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MicroCT imaging of long bones: archaeozoology and domestication from a digital perspective

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***Abstract* – X-ray microCT imaging offers the possibility to study interior structure of animal remains detecting age-related changes of bone microstructure. In the present paper we analyse patterns in the development of diaphyseal structure in canids. In particular, the first metacarpal of present-day and archaeological red fox (*Vulpes vulpes*) and wolf (*Canis lupus*) individuals have been analysed. Variables describing bone structure were measured by inferring bone development through observation of cross-sections. Results show how bone structure changes through life and how this approach allows to separate young individuals from older ones. This is important both from a zooarchaeological perspective, since microCT imaging is a non-invasive tool to estimate the age at death of animal remains, and to discriminate taxa characterized by a close morphology but different adult body size.**

I. INTRODUCTION

Computed microtomography (microCT) has been proposed and successfully used in zooarchaeology [1][2][3][4][5]. An interesting application is the estimation of the age-at-death of individuals through the structural analysis of bone tissue. This is of great importance when bone specimens lack diagnostic features, such as metaphyses, either because they are naturally lacking or because they are fragmented. A correct age estimation gives information on exploitation of animal resources by past human communities [3], or it can be useful in discriminating taxa characterized by a close morphology but different adult body size [4]. In addition, bone microstructure can be diagnostic from a taxonomic perspective [6]. Since we already tested the usefulness of spongy bone tissues [1][4], this paper will focus on the diaphyseal structure in canids long bones.

II. MATERIALS AND METHODS

In this work, we investigate the first metacarpal of 10 modern red foxes (*Vulpes vulpes* Linnaeus, 1758), from cubs aged a few months to adults, to define microstructural parameters related to their age at death. Specimens are part of the osteological comparative collections of the Dipartimento di Scienze Fisiche, della Terra e dell'Ambiente, Research Unit of Prehistory and Anthropology, of the University of Siena (Italy). Age-at-death was estimated considering tooth eruption and epiphyseal fusion [7]. Data are shown in table 1.

Table 1. Red fox specimens analysed in this paper.

Specimen ID	Age (months)
Fox 253	2
Fox 254	2
Fox 329	5-6
Fox 458	6
Fox 73	6-8
Fox 313	6-8
Fox 160	8-12
Fox 47	>12
Fox 299	>12
Fox 338	>12

In addition, we analyse the first metacarpal of 10 wolves (*Canis lupus* Linnaeus, 1758). Four of them are modern wild wolves from Italy (n° 362, 353, 196, 361); three are modern zoo-wolves (n°180, 52, 214); three specimens are Late Pleistocene wolves from Grotta Paglicci, an important Palaeolithic site located in southern Italy [4][8][9][10][11][12]. Modern specimens are part of the above-mentioned osteological reference collection. Specimens 362 and 353 belong to young not fully developed individuals. All other specimens show a fully fused distal epiphysis. Since archaeological remains are isolated scattered bones, good data about ontogeny are not available. For this reason, only a general age is reported for wolves in table 2.

The microCT scanning has been carried out at the Multidisciplinary Laboratory of the Abdus Salam International Centre for Theoretical Physics of Trieste, in Italy [13]. The resulting µCT slices have been reconstructed using the commercial software DigiXCT (DIGISENS) in 32-bit format. A semi-automatic threshold-based segmentation has been carried out to separate the bone component from the interstitial air between the trabeculae and from the marrow cavity [14][15][16]. After the segmentation, every specimen has been aligned to its longitudinal axis. The diaphysis has been isolated separating the two epiphyses. The proximal one has been separated from the rest of the bone using a transversal plane tangent to the distal ridge of the articular facet on the palmar side. The distal epiphysis has been separated using a transversal plane tangent to the most proximal ridge of the distal articular facet on the palmar side (Figure 1). A ratio between Porosity Surface and Bone Surface (PS/BS) has been calculated on seven cross sections per each specimen. The void of the marrow cavity is not considered. Cross sections have been taken at 20 %, 25%, 40%, 50%, 60%, 75% and 80% of the diaphysis length starting from the proximal extremity.

Table 2. Wolf specimens analysed in this paper.

Specimen ID	Development
Wolf 362	Not fully developed
Wolf 353	Not fully developed
Wolf 196	Adult
Wolf 361	Adult
Zoo-Wolf 180	Adult
Zoo-Wolf 52	Adult
Zoo-Wolf 214	Adult
Pleistocene Wolf 1971	Adult
Pleistocene Wolf R23	Adult
Pleistocene Wolf R24	Adult

III. RESULTS

Cubs of red fox have a very porous diaphysis. When individuals reach the full body size, even if still young (5-6 months), porosity is comparable with that of adult individuals. Results are shown in Table 3 and Figure 2.

Table 3. Red fox: PS/BS ratio in the seven cross-sections

ID	20%	25%	40%	50%	60%	75%	80%
253	0.390	0.374	0.263	0.260	0.302	0.705	1.104
254	0.354	0.387	0.394	0.318	0.332	0.302	1.811
329	0.003	0.001	0.000	0.000	0.001	0.003	0.013
458	0.002	0.001	0.000	0.000	0.000	0.001	0.009
73	0.001	0.000	0.001	0.000	0.000	0.001	0.004
313	0.002	0.003	0.000	0.000	0.000	0.001	0.003
160	0.000	0.000	0.000	0.000	0.000	0.000	0.000
47	0.006	0.002	0.007	0.009	0.014	0.052	0.097
299	0.005	0.004	0.004	0.006	0.006	0.010	0.019
338	0.004	0.003	0.002	0.001	0.002	0.012	0.035

Figure 1 Cross-sections on Zoo-Wolf 52

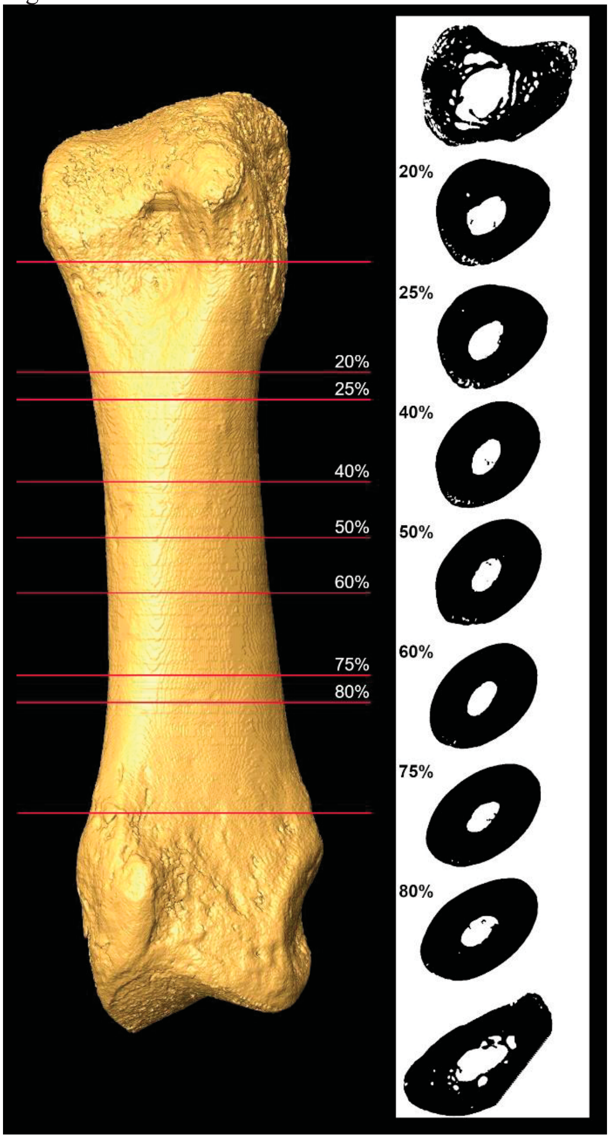
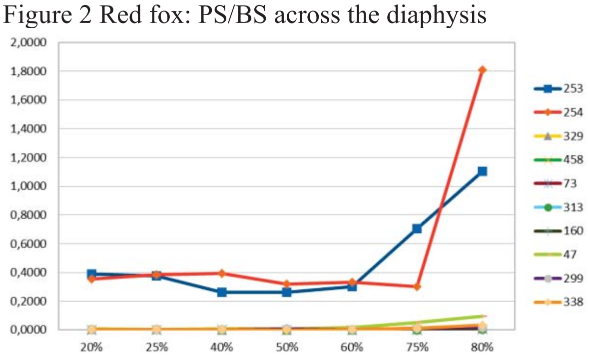


Figure 2 Red fox: PS/BS across the diaphysis

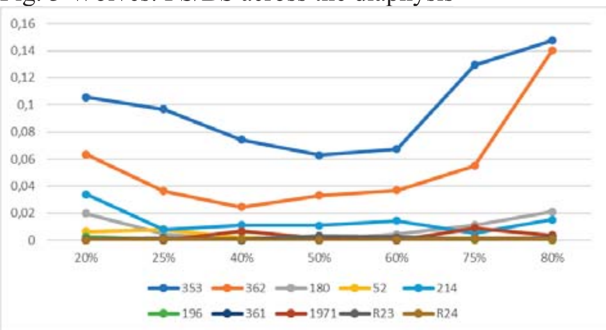


Young wolves show a pattern like that of foxes: porosity of the diaphysis is higher than that of adult individuals. Nevertheless, among adults, zoo-wolves show a higher porosity at the extremities of the diaphysis. Adult wild wolves, both modern and fossils, form a quite homogeneous group (Table 4, Figure 3).

Table 4. Wolves: PS/BS ratio in the seven cross-sections

ID	20%	25%	40%	50%	60%	75%	80%
353	0.106	0.097	0.074	0.063	0.067	0.130	0.148
362	0.063	0.036	0.025	0.033	0.037	0.055	0.140
180	0.020	0.005	0.000	0.000	0.004	0.011	0.021
52	0.006	0.008	0.002	0.001	0.001	0.000	0.000
214	0.034	0.008	0.011	0.011	0.014	0.005	0.015
196	0.003	0.000	0.000	0.000	0.001	0.001	0.000
361	0.001	0.002	0.000	0.000	0.000	0.002	0.001
1971	0.000	0.000	0.007	0.002	0.000	0.009	0.004
R23	0.001	0.001	0.001	0.003	0.002	0.001	0.002
R24	0.000	0.001	0.001	0.000	0.000	0.002	0.001

Fig. 3 Wolves: PS/BS across the diaphysis



IV. CONCLUSIONS

Our data, even if at a preliminary level due to the small sample size, show that diaphyseal internal structure can give information about age-at-death of individuals. This data cannot be used to build up accurate mortality profiles because of the low sensitivity of the method. Indeed, only young, still growing individuals can be separated from the others. From this perspective, spongy tissues look to be a bit more sensitive [1]. Nevertheless, this kind of data can be used to discriminate between taxa characterized by a close morphology and a different adult body size. From this perspective, it is interesting to point out that 5-6 months old foxes, which should already have reached the adult body size [17][18], show a bone porosity fully comparable with that of older individuals. As already stated in a previous methodological paper [1], the possibility to discriminate populations characterized by different body size is of pivotal importance for the study of domestication. A similar method, based on the analysis of spongy bone tissue, has already been successfully applied on a Palaeolithic sample leading to the identification of domestic dog remains [4]; here we add clues on a different kind of bone tissue. Effect of animal management and domestication on bone tissues have been tested and documented in some recent works. Analysis of the bones' external shape by means of geometric morphometrics is the most common protocol [19][20][21], but internal structure has been also analysed [22]. It is clear that domestication, captivity and management have an effect on bone shape and structure, due to the different lifestyle of tamed individuals in comparison with their wild counterparts. In this perspective it is interesting to note the higher porosity of the diaphysis among the zoo-wolves of our sample: internal structure of bones is influenced by external mechanical loads (i.e., living conditions) [23][24], and the signal observed in our sample may be related to captivity. Studies on the effects of domestication on limb bone's structure focused on cortical bone thickness [22]. Porosity may be another parameter to be taken into consideration. This brief study confirms that analysis of bone microstructure can be used to identify, among zooarchaeological samples, skeletal elements of individuals which lived in captivity. This is of pivotal importance when research is focused on the first steps of animal domestication, when domesticates were morphologically very close to their wild counterparts but may be lived in very different conditions. Further step of research should be the analysis of the whole diaphysis, and the combination of shape analysis of the whole bone surface with the analysis of the internal structure. This approach looks to be very promising, as demonstrated by a recent study on human remains [25].

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