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Comparative cortical bone thickness between the long bones of humans and five common non-human mammal taxa

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ABSTRACT

The task of identifying fragments of long bone shafts as human or non-human is difficult but necessary, for both forensic and archaeological cases, and a fast simple method is particularly useful. Previous literature suggests there may be differences in the thickness of the cortical bone between these two groups, but this has not been tested thoroughly. The aim of this study was not only to test this suggestion, but also to provide data that could be of practical assistance for future comparisons. The major limb bones (humerus, radius, femur and tibia) of 50 Caucasoid adult skeletons of known age and sex were radiographed, along with corresponding skeletal elements from sheep, pigs, cattle, large dogs and kangaroos. Measurements were taken from the radiographs at five points along the bone shaft, of shaft diameter, cortical bone thickness, and a cortical thickness index (sum of cortices divided by shaft diameter) in both anteroposterior and mediolateral orientations. Each variable for actual cortical bone thickness as well as cortical thickness indices were compared between the human group (split by sex) and each of the non-human groups in turn, using Student's *t*-tests. Results showed that while significant differences did exist between the human groups and many of the non-human groups, these were not all in the same direction. That is, some variables in the human groups were significantly greater than, and others were significantly less than, the corresponding variable in the non-human groups, depending on the particular non-human group, sex of the human group, or variable under comparison. This was the case for measurements of both actual cortical bone thickness and cortical thickness index. Therefore, for bone shaft fragments for which the skeletal element is unknown, the overlap in cortical bone thickness between different areas of different bones is too great to allow identification using this method alone. However, by providing extensive cortical bone thickness data for a range of bones, this study may be able to assist in the identification of some bone fragments by providing another piece of evidence that, used in conjunction with other clues, can provide a likely determination of the origin of a bone fragment.

1. Introduction

When skeletal remains are discovered, the identification of bone as human or non-human in origin is one of the earliest and most crucial steps. If the bones are intact, or at least display diagnostic features, identification can be made by observing the external morphology [1]. Yet if the remains are fragmented, such identifying features may not be evident. This is particularly problematic with the shafts of long bones, which not only lack diagnostic features but are reasonably robust, ensuring relatively long-term survival and therefore a potentially higher incidence of discovery. A number of technical methods have been developed that may be capable of accurately identifying bone as human or non-human, such as histological analysis [2–7], immunological analysis [8], X-ray diffraction analysis [9] and DNA analysis [2,10–12]. However, such methods require specialist laboratory facilities, can take time to perform (especially considering the potentially lengthy backlogs in forensic laboratories) and require destruction of part of the sample. Therefore such methods are not ideal for many crime scenes or archaeological sites, where a fast, simple, inexpensive, non-destructive method would be more useful in order to process the site correctly.

Suggestions in the literature indicate a potential difference in the thickness of the cortical bone of the long bone shafts between human and non-human mammals that may be useful in identification [13–16]. Considering that an assessment of the

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cortical bone thickness would be possible in the majority of long bone shaft fragments, without the use of complicated laboratory techniques or further destruction of the fragment, such a method would have great practical application. Brothwell [13] mentioned simply that there is a difference in bone thickness between different mammals; although the context inferred humans, no further detail was provided. Ubelaker [14] stated that the bone cortex of most non-human animals similar in size to humans is usually thicker. Specific details concerning the particular skeletal elements and non-human taxa were not given. Wolf [15] agreed that non-human cortical bone is relatively thicker than that of the human. He used the example of a femur or humerus, stating that the thickness of the cortical bone in the human is one-quarter of the total bone diameter (presumably just one side of the bone cortex). This was followed by a diagram (not to scale), the text of which stated that for large mammals, such as deer, cattle, horses and sheep, the thickness of the cortical bone is one-third of the total bone diameter.

Other researchers have found differences in the opposite direction. Croker et al. [16] found that, at the midshaft of the femur, the cortex of human bones was significantly thicker than either sheep or kangaroos. This was calculated by determining the mean proportion of the shaft diameter that was occupied by the cortical bone in a cross-section. For the human sample, this was 51.5%, whereas for the kangaroo it was 34.6% and for the sheep just 25.2%. Foote [17] also compared the femora of humans and a great number of animal species, by formulating a "medullary index", essentially a ratio representing the size of the medullary cavity compared with the thickness of the cortical bone. The index, calculated as the ratio of the mean diameter of the medullary cavity (squared and multiplied by 100) to the difference between the mean bone diameter squared and the mean medullary cavity squared, is high in animals where the medullary cavity is large compared with the cortical bone. The mean index for human femora was 38.6% and for the 117 non-human species the overall mean was 63.3%. Therefore Foote's [17] study also found human femora to have relatively thicker cortical bone than non-human femora. Urbanová and Novotný [7] measured cortical bone thickness in the femur as part of their histomorphometric comparative study, and stated that, of the common non-human mammals studied, only pigs were similar in cortical bone thickness to humans. Analysis of this feature alone was not presented, but they found that by incorporating cortical bone thickness into the discriminant functions for their histological analysis, the diagnostic capability of the functions was improved. On the other hand, Rérolle et al. [18] do not believe there is enough difference in the relative cortical bone thickness of long bones to distinguish human from non-human (pig, dog and sheep) bones. Their article considered the corticomedullary index (the ratio of the diameter of the medullary cavity to the external shaft diameter of the bone), but the samples used for reference values are not well-described.

As suggested in the study by Croker et al. [16], the various points of confusion in the current literature show that there is a need for a thorough comparison of human and non-human cortical bone thickness. Different areas of the bone shaft should be incorporated, as should several different long bones and a wide range of non-human mammals, to explore more clearly the possibilities and limitations of this method. This is the overall purpose of the study presented here. Studies such as those of Croker et al. [16] have only considered the midpoint of the shaft, yet bone thickness can vary along the shaft [18,19]. Several different skeletal elements are comparable between taxa in terms of overall size and shaft form, so the major long bones of humerus, radius, femur and tibia at least should be included. An effective comparison of bone thickness from a forensic viewpoint should include several non-human taxa that are likely to be confused with humans locally. In this case, sheep, kangaroos, juvenile pigs, large dogs (greyhound type) and cattle were chosen due to the broad similarity in size (or at least diameter) of their long bones when compared with adult humans and the frequency with which they are presented for expert identification, at least in the Sydney region in Australia.

As it is not clear how some of the figures in the literature have been derived, the first aim of this study is to quantify long bone shaft diameters and cortical bone thicknesses for adult humans and several common non-human mammals. Presenting these actual data will provide an important benchmark in allowing meaningful comparisons to be made for both past and future research. The second aim of the study is to determine whether there are significant differences in the cortical bone thickness between the adult humans and non-human mammals in the study. These are compared in terms of both the actual cortical bone thickness measurements themselves, and a cortical bone thickness index that takes into account the shaft diameter.

2. Materials

The human sample was sourced from the Robert J. Terry Collection, housed at the National Museum of Natural History in Washington, DC, USA. This collection was used because there are known biological data for these remains, which was important to control for as previous research has shown that factors such as age and sex may affect cortical bone thickness [20–22]. Adult Caucasoid specimens from age 24 years to 86 years were used (see Table 1). The specimens were selected so that approximately two to three years separated the ages of each male and female specimen, ensuring as even as possible a spread of ages across the sample. Within these guidelines, the specimens were chosen at random from their catalogue numbers. Right and left sides were sampled equally, also chosen at random from the catalogue. The humerus, radius, femur and tibia from the same side of each individual were sampled. Apart from traces of osteoarthritis in some of the older individuals, there were no externally obvious pathological conditions in the sample selected, though it was not possible to determine beforehand if any of the individuals were osteoporotic.

The non-human sample (comprised of kangaroos, sheep, pigs, dogs and cattle) originated from a number of sources, explained in

Table 1
Summary of specimens used.

Group	Sex	Age range	Number of each skeletal element			
			Humerus	Radius	Femur	Tibia
Human	Male	27–85 years	25	25	25	25
	Female	24–86 years	25	25	25	25
Kangaroo	Mostly unknown	Presume adult	9	24	30	24
Sheep	Unknown	Approx. 6 months-adult	24	27	28	24
Pig (juvenile)	Unknown	Approx. 5 months	18	22	27	23
Dog (greyhound)	Unknown	Mostly adult	19	22	17	18
Cattle	Unknown	Approx. 15 months-adult	29	28	24	24