopatija daugiausia susijusi su amžiumi ir ryškesnė gali būti intensyviai treniruotų sportinių žirgų.

Raktažodžiai: arklių naudojimas, entezopatija, arklių kaukolės, su darbu susiję pokyčiai, su amžiumi susiję pokyčiai.

Introduction. The impact of horse use on human society and economy in the past was immense (Levine 1996). To understand these cultural changes we need to be able to record and plot changes in the use of horses through time. One of the problems in the interpretation of horse use from archaeological bone assemblages is that there is only limited understanding of some of the observable changes that occur in their skeletons, in terms of the factors that cause these manifestations such as age, sex, weight, genes, work, etc. This is compounded by problems associated with interpreting pathologies and other bony changes identified from disarticulated and fragmentary remains.

The improved extraction of information from disarticulated skeletal remains is important, as complete skeletons are relatively rare in the archaeological record. With the aim of exploring evidence for use that does not rely upon complete skeletons (but can also be applied to whole skeletons, when present), the skulls of modern known life history equids from museum collections were examined for possible use-related changes (Bendrey, 2007b). This research has led to the refinement of bitting damage methodologies (Bendrey, 2007a). This paper explores the variation in size and shape of an enthesopathy located on the back of equid skulls, and considers factors effecting its development, and assesses it as evidence for work. To this end it analyses this phenomenon in collections of equids with known life histories.

Materials and Methods

The known life history equids

A number of equid skeletons with known life histories held at the Natural History Museum, London (United Kingdom), National Museum, Prague (Czech Republic), and Museum für Haustierkunde "Julius Kühn", Martin-Luther-Universität, Halle-Wittenberg (Germany) were examined for this research (Table 1). These are the same modern comparative collection as used for the bitting damage study (Bendrey, 2007a).

Table 1. **Known life histories of equid remains studied from the Natural History Museum, London (NHM), National Museum, Prague (NMP) and Museum für Haustierkunde "Julius Kuhn", Martin-Luther-Universitat, Halle-Wittenberg (MfH). Documented ages are given where known, otherwise age was estimated on the basis of incisor wear (Cornevin and Lesbre, 1894). MSM development scores are given for each animal** (see text for details)

<table>
<tr><th rowspan="2">ref. no.</th><th rowspan="2">host museum</th><th rowspan="2">registration number</th><th rowspan="2">museum description</th><th rowspan="2">specimen use</th><th rowspan="2">sex</th><th rowspan="2">documented age (estimated age)</th><th colspan="2">MSM scores</th></tr>
<tr><th>Area A</th><th>Area B</th></tr>
<tr><td>WR1</td><td>NHM</td><td>ADAR.H43</td><td>Thoroughbred racehorse</td><td>worked (riding)</td><td>male</td><td>21y</td><td colspan="2">6</td></tr>
<tr><td>WR2</td><td>NHM</td><td>ZE.1924.5.4.1</td><td>Arab</td><td>worked (riding)</td><td>male</td><td>30y</td><td colspan="2">4</td></tr>
<tr><td>WR3</td><td>NHM</td><td>ADAR.H40</td><td>Arab racing pony</td><td>worked (riding)</td><td>male</td><td>(11.5y)</td><td>3</td><td>3</td></tr>
<tr><td>WR4</td><td>NHM</td><td>ZE.1940.7.26.1</td><td>Thoroughbred racehorse</td><td>worked (riding)</td><td>male</td><td>(10-10.5y)</td><td colspan="2">5</td></tr>
<tr><td>WR5</td><td>NHM</td><td>ADAR.H44</td><td>Thoroughbred racehorse</td><td>worked (riding)</td><td>male</td><td>(18y+)</td><td colspan="2">6</td></tr>
<tr><td>WR6</td><td>NHM</td><td>ADAR.H16</td><td>Thoroughbred racehorse</td><td>worked (riding)</td><td>male</td><td>20y</td><td colspan="2">5</td></tr>
<tr><td>WR7</td><td>NHM</td><td>ADAR.H31</td><td>Thoroughbred racehorse</td><td>worked (riding)</td><td>male</td><td>24y</td><td colspan="2">5</td></tr>
<tr><td>WR8</td><td>NHM</td><td>ZD.1876.8.4.1</td><td>Thoroughbred racehorse</td><td>worked (riding)</td><td>male</td><td>27y</td><td colspan="2">6</td></tr>
<tr><td>WR9</td><td>NHM</td><td>ADAR.H39</td><td>Thoroughbred racehorse</td><td>worked (riding)</td><td>male</td><td>25y</td><td colspan="2">5</td></tr>
<tr><td>WR10</td><td>NHM</td><td>ADAR.H1</td><td>Thoroughbred racehorse</td><td>worked (riding)</td><td>female</td><td>23y</td><td colspan="2">5</td></tr>
<tr><td>WR11</td><td>NHM</td><td>ZE.1948.10.11.1</td><td>Thoroughbred racehorse</td><td>worked (riding)</td><td>female</td><td>(20y+)</td><td colspan="2">6</td></tr>
<tr><td>WR12</td><td>NHM</td><td>ADAR.H42</td><td>Thoroughbred racehorse</td><td>worked (riding)</td><td>male</td><td>21y</td><td colspan="2">6</td></tr>
<tr><td>WR13</td><td>MfH</td><td>-</td><td>English fullblood</td><td>worked (riding)</td><td>male</td><td>(14-18y)</td><td colspan="2">5</td></tr>
<tr><td>WR14</td><td>MfH</td><td>E arb 6</td><td>English fullblood</td><td>worked (riding)</td><td>male</td><td>23y</td><td colspan="2">5</td></tr>
<tr><td>WD1</td><td>NHM</td><td>ADAR.H18</td><td>Shire horse</td><td>worked (driving)</td><td>male</td><td>22y</td><td colspan="2">5</td></tr>
<tr><td>WD2</td><td>NHM</td><td>ADAR.H14</td><td>Shire horse</td><td>worked (driving)</td><td>male</td><td>20y</td><td colspan="2">5</td></tr>
<tr><td>WD3</td><td>MfH</td><td>E dän 1</td><td>Danish horse</td><td>worked (driving)</td><td>castrate</td><td>(7.5-10.5y)</td><td colspan="2">4</td></tr>
<tr><td>WD4</td><td>MfH</td><td>Eml mlt 5</td><td>Mule</td><td>worked (driving)</td><td>male</td><td>(12.5-18y)</td><td colspan="2">4</td></tr>
<tr><td>WD5</td><td>MfH</td><td>Eml mlt 4</td><td>Mule</td><td>worked (driving)</td><td>male</td><td>21y</td><td>2</td><td>2</td></tr>
<tr><td>WD6</td><td>MfH</td><td>Eml mlt 3</td><td>Mule</td><td>worked (driving)</td><td>male</td><td>19y</td><td colspan="2">4</td></tr>
<tr><td>WD7</td><td>MfH</td><td>Eml mlt 2</td><td>Mule</td><td>worked (driving)</td><td>castrate</td><td>9y</td><td>3</td><td>3</td></tr>
<tr><td>WD8</td><td>MfH</td><td>Eml mlt 1</td><td>Mule</td><td>worked (driving)</td><td>female</td><td>(10-12.5y)</td><td>2</td><td>2</td></tr>
<tr><td>WD9</td><td>MfH</td><td>Ehn mle 7</td><td>Hinny</td><td>worked (driving)</td><td>female</td><td>25y</td><td>2</td><td>2</td></tr>
<tr><td>WD10</td><td>MfH</td><td>Ehn mle 10</td><td>Hinny</td><td>worked (driving)</td><td>male</td><td>25y</td><td>2</td><td>2</td></tr>
<tr><td>WD11</td><td>MfH</td><td>Ehn mle 6</td><td>Hinny</td><td>worked (driving)</td><td>castrate</td><td>23y</td><td colspan="2">4</td></tr>
<tr><td>WD12</td><td>MfH</td><td>Ehn mle 4</td><td>Hinny</td><td>worked (driving)</td><td>female</td><td>22y</td><td>1</td><td>1</td></tr>
<tr><td>WD13</td><td>MfH</td><td>Ehn mle 2</td><td>Hinny</td><td>worked (driving)</td><td>female</td><td>24y</td><td colspan="2">4</td></tr>
<tr><td>WD14</td><td>MfH</td><td>Ehn mle 1</td><td>Hinny</td><td>worked (driving)</td><td>female</td><td>25y</td><td>2</td><td>2</td></tr>
<tr><td>WD15</td><td>MfH</td><td>Ehn mle 3</td><td>Hinny</td><td>worked (driving)</td><td>castrate</td><td>26y</td><td>2</td><td>2</td></tr>
<tr><td>WD16</td><td>MfH</td><td>E mgl 2</td><td>Mongolian domestic horse</td><td>worked (driving)</td><td>female</td><td>(12.5-13y)</td><td>3</td><td>3</td></tr>
<tr><td>WD17</td><td>MfH</td><td>E mgl 4</td><td>Mongolian domestic horse</td><td>worked (driving)</td><td>female</td><td>(18y+)</td><td>3</td><td>3</td></tr>
<tr><td>WD18</td><td>NHM</td><td>ZE.1959.7.14.1</td><td>Hackney</td><td>worked (driving?)</td><td>male</td><td>c.23y</td><td colspan="2">5</td></tr>
<tr><td>NW1</td><td>NHM</td><td>ZE.1945.6.11.1</td><td>Przewalski's horse</td><td>unworked</td><td>female</td><td>(12.5-13y)</td><td>2</td><td>2</td></tr>
<tr><td>NW2</td><td>NHM</td><td>ZD.1907.5.15.1</td><td>Przewalski's horse</td><td>unworked</td><td>female</td><td>(5y)</td><td>3</td><td>1</td></tr>
<tr><td>NW3</td><td>NHM</td><td>ZE.1960.2.1.4</td><td>Przewalski's horse</td><td>unworked</td><td>female</td><td>3y</td><td>1</td><td>1</td></tr>
<tr><td>NW4</td><td>NHM</td><td>ZE.1961.5.10.2</td><td>Przewalski's horse</td><td>unworked</td><td>female</td><td>c.20y+</td><td colspan="2">4</td></tr>
<tr><td>NW5</td><td>NHM</td><td>ZE.1963.1.25.1</td><td>Przewalski's horse</td><td>unworked</td><td>male</td><td>31y, 4m</td><td>3</td><td>2</td></tr>
<tr><td>NW6</td><td>NHM</td><td>ZD.1972.813</td><td>Przewalski's horse</td><td>unworked</td><td>male</td><td>5y, 6m</td><td>2</td><td>3</td></tr>
<tr><td>NW7</td><td>NHM</td><td>ZD.1902.9.25.1</td><td>Przewalski's horse</td><td>unworked</td><td>female</td><td>(3y)</td><td>2</td><td>1</td></tr>
<tr><td>NW8</td><td>NMP</td><td>P6V 90200</td><td>Przewalski's horse</td><td>unworked</td><td>female</td><td>21y</td><td>2</td><td>2</td></tr>
<tr><td>NW9</td><td>NMP</td><td>P6V 47165</td><td>Przewalski's horse</td><td>unworked</td><td>female</td><td>22y</td><td colspan="2">4</td></tr>
<tr><td>NW10</td><td>NMP</td><td>P6V 47167</td><td>Przewalski's horse</td><td>unworked</td><td>female</td><td>23y</td><td colspan="2">5</td></tr>
<tr><td>NW11</td><td>NMP</td><td>P6V 46585</td><td>Przewalski's horse</td><td>unworked</td><td>female</td><td>7y</td><td colspan="2">4</td></tr>
<tr><td>NW12</td><td>NMP</td><td>P6V 22772</td><td>Przewalski's horse</td><td>unworked</td><td>female</td><td>29y</td><td>2</td><td>3</td></tr>
<tr><td>NW13</td><td>NMP</td><td>P6V 47160</td><td>Przewalski's horse</td><td>unworked</td><td>female</td><td>22y</td><td colspan="2">4</td></tr>
<tr><td>NW14</td><td>NMP</td><td>P6V 46161</td><td>Przewalski's horse</td><td>unworked</td><td>female</td><td>5y</td><td>2</td><td>3</td></tr>
<tr><td>NW16</td><td>NMP</td><td>P6V 90195</td><td>Przewalski's horse</td><td>unworked</td><td>male</td><td>10y</td><td>2</td><td>3</td></tr>
<tr><td>NW17</td><td>NMP</td><td>P6V 48351</td><td>Przewalski's horse</td><td>unworked</td><td>female</td><td>29y</td><td>3</td><td>2</td></tr>
<tr><td>NW18</td><td>NMP</td><td>P6V 48278</td><td>Przewalski's horse</td><td>unworked</td><td>male</td><td>6y</td><td>2</td><td>2</td></tr>
<tr><td>NW19</td><td>NMP</td><td>P6V 49009</td><td>Przewalski's horse</td><td>unworked</td><td>male</td><td>8y</td><td colspan="2">4</td></tr>
<tr><td>NW20</td><td>NMP</td><td>P6V 47173</td><td>Przewalski's horse</td><td>unworked</td><td>female</td><td>7y</td><td>2</td><td>2</td></tr>
<tr><td>NW21</td><td>NMP</td><td>P6V 48756</td><td>Przewalski's horse</td><td>unworked</td><td>female</td><td>29y</td><td>2</td><td>2</td></tr>
<tr><td>NW23</td><td>NMP</td><td>P6V 24688</td><td>Przewalski's horse</td><td>unworked</td><td>male</td><td>30y</td><td colspan="2">4</td></tr>
<tr><td>NW24</td><td>NMP</td><td>P6V 90194</td><td>Przewalski's horse</td><td>unworked</td><td>male</td><td>16y</td><td colspan="2">5</td></tr>
<tr><td>NW25</td><td>MfH</td><td>E wld 1</td><td>Przewalski's horse</td><td>unworked</td><td>male</td><td>(7.5-9y)</td><td>3</td><td>2</td></tr>
<tr><td>NW26</td><td>MfH</td><td>E wld 5</td><td>Przewalski's horse</td><td>unworked</td><td>male</td><td>(12.5-13y)</td><td>2</td><td>2</td></tr>
<tr><td>NW27</td><td>MfH</td><td>E wld 2</td><td>Przewalski's horse</td><td>unworked</td><td>female</td><td>8y</td><td>3</td><td>2</td></tr>
<tr><td>NW28</td><td>MfH</td><td>E wld 4</td><td>Przewalski's horse</td><td>unworked</td><td>female</td><td>9y</td><td>2</td><td>2</td></tr>
</table>

Worked equids examined include domestic horses (*Equus caballus*), mules (*Equus asinus* x *Equus caballus*) and hinnies (*Equus caballus* x *Equus asinus*) and unworked equids consist of populations of Przewalski's horse (*Equus ferus przewalskii*). During the course of this research it was not possible to find collections of unworked domestic horse populations for analysis and so Przewalski's horse remains have been used as a proxy (Bendrey, 2007b). The availability of appropriate materials is a considerable problem as it has not been possible to find comparative skeletal collections that are more closely analogous to prehistoric horses (in terms of size, conformation, genetics, use, etc: see summary of host museum descriptions in Table 1).

Known use, sex and age of the equids are presented in Table 1. Information on the life histories of the equids consists of whether they were ridden, driven, or unworked; unfortunately this does not include data such as how much they were ridden or driven. This is a caveat to the study, as individual animals will have been ridden/driven in different ways and for different durations (for example, the differences in use between the shire horses, mules and hinnies; all of which were used for traction).

Enthesopathies

Enthesopathies are skeletal manifestations associated with tendinous or ligamentous insertions (Jurmain, 1999, 142). These have received much attention in human bone studies, but have been the subject of relatively little research in archaeozoology. Hawkey and Merbes (1995, 324) use the term musculoskeletal stress markers (MSM) "to refer specifically to a distinct skeletal mark that occurs where a muscle, tendon or ligament inserts onto the periosteum and into the underlying bony complex". Osteon remodelling is stimulated by increased blood flow when the muscle/tendon/ligament-bone junctions are regularly subjected to minor stress. Hypertrophy of bone, in the form of a robust muscle-attachment, is the direct result of this increased, repetitive, stress (Hawkey and Merbs, 1995, 324). The MSM being considered in the present study is the attachment site of the nuchal ligament located on the external occipital protuberance (Figures 1 and 2).

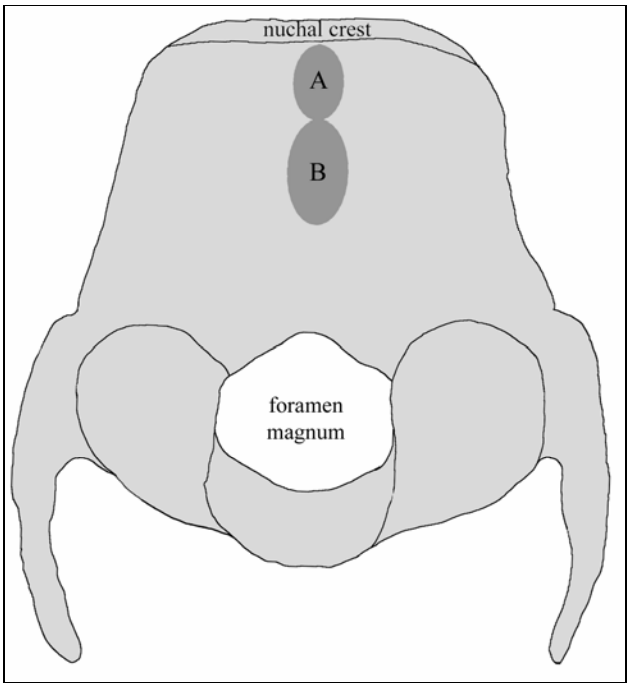

Figure 1. **Occipital bone of horse skull: posterior view. A is the central portion of the posterior wall of the occipital bone between the external occipital protuberance and the nuchal crest, and B is the area of the external occipital protuberance.**

Figure 2. **Examples of MSM expression on the posterior wall of equid skulls** (see text for descriptions of location and MSM development): a - A = 1; B = 1 (NW3); b - A = 3; B = 2 (WR3); c - A and B = 5 (WR7); d - A and B = 6 (WR8). © Natural History Museum, London

Hawkey and Merbs (1995, 325) suggest that a study of activity induced changes in a human population should ideally include a relatively large sample size with good skeletal preservation, a relatively narrow time span, cultural and genetic isolation and a limited number of specialized, but known, activities. The quality of skeletal preservation in the collections studied is excellent, although the sample size is rather small. Within the separate equid groups examined for this study there is a relatively narrow time span, and human influence can be assumed to be fairly consistent within the groups (Table 1). The effect of genetic differences (on enthesial development) between the groups is unknown. This will be discussed further below.

The external occipital protuberance

The posterior wall and part of the ventral wall of equid skulls are formed by the occipital bone (Figure 1). The basilar and lateral parts of the occipital bone form the lower part and bound the foramen magnum and the upper part is formed by the squamous part (Sisson and Grossman, 1966, figure 29). The external surface of the squamous part is crossed by the nuchal crest, the medial section of which is a thick, transverse ridge which forms the highest point of the skull when the head is in the ordinary position (Sisson and Grossman, 1966, 47). The area ventral to the nuchal crest has two rough areas for the attachment of the complexus muscles and a central eminence, the external occipital protuberance, on which the funicular part of the ligamentum nuchae is attached (Sisson and Grossman, 1966, 47 and 75).

The ligamentum nuchae, or nuchal ligament, is a powerful elastic apparatus, the principal function of which is to assist the extensor muscles of the head and neck (Sisson and Grossman, 1966, 215). It consists of two parts, the funicular and laminar parts, and the funicular part is anchored at the external occipital protuberance and extends to the summits of the 3rd, 4th, or 5th thoracic vertebrae (Budras *et al*, 2003. 50-1). At the external occipital protuberance it is around 3 cm in height and flattened laterally, although changes rapidly to a rounded shape around half this height (Sisson and Grossman, 1966, 215).

A number of the cervical muscles relate to the ligamentum nuchae and several have insertions on the occipital bone [see Sisson and Grossman (1966, 268-278) and Budras *et al* (2003, 52-3 and 89-90) for descriptions of muscle insertion sites and actions]. Some, such as the complexus, mentioned above, act (together) to extend the head and neck; other muscles have other actions, for example the splenius can be used to elevate the head and neck (Sisson and Grossman, 1966, 268-278). The insertion points of the individual muscles vary, with some on the nuchal crest and others ventral to it.

The habitual activity of the horse - whether it is pulling a load, carrying a rider, its speed and gait (which relates to the motion of the head and neck) - will all affect the development of muscles and MSMs. It must be remembered that multiple activities can contribute to the development of a single MSM (Wilczak, 1998, 311).

Proposed recording methodology: scoring the MSM

Hawkey and Merbes (1995, 327-9) scored three main categories of MSM expression: robusticity markers (reflecting habitual activity that produce rugged markings at the musculoskeletal site of attachment); stress lesions (a pitting into the cortex representing activity induced continual microtrauma at the attachment site); ossification exostosis (reflecting an abrupt macrotrauma, such as a muscle rupture, resulting in an exostosis, or bony 'spur'). The changes observed on the comparative equid skulls examined for this study all represent bone formation rather than resorption. The skulls of the equids with known life histories have been examined and the development of the cranial muscle-attachment recorded using the following system, based on size and location of the MSM.

The location of MSM development varies in the less pronounced stages noted (scores 1-3) which have been recorded as locations A and B. A is the central portion of the posterior wall of the occipital bone between the external occipital protuberance and the nuchal crest, and B is the area of the external occipital protuberance (Figure 1). For the less pronounced stages the two areas are scored separately for MSM development (e.g. Figure 2, a-b):

0 absent, no discernable development

1 roughened bone (texture of coarse sand paper)

2 rugged/craggy texture (not sand-papery), sometimes numbers of small peaks (the beginnings of palpable bone changes)

3 palpable bony (hypertrophic) projection

The more pronounced stages (scores 4-6) are manifested as a hypertrophy of bone that covers both areas A and B (e.g. Figure 2, c-d); these are awarded one score for the combined area (see Table 1):

4 bony (hypertrophic) projection, of less than 0.75 cm in length, that covers A and B

5 bony (hypertrophic) projection, 0.75 – 1.5 cm in length, that covers A and B

6 bony (hypertrophic) projection, of more than 1.5 cm in length, that covers A and B

The expression of MSMs are continuous traits and some may not fit neatly into these categories. Use of measurements as limits for scores is not ideal, as equids can vary considerably in size, but appears to be the best way to quantify the variation observed.

Results

MSM development at, and above, the external occipital protuberance on the skulls of the known life history equids, using the scoring system as set out above, is listed in Table 1. A number of important factors, in addition to habitual stress, are known to influence MSM development, including: sex, age, hormonal levels and genetics (Jurmain, 1999, 144-9; Wilczak, 1998, 312). These must be considered before the significance of this MSM as an indicator of 'work' can be assessed.

Age has been shown to influence the development of enthesopathies. Jurmain (1999, 146-7) stresses the effect of age on the development of enthesopathies and calls for rigorous age controls in analysis, without which reports on enthesial involvement should be considered meaningless. Comparing animals of similar age will allow some control on this variable: MSM scores for worked and unworked equids are plotted in 5 – year age groups in Table 2a. This table presents cross-tabulations of MSM scores for areas A and B on the occipital bone: this allows the variability in expression of MSM to be explored. That the manifestation of this MSM is to some degree age-related is shown by a comparison of MSM expression with age for the unworked equids (Table 2a). In this table the distribution of MSM expression can be seen to be similar in the worked and unworked populations of the same age, although the worked equids over 20 years of age do exhibit scores of 6, which the unworked equids do not. Age, therefore, is a major factor in the development of this MSM.

The time scale of resorption of MSMs, once developed, is uncertain. Whether a very old animal, such as NW5 at over 30 years of age at death (Table 1), would be in the process of resorbing the MSM, for example if it was no longer as active, is unknown. Atrophy of muscle, broadly defined as a reduction in size, occurs in a variety of circumstances, including old age, each of which has a slightly different impact on the muscle fibres and leads to different long-term responses (Hulland, 1985, 146). Disuse atrophy, for example, results from reduced stimulation or reduced movement of a normally innervated muscle, or from an absence of normal muscle tension (Hulland, 1985, 149). Atrophy may also be related to malnutrition, injury and disease. Muscle structure is arranged around muscle fibres and the size of muscle fibres increases with age until puberty, when males have slightly larger fibres than females, and in old age fibre diameter slowly decreases (Hulland, 1985, 140).

Sexual differences, in particular the effects of hormones such as testosterone (Jurmain, 1999, 144 and 149), will also have an effect on MSM development. To exclude the variable of work, sex differences are examined in the unworked animals (Table 2b). There do not appear to be any notable differences between the distribution of MSM expression in the male and female unworked animals (allowing for small sample size). As well as testosterone; age, metabolic agents, endocrine status and diet are all likely to influence rates of bone turnover (Jurmain, 1999, 144 and 148).

Table 2. **Comparisons of enthesopathy scores between**: a.) worked and unworked equids; b.) male and female unworked equids; c). worked equids used for riding and driving. **Animals are divided into five-year age groups for comparison, and cross-tabulating the scores for areas A and B shows the range of expression of the enthesopathy for each age group**

		2a.)												2b.)											
		worked						unworked						male unworked						female unworked					
age (yrs)		A						A						A						A					
		1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
0-5	B 1	-	-	-				1	1	1				-	-	-				1	1	1			
	2	-	-	-				-	-	-				-	-	-				-	-	-			
	3	-	-	-				-	1	-				-	-	-				-	1	-			
	4				-						-						-						-		
	5					-						-						-						-	
	6						-						-						-						-
>5-10	B 1	-	-	-				-	-	-				-	-	-				-	-	-			
	2	-	-	1				-	3	2				-	1	1				-	2	1			
	3	-	-	-				-	2	-				-	2	-				-	-	-			
	4				1						2						1						1		
	5					-						-						-						-	
	6						-						-						-						-
>10-15	B 1	-	-	-				-	-	-				-	-	-				-	-	-			
	2	-	-	2				-	2	-				-	1	-				-	1	-			
	3	-	1	-				-	-	-				-	-	-				-	-	-			
	4				-						-						-						-		
	5					1						-						-						-	
	6						-						-						-						-
>15-20	B 1	-	-	-				-	-	-				-	-	-				-	-	-			
	2	-	-	-				-	-	-				-	-	-				-	-	-			
	3	-	-	-				-	-	-				-	-	-				-	-	-			
	4				2						-						-						-		
	5					1						1						1						-	
	6						-						-						-						-
>20	B 1	1	-	-				-	-	-				-	-	-				-	-	-			
	2	-	3	1				-	2	2				-	-	1				-	2	1			
	3	-	2	-				-	1	-				-	-	-				-	1	-			
	4				3						4						1						3		
	5					8						1						-						1	
	6						5						-						-						-

Table 2. **(cont.).**

2c.)

age (yrs)			riding						driving					
			A						A					
			1	2	3	4	5	6	1	2	3	4	5	6
0-5	B	1	-	-	-				-	-	-			
		2	-	-	-				-	-	-			
		3	-	-	-				-	-	-			
		4				-						-		
		5					-						-	
		6						-						-
>5-10	B	1	-	-	-				-	-	-			
		2	-	-	-				-	-	**1**			
		3	-	-	-				-	-	-			
		4				-						**1**		
		5					-						-	
		6						-						-
>10-15	B	1	-	-	-				-	-	-			
		2	-	-	**1**				-	-	**1**			
		3	-	-	-				-	**1**	-			
		4				-						-		
		5					**1**						-	
		6						-						-
>15-20	B	1	-	-	-				-	-	-			
		2	-	-	-				-	-	-			
		3	-	-	-				-	-	-			
		4				-						**2**		
		5					**1**						-	
		6						-						-
>20	B	1	-	-	-				**1**	-	-			
		2	-	-	-				-	**3**	**1**			
		3	-	-	-				-	**2**	-			
		4				**1**						**2**		
		5					**5**						**3**	
		6						**5**						-

Jurmain (1999, 147-9) suggests that underlying systemic factors may be at work on enthesial formation, producing hypertrophic reactions in some individuals at certain skeletal sites; and that it is likely that important genotypic factors are operating, affecting the ability of an animal to form bone in response to stress, as opposed to differences in bone formation reflecting differences in stress. This final point may be particularly relevant to the different populations used for this analysis – including different equid species and hybrids (Table 1) – although similarities in the range of expression shown between the worked and unworked animals (Table 2a) suggests that there may be general applications for this method to the study of equid populations.

As well as genotypic factors, physical differences in conformation will also be important. Significant differences in size and shape exist between some of the worked equids with known life histories examined for this study, for example there are shire stallions, hinnies and Thoroughbred racehorses (Table 1). These differences will effect MSM expression. A comparison of MSM expression between riding and driving animals presents a contrast in the oldest age group (>20 yrs), which is the largest sample of any age group (Table 2c). Here riding animals vary in MSM expression from 4-6, whereas the driving animals vary from 1-5. The greater proportion of higher scores in the riding animals may be linked to the fact that many of these are highly trained Thoroughbred racehorses, whereas many of the driving animals are mules and hinnies used for agricultural purposes (Wussow, *pers. comm.*); racehorses have many more muscle fibres in strategic places than nonracing animals, and exhibit slightly larger fibres when they are highly trained (Hulland, 1985, 151).

Discussion and conclusions

The study suggests that the development of the MSM located at, and above, the external occipital protuberance on the skulls of the equids with known life histories is to a large degree age-related. The results also suggest that it may exhibit variability between racehorses and nonracing animals. The utility of this technique for identifying the particular use that an individual horse was put to in the past is therefore minimal, although it might be able to identify highly trained animals such as racehorses. The method may prove useful, however, in comparing differences in horse use or fitness between different archaeological populations of horses, in combination with other methods such as bitting damage (Bendrey, 2007a).

Age and use, however, are not the only variables affecting MSM expression in the animals studied, and it seems likely that genotype is another major influence on enthesopathy formation. Comparison of MSM scores in the comparative sample between the worked and unworked equids does indicate that it is only the worked horses that exhibit scores of 6 (Table 2a); also it is only the riding animals that exhibit scores of 6, and not the driving animals (Table 2c). Although this could indicate that riding encourages larger MSM development at this site, it is probably due to the fact that most of the riding animals are Thoroughbred racehorses (Table 1).

This study has produced worthwhile preliminary results for the application of this methodology. As stated above, there are a number of caveats to this study: one is the small sample size of comparative material used; the other is suitability of the comparative material. Locating suitable modern comparative material is identified as a serious problem and the known life history equids used for these studies are not closely analogous to archaeological horses. The development of these methods in the future should focus on finding larger, more homogenous modern comparative samples, which are more analogous to prehistoric horses. This being stated, however, this study presents preliminary results into the understanding of MSM development in horses on which further research can be based.

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