Robusticity of Bovidae skeletal elements from southern Africa and their potential in species identification

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Faunal analysis is crucial in the investigation of the complexity of caves and archaeological sites. Osteological measurements are often used for human remains as a means of identification, and can also be used for animal bones. Sometimes measurements constitute the only method of accurate identification and can be used to distinguish between similar species. The aim of this study was to assess measurements reflecting robusticity in bovids, in order to establish whether this could be used for identification of unknown animal bones, or at least indicate bovid size class. In total, 846 femora, tibiae, and metatarsals of bovids in the various size classes classified as proposed by Brain (1974) were measured. The maximum long bone length and smallest shaft circumference of modern southern African specimens were used. In order to assess the robusticity of the bones, a robusticity index was calculated for each bone. The calculated indices for the three hind limb bones showed that there is a large degree of overlap between most of the species on all three bones. There are, however, a few species that could be identified purely on their index values if the Bovid size class were known. Buffalo (*Syncerus caffer*) showed almost no overlap with any other species and was the most robust in all three long bones. Sitatunga (*Tragelaphus spekeii*) femur and tibia were the least robust, whereas springbok (*Antidorcas marsupialis*) had the most gracile metatarsal. Bov classes I and II were overall less robust than Bov classes III and IV in all three bones. With further studies and a larger specimen database, specific values may prove to be important in identifying the different Bovid size classes and possibly give some insight into lifestyle adaptations in mammals.

Keywords: Archaeozoology, Faunal Analysis, Bovidae, Osteometry, Hind Limb.

INTRODUCTION

Faunal analysis is crucial in the investigation of the complexity of caves and archaeological sites. The process of faunal analysis is usually done by an expert and involves the comparison of excavated specimens with their modern counterpart. Osteological measurements are often utilized to test an identification in both the analyses of human and animal remains. Often these measurements constitute the only method of accurate identification, for example when distinguishing sheep and goat specimens (*e.g.*,Boessneck *et al.,* 1964; Boessneck, 1969), or between other similar species (*e.g.*, Plug and Peters, 1991; Peters, 1986; Peters and Brink, 1992; Watson and Plug, 1995). Osteometry is also used in studies of domestication (*e.g.*, O'Connor, 2004; Higham, 1968; Davis, 1981), and to assess size changes through time and space (*e.g.*, Audoin-Rouzeau, 1995; Badenhorst and Plug, 2003).

Metric data can sometimes be more sensitive and objective than morphological assessment. However, it depends on the aim of the analysis and nature of the specimens, and can never replace morphological description and identification.

If osteometry is used as a means of identification, it is vital that comparative metric data should be available on a wide range of species, in order to assess similarities and differences between the measurements of various species. Authors such as Walker (1985) and Von den Driesch (1976) have developed and applied a large variety of measurements for animal bones. These measurements can be used as single entities or in combination to provide insight into the shape or structure of a bone.

It is generally known that a bone's form reflects its mechanical loading history (Ruff *et al.*, 2006). Wolff's law states that mechanical load applied to living bone tissue will, over time, influence the structure of bone tissue (Wolff, 1892). Although the general concept has been accepted, it has been scrutinized by various authors with new experimental evidence which suggested that this law should be replaced by a more general concept called bone functional adaptation (Ruff *et al.,* 2006). Various

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*Author for correspondence. E-mail: eswanepoel@uj.ac.za studies have been performed to investigate the functional adaptation of bone and the factors that influence the shape and form of a bone (*e.g.*, Carter and Beaupre, 2001; Chamay and Tschantz, 1972; Lanyon *et al.,* 1982; Stock, 2004). The robusticity and cross-sectional shape of the diaphysis are measurement tools that have been utilized to assess adaptation of bone (Hindelang *et al.*, 2002; Heinrich and Biknevicius, 1998; Riesenfeld, 1978). It can thus be deducted that the robusticity of the bones of a specific animal species will reflect something of their body size in general, as well as their habitat and way of life.

In studies of hominid evolution and modern human adaptation, robusticity of long bones has been used in order to assess evolutionary trends (*e.g.*, Ruff *et al.,* 1993; Ruff *et al.,* 1994), mobility patterns (*e.g.*, Wescott, 2006; Stock, 2006; Carlson *et al.,* 2007), climatic adaptation (*e.g.*, Churchill, 1998; Stock, 2006), and subsistence patterns (*e.g.*, Churchill and Morris, 1998; Shackelford, 2007; Sparcello *et al.*, 2010). Little has been done in this regard as far as animal bones are concerned, particularly in a southern African context. Information on robusticity of modern animal bones can therefore potentially provide much information that can be included in studies which attempt to assess evolutionary changes and subsistence strategies in such a regional context.

The aim of this study was to investigate the robusticity of long bones in bovids, in order to, firstly, assess what they reflect with regards to the habitat and way of life of the particular bovid. Secondly, it was aimed to establish whether the differences in robusticity between various species are significant enough so that they could be usable as a means of identification of unknown animal bones. For this purpose, only the hind limb bones of South African bovids were used. This study formed part of a larger osteometric analysis of animal bones (Swanepoel, 2003; Swanepoel *et al.,* 2008).

MATERIAL AND METHODS

For the purpose of this study, only the hind limb bones of South African Bovidae were used. Therefore, the femora, tibiae, and metatarsals of bovids in the various size classes were measured. Brain (1974) classified all 34 South African bovids into four classes, depending on their size (Table 1), and this classification was used in this study.

All known modern specimens of hind limb bovid bones, available in South African museums, were measured. These collections are housed at the Ditsong National Museum of Natural History (formerly the Transvaal Museum, Pretoria), the National Museum (Bloemfontein) and the Iziko South African Museum (Cape Town). Although all attempts were made to collect as many specimens for measurement purposes as possible, four species were unfortunately not represented in these Southern African modern collections from southern Africa and no measurements could thus be recorded for dik-dik (*Madoqua kirki*), Sharp's grysbok (*Raphicerus sharpei*), puku (*Kobus vardonii*) and Lichtenstein's hartebeest (*Alcelaphus lichtensteinii*). Not all species are adequately represented in the modern skeletal collection, thus although sample sizes of more than 20 are preferred, some species are represented by fewer individuals. Tsessebe (*Damaliscus lunatus*) was, for example, represented by only one specimen while the maximum sample size comprised 29 specimens for the bontebok (*Damaliscus dorcas dorcas*) as can be seen in Table 1.

Only adult specimens were utilized for this study. Even though the sex of a particular individual was documented in some cases, male and female data were pooled as the sample sizes were inadequate and sex was not known in all cases. While the origin of the specimens, whether zoo- or wild-born was not available in most specimens measured, it was documented in known cases.

The left sided bone was used in each case unless only the right side was available, in which case it was documented as being the right side. The individuals were selected upon condition that all three bones were available and measurable. All specimens measured were assessed skeletally as being apparently healthy and showing no injuries such as healed or unhealed fractures. Measurements were done by the first author only and an osteometric box and metal measuring tape were used.

Maximum long bone length and smallest shaft circumference of the femur, tibia and metatarsal were measured on each of the available specimens. Measurements used were defined and used by Von den Driesch (1976) and Walker (1985), but new abbreviations were allocated for each measurement for descriptive purposes (Table 2). Most human robusticity studies have utilized long bone length and mid-shaft diameter to assess robusticity (Riesenfeld, 1978; Ruff, 2002) and more recent studies utilize computer tomography to analyse cross sectional diameters (Carlson, 2005). It was, however, decided to utilize measurements already used by most faunal analysts in southern African (Von den Driesch, 1976; Walker, 1985) as these are well known and easy to utilize during faunal analysis.

In order to assess the robusticity of the bones, a robusticity index was calculated for each. These reflect the specimen's circumference in relation to its length. This index therefore allows for clear comparison between species by excluding absolute size. Smaller and larger animals can therefore have the same robusticity index, even though their

Table 1
Number of specimens of different bovid species measured. Details of actual specimens used, with specimen numbers, can be found in Swanepoel (2003).

Bovid size class	Species		*n*
Bovid size class I	*Neotragus moschatus*	Suni	2
(0 kg–23 kg)	*Philantomba monticola*	Blue duiker	5
	Raphicerus melanotis	Cape grysbok	23
	Cephalophus natalensis	Red duiker	10
	Oreotragus oreotragus	Klipspringer	2
	Raphicerus campestris	Steenbok	20
	Sylvicapra grimmia	Grey / Common duiker	16
	Ourebia ourebi	Oribi	5
Bovid size class II	*Antidorcas marsupialis*	Springbok	20
(23 kg–84 kg)	*Redunca fulvorufula*	Mountain reedbuck	7
	Pelea capreolus	Grey rhebok	4
	Tragelaphus scriptus	Bushbuck	4
	Damaliscus pygargus philipsii	Blesbok	13
	Damaliscus dorcas dorcas	Bontebok	29
	Aepyceros melampus melampus	Impala	17
	Redunca arundinum	Southern reedbuck	6
Bovid size class III	*Kobus leche*	Lechwe	5
(84 kg–296 kg)	*Tragelaphus angasii*	Nyala	6
	Tragelaphus spekii	Sitatunga	2
	Damaliscus lunatus	Tsessebe	1
	Alcelaphus buselaphus	Red hartebeest	9
	Tragelaphus strepsiceros	Greater kudu	8
	Connochaetes gnou	Black wildebeest	21
	Kobus ellipsiprymnus	Waterbuck	6
	Oryx gazella	Gemsbok	6
	Hippotragus niger	Sable	6
	Connochaetes taurinus	Blue wildebeest	5
	Hippotragus equinus	Roan	3
Bovid size class IV	*Tragelaphus oryx*	Eland	15
(>296 kg)	*Syncerus caffer*	Buffalo	6
Total:			282

Table 2
Measurements used for robusticity indices.

	Measurement	Measurement description	Measurement defined by	Abbreviation	Instrument used
Femur	F(GL)	Femur (greater length)	Von den Driesch (1976)	GL	Osteometric box
	F(SCD)	Femur (smallest circumference diaphysis)	Von den Driesch (1976)	CD	Metal measuring tape
Tibia	T(GL)	Tibia (greater length)	Von den Driesch (1976)	GL	Osteometric box
	T(SCD)	Tibia (smallest circumference diaphysis)	Von den Driesch (1976)	CD	Metal measuring tape
Metatarsal	M(GL)	Metatarsal (greater length)	Von den Driesch (1976)	GL	Osteometric box
	M(SCD)	Metatarsal (smallest circumference diaphysis)	Von den Driesch (1976)	CD	Metal measuring tape

Table 3
Basic descriptive statistics, including robusticity indices, for the femur.

Species	*n*	Mean F(GL)	S.D. F(GL)	Mean F(SCD)	S.D. F(SCD)	Mean Index	S.D. Index	Range Index
BOV I								
Neotragus moschatus	2	114.3	6.0	29.0	0.7	25.4	0.7	24.9–25.9
Philantomba monticola	5	103.9	4.8	27.2	1.5	26.2	2.0	24.0–29.0
Raphicerus melanotis	23	152.2	6.2	39.8	2.3	26.1	1.3	23.8–28.9
Cephalophus natalensis	10	142.6	2.8	40.6	1.6	28.4	0.9	27.2–29.7
Oreotragus oreotragus	2	152.8	4.6	43.0	1.4	28.1	0.1	28.1–28.2
Raphicerus campestris	20	141.2	8.8	37.9	2.3	26.9	1.7	24.5–30.0
Sylvicapra grimmia	16	163.6	5.0	44.5	2.4	27.2	1.1	25.3–29.2
Ourebia ourebi	5	168.3	4.4	46.5	1.3	27.6	0.7	26.5–28.5
BOV II								
Antidorcas marsupialis	20	204.2	14.9	56.9	4.1	27.9	0.7	26.7–29.1
Redunca fulvorufula	7	206.0	7.3	53.6	4.9	26.0	1.8	23.4–28.8
Pelea capreolus	4	194.4	7.1	50.9	2.4	26.2	0.5	25.7–26.9
Tragelaphus scriptus	4	227.4	10.3	66.5	5.6	29.2	1.4	28.0–30.9
Damaliscus pygargus philipsii	12	224.8	6.2	67.5	2.8	30.0	0.8	29.0–31.4
Damaliscus dorcas dorcas	29	232.0	9.9	66.5	4.2	28.7	1.1	27.2–32.0
Aepyceros melampus melampus	17	233.7	8.6	64.8	5.0	27.7	1.4	25.0–30.3
Redunca arundinum	6	252.6	12.0	68.9	3.9	27.3	1.4	25.0–28.9
BOV III								
Kobus leche	5	281.7	10.3	77.1	6.0	27.3	1.4	26.2–29.6
Tragelaphus angasii	6	265.9	22.8	76.5	8.6	28.7	1.0	27.2–29.9
Tragelaphus spekii	2	310.0	1.4	76.3	2.5	24.6	0.9	24.0–25.2
Damaliscus lunatus	1	279.0	N/A	82.0	N/A	29.4	N/A	29.4
Alcelaphus buselaphus	9	283.9	11.3	83.3	4.8	29.3	1.2	27.5–31.0
Tragelaphus strepsiceros	8	355.0	22.1	109.6	11.4	30.8	1.4	29.1–33.1
Connochaetes gnou	21	268.0	13.9	90.9	4.9	33.9	0.8	32.5–35.7
Kobus ellipsiprymnus	6	341.1	14.2	111.2	2.9	32.9	0.9	31.5–33.7
Oryx gazella	6	312.7	12.3	101.3	7.0	32.4	1.4	31.3–34.8
Hippotragus niger	6	320.0	6.0	98.8	3.1	30.9	0.8	30.1–32.1
Connochaetes taurinus	5	315.6	11.2	110.8	4.1	35.1	1.1	34.0–36.4
Hippotragus equinus	3	341.0	32.2	104.7	6.4	30.8	1.2	29.9–32.2
BOV IV								
Tragelaphus oryx	15	409.4	32.8	132.5	16.0	32.3	1.7	29.2–35.0
Syncerus caffer	6	400.1	26.6	152.0	13.3	38.0	2.3	34.9–41.0

overall size is very different. The three calculated indices were thus:

Femur robusticity =

$$\frac{\text{Femur (smallest circumference diaphysis)}}{\text{Femur (greatest length)}} \times 100$$

Tibia robusticity =

$$\frac{\text{Tibia (smallest circumference diaphysis)}}{\text{Tibia (greatest length)}} \times 100$$

Metatarsal robusticity =

$$\frac{\text{Metatarsal (smallest circumference diaphysis)}}{\text{Metatarsal (greatest length)}} \times 100$$

With these data available, the mean robusticity index for each species was calculated, with its standard deviation and range within each species (Tables 3–5).

RESULTS

The basic descriptive statistics for the femur, tibia and metatarsal of the 30 southern African bovids, in their bovid size classes, are provided in Tables 3–5. These tables also include the means and ranges for the calculated robusticity indices. The data for the robusticity indices are also graphically represented in Figs 1–3.

The mean robusticity of Bov I and II is similar for both the femur and tibia specimens (averages ranging between 24.9 and 28.9 for the femur and 18.8 and 22.0 for the tibia) and an increase is only visible in Bov III and Bov IV. Buffalo is by far the most robust of all the animals (Figs 1, 2).The means of the metatarsal specimens of Bov I and Bov II are much more variable and there are several species, such as klipspringer (*Oreotragus oreotragus*), springbok and bushbuck (*Tragelaphus scriptus*) that fall

Table 4
Basic descriptive statistics, including robusticity indices, for the tibia.

Species	*n*	Mean T(GL)	S.D. T(GL)	Mean T(SCD)	S.D. T(SCD)	Mean Index	S.D. Index	Range Index
BOV I								
Neotragus moschatus	2	138.3	7.4	26.3	1.8	19.0	0.3	18.8–19.2
Philantomba monticola	5	114.6	7.7	23.2	1.3	20.3	1.7	18.8–23.2
Raphicerus melanotis	22	180.2	6.6	36.1	1.4	20.0	0.9	18.1–21.9
Cephalophus natalensis	10	153.0	4.2	36.0	1.5	23.5	0.9	22.1–24.7
Oreotragus oreotragus	3	172.2	3.4	37.8	1.3	22.0	0.4	21.5–22.2
Raphicerus campestris	21	179.3	8.1	35.5	2.3	19.8	1.0	18.0–21.6
Sylvicapra grimmia	16	191.5	8.4	41.5	2.6	21.7	0.8	20.6–23.2
Ourebia ourebi	5	205.6	8.9	43.5	2.1	21.2	0.9	19.9–22.0
BOV II								
Antidorcas marsupialis	20	258.1	19.1	53.9	4.0	20.9	0.8	19.7–22.9
Redunca fulvorufula	8	254.0	7.4	50.4	2.3	19.8	0.6	18.8–20.5
Pelea capreolus	3	243.7	12.7	50.4	6.3	21.0	2.5	19.4–23.8
Tragelaphus scriptus	4	249.9	13.8	56.5	5.8	22.6	1.7	21.2–25.0
Damaliscus pygargus philipsii	13	270.7	7.0	60.0	3.2	22.2	0.9	20.4–24.1
Damaliscus dorcas dorcas	29	282.3	10.3	61.7	3.4	21.8	0.7	20.7–23.6
Aepyceros melampus melampus	17	285.4	7.6	62.6	4.5	21.9	1.2	19.9–23.6
Redunca arundinum	6	309.8	7.7	62.3	2.9	20.1	0.9	19.0–21.5
BOV III								
Kobus leche	5	326.4	7.4	72.4	8.7	22.2	2.4	20.7–26.3
Tragelaphus angasii	5	306.9	25.7	68.3	4.5	22.3	1.7	19.7–23.7
Tragelaphus spekii	2	373.0	0.0	69.0	1.4	18.5	0.4	18.2–18.8
Damaliscus lunatus	1	335.0	N/A	81.0	N/A	24.2	N/A	24.2
Alcelaphus buselaphus	9	336.2	12.8	81.8	3.9	24.4	1.0	23.1–25.6
Tragelaphus strepsiceros	8	388.9	28.0	99.9	9.6	25.7	1.1	24.3–27.3
Connochaetes gnou	21	310.5	15.7	80.8	4.6	26.0	0.9	24.3–27.6
Kobus ellipsiprymnus	7	367.6	13.7	99.4	3.9	27.1	1.3	25.1–28.3
Oryx gazella	6	337.8	6.6	92.3	6.0	27.3	1.5	25.3–29.7
Hippotragus niger	6	344.7	8.4	94.5	1.9	27.4	0.6	26.4–28.4
Connochaetes taurinus	4	359.4	22.2	102.5	7.0	28.6	2.2	26.3–30.5
Hippotragus equinus	3	377.5	45.7	101.2	7.8	26.9	1.2	25.7–28.0
BOV IV								
Tragelaphus oryx	16	403.4	25.8	119.3	10.6	29.6	1.5	26.8–32.5
Syncerus caffer	7	384.1	20.1	136.2	15.2	35.4	2.9	31.1–39.9

outside the general trend of the other Bov I and Bov II (Fig. 3). The ranges of the femur and tibia gradually increase with an increase in bovid size class, but the metatarsal ranges show a large amount of variation even within a bovid size class. Once again the buffalo is by far the most robust.

The femur indices show overlapping of all species (Fig. 1), except for the buffalo which is much more robust than all other species. Generally the robusticity increases in the larger bovid species such as the greater kudu (*Tragelaphus strepsiceros*) and waterbuck (*Kobus ellipsiprymnus*), although sitatunga (*Tragelaphus spekei*) seems to have a relatively gracile femur for a member of the Bov III size class. The robusticity index of the sitatunga shows no overlap with the species within this Bovid III group. If the Bovid class of a specimen measured is known, the femur index of the sitatunga might thus be usable in identification. The sample size of sitatunga was, however, very small and a larger sample may change these results. Bov IV shows no overlapping for the femur, thus indicating that there will be a clear distinction between the eland (*Taurotragus oryx*) and buffalo species on the femur index values.

The same tendency is seen in the tibial indices (Fig. 2), with similar indices for Bov I, II and even some of the Bov III. It increases from kudu upwards, with the two species in Bov IV being much more robust. The sitatunga once again seems to be the least robust in the Bov III group. The close overlap of the tibial robusticity values between Bov I and Bov II may render these values unusable for identification purposes. Bov III shows overlapping values within the group, but may be used to distinguish a Bov III specimen from Bov I and Bov II, with the exception

Table 5

Basic descriptive statistics, including robusticity indices, for the metatarsal.

Species	*n*	Mean M(GL)	S.D. M(GL)	Mean M(SCD)	S.D. M(SCD)	Mean Index	S.D. Index	Range Index
BOV I								
Neotragus moschatus	2	107.8	6.7	22.8	1.1	21.1	0.3	20.9–21.3
Philantomba monticola	5	84.1	7.5	20.3	1.3	24.8	21.	22.7–27.6
Raphicerus melanotis	23	129.3	4.6	31.0	1.6	23.9	1.4	20.3–27.4
Cephalophus natalensis	10	111.3	4.8	30.8	0.9	27.7	1.1	26.0–29.5
Oreotragus oreotragus	3	122.8	26.6	35.2	2.1	33.5	2.2	31.9–35.0
Raphicerus campestris	21	135.7	5.0	30.9	1.6	22.8	1.0	21.2–25.0
Sylvicapra grimmia	16	157.5	6.3	34.6	1.8	21.9	0.7	21.2–23.9
Ourebia ourebi	5	158.4	4.3	36.1	1.9	22.8	0.7	21.8–23.5
BOV II								
Antidorcas marsupialis	20	235.4	16.1	45.6	2.8	19.4	0.8	17.7–20.5
Redunca fulvorufula	7	187.1	5.4	42.5	2.3	22.7	0.8	21.6–23.7
Pelea capreolus	4	189.3	5.1	42.9	1.3	22.7	0.3	22.4–23.1
Tragelaphus scriptus	4	171.8	10.4	46.6	4.4	27.1	1.7	25.2–29.2
Damaliscus pygargus philipsii	12	220.5	5.7	52.0	2.8	23.6	1.0	22.0–24.9
Damaliscus dorcas dorcas	29	224.4	6.5	53.6	1.6	23.9	0.7	22.5–25.4
Aepyceros melampus melampus	17	240.7	5.7	53.7	3.3	22.3	1.2	20.5–24.6
Redunca arundinum	5	235.5	7.0	55.0	27.8	23.4	1.2	22.0–25.0
BOV III								
Kobus leche	5	229.8	5.3	64.8	4.4	28.2	1.9	26.7–31.3
Tragelaphus angasii	6	230.0	12.2	59.0	5.9	25.6	1.3	23.7–27.3
Tragelaphus spekii	2	250.3	9.5	66.8	0.4	26.7	1.2	25.9–27.5
Damaliscus lunatus	1	269.0	N/A	67.5	N/A	25.1	N/A	25.1
Alcelaphus buselaphus	9	261.3	7.4	69.7	4.1	26.7	1.3	24.7–28.2
Tragelaphus strepsiceros	7	308.1	28.6	85.6	8.4	27.8	0.7	26.8–29.0
Connochaetes gnou	20	220.8	10.5	68.9	3.5	31.2	1.6	28.2–33.6
Kobus ellipsiprymnus	7	239.1	5.8	89.6	1.7	37.5	1.1	36.0–39.2
Oryx gazella	6	245.4	11.5	79.4	5.7	32.4	2.8	27.1–35.1
Hippotragus niger	6	240.2	4.1	81.3	2.1	33.8	1.0	32.6–35.3
Connochaetes taurinus	4	253.8	10.8	84.9	4.8	33.5	1.5	31.5–34.8
Hippotragus equinus	3	267.0	31.2	86.2	6.2	32.4	1.6	30.7–33.8
BOV IV								
Tragelaphus oryx	14	293.0	16.0	99.9	7.8	34.4	2.2	30.8–38.6
Syncerus caffer	7	216.5	14.7	119.8	11.6	55.6	6.7	43.9–64.5

of the nyala (*Tragelaphus angasii*) and lechwe (*Kobus leche*). Again the sitatunga shows no overlap within its Bovid group, thus the tibial indices may also assist in identifying tibial remains of this species. Bov IV shows little overlap, again being useful for identification.

As mentioned before, metatarsal robusticity indices vary greatly even within a Bovid size class (Fig. 3). The most gracile metatarsals (indices between 26.7 and 29.1) were found in springbok, with red duiker (*Cephalophus natalensis*) (26.0–29.5) and klipspringer (31.9–35.0) being fairly robust for the Bov I group. The bushbuck in Bov II, lechwe, blue wildebeest (*Connochaetes taurinus*), waterbuck, gemsbok (*Oryx gazella*), sable (*Hippotragus niger*) and roan (*Hippotragus equinus*) in Bov III as well as eland in Bov IV are more robust, with buffalo being the most robust of all (43.9–64.9). The waterbuck shows no overlap within the Bovid III group to which it belongs. If the Bovid class of the specimen measured is known, it would be possible to identify a waterbuck according to its metatarsal robusticity value. Springbok and buffalo, however, show no overlap with any of the other species. Springbok has the lowest robusticity value, which indicates a thin, long metatarsal, whereas buffalo has the highest value indicating a thick, short metatarsal. Thus, the metatarsals of these two species can be identified simply according to their metatarsal index values.

Buffalo show almost no overlap with any other species. All three index values can therefore be used in osteometric identification because of the distinguishable robusticity indices of this species.

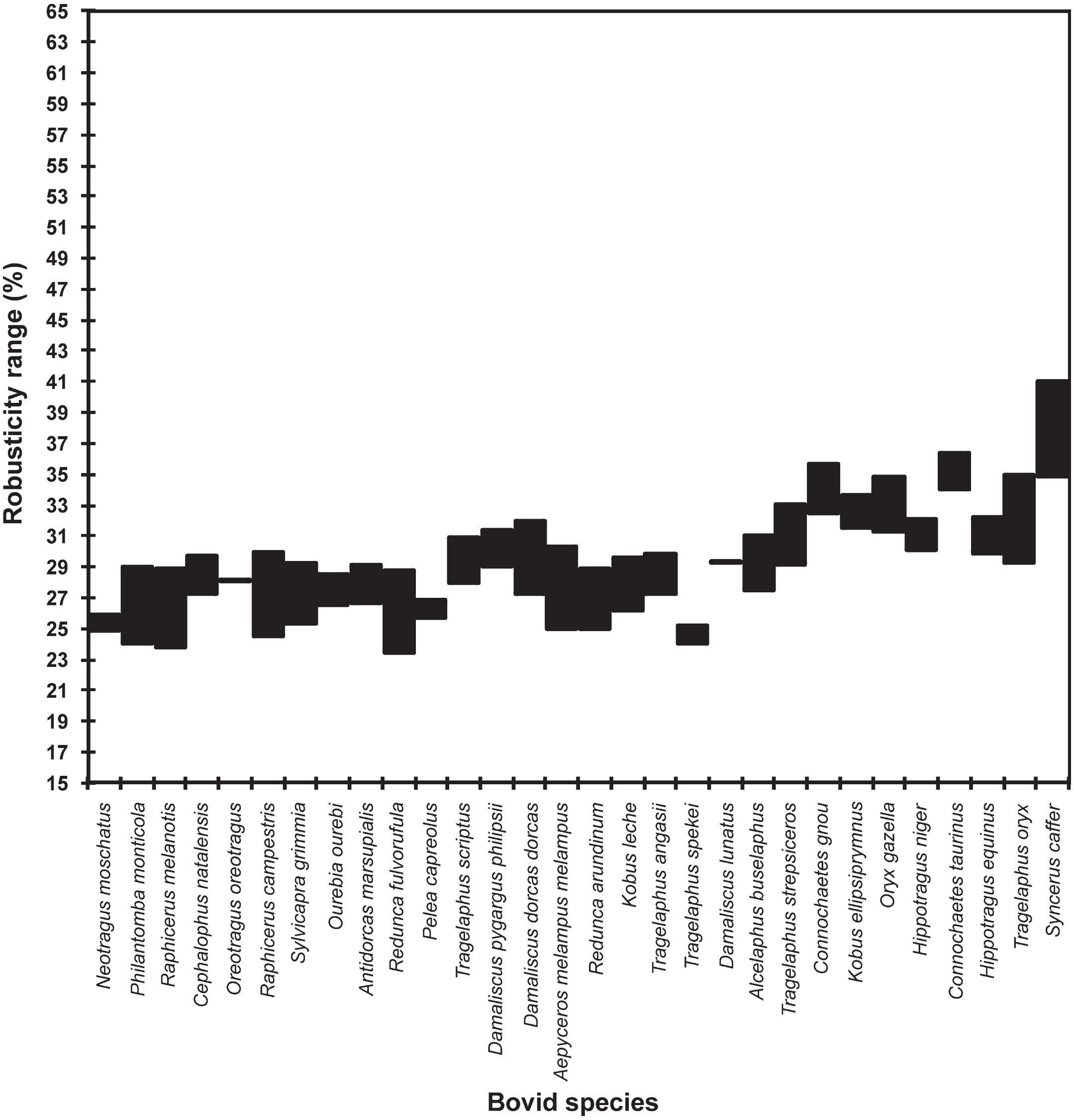

Fig. 1

Robusticity ranges: femur.

DISCUSSION

The three calculated indices show that there is a large area of overlap as far as robusticity is concerned between most of the species on all three bones. In general it was shown that the larger the Bov class, the more robust the femora and tibiae become. This is true for some of the metatarsals, although not all. It is interesting to note that in some animals the robusticity in all three bones is similar, while in others the metatarsal index shows little relationship with robusticity in the other two bones (Fig. 4). This is particularly true for klipspringer, springbok, bushbuck, lechwe, sitatunga, waterbuck, blue wildebeest and buffalo.

In a human study Burr *et al.* (1996) found that higher strain would be forced upon a bone during 'zigzag' running or walking than during straight walking or running. They speculated that this is due to the fact that a gait change created a new mechanical environment to adapt to. It may therefore be argued that the four species indicated as having very obvious robust metatarsals (klipspringer,

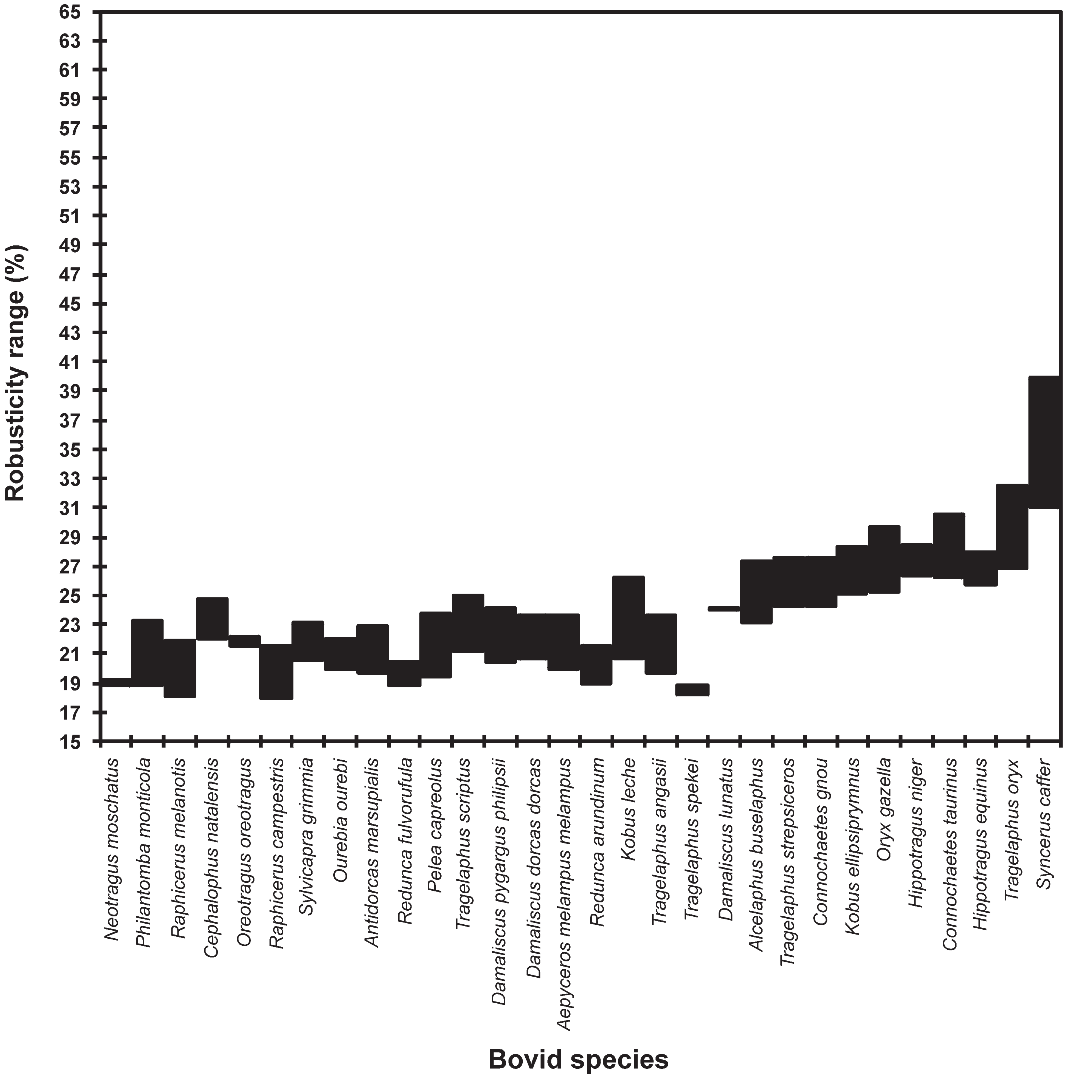

Fig. 2

Robusticity ranges: tibia.

bushbuck, waterbuck and lechwe; Fig. 4), may have different or more difficult terrain (water and rocky areas, respectively) to navigate than the other species. This is because of greater stresses being forced onto bone and therefore extra bone deposition in response during terrestrial movement where there are bound to be unexpected changes in the walking/running surface. Therefore frequent, sudden, unexpected change of terrain for klipspringer (which habitat is mostly rocky outcrops), bushbuck (which habitat is mostly highly vegetated areas with poor sight to antelope), and lechwe and waterbuck being in shallow and deep water respectively, may create more or different stresses than antelope utilizing more even terrain (Skinner, 2005). As there are more stresses loaded on these bones, more bone may be deposited for rigidity and stability (Carlson, 2005). The opposite might then be argued for the springbok which has an extremely gracile metatarsal (Fig. 4) as this antelope is naturally found in flat, barren areas with little unexpected changes during movement. There are, however, various other bovid species that are also subjected to unexpected terrain changes during their daily locomotion, so the development of the degree of robusticity in the tibiae is most probably multifactorial.

Other factors that may contribute to differential

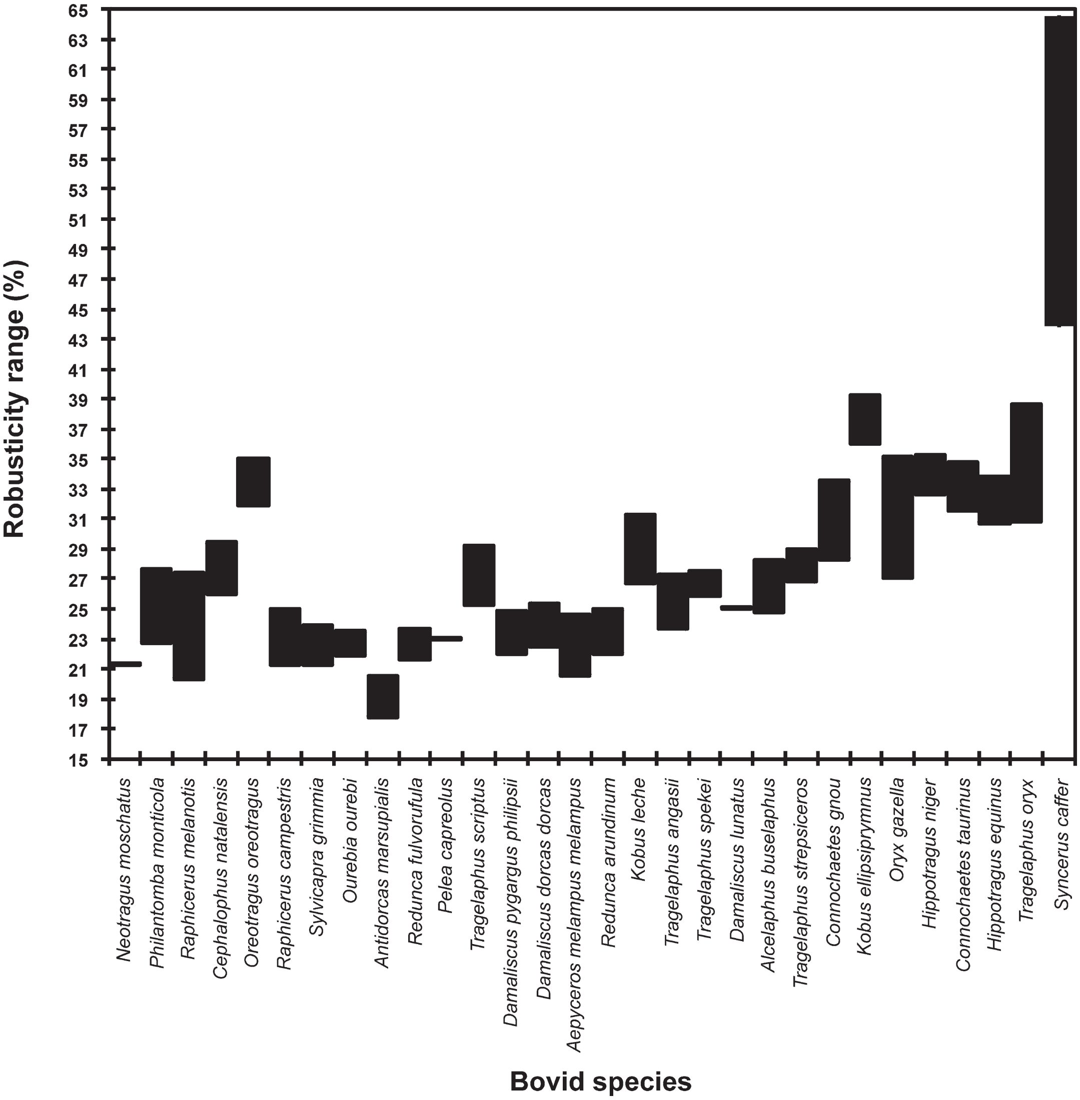

Fig. 3

Robusticity ranges: metatarsal.

robusticity include sexual dimorphism, exercise, nutrition and age of individuals within the sample. Bertram and Swartz (1991) noted that most bone form adjustments associated with mechanical loads take place during the developmental growth period, which in bone persists into young adulthood. Therefore immature skeletal specimens were excluded from this study in an attempt to isolate only specimens that have undergone most shape adjustments. As the above-mentioned growth period includes early adulthood in humans, younger adult specimens may still have changed slightly depending on age as the positive period of skeletal growth includes the increase of bone mass while increase in bone length has largely ceased (Riggs and Melton, 1992).

Although researchers such as Peacock *et al.* (2005) showed that heritability of various bone structural traits is sometimes sex-linked in humans, Riesenfeld (1978) found that sexual dimorphism of skeletal robusticity in mammalian orders seems to be highly species-specific. Most bovid species do, however, show differences in body weight between male and female individuals (Skinner and Chimimba, 2005). The fact that specimens were pooled in this study may therefore have an influence

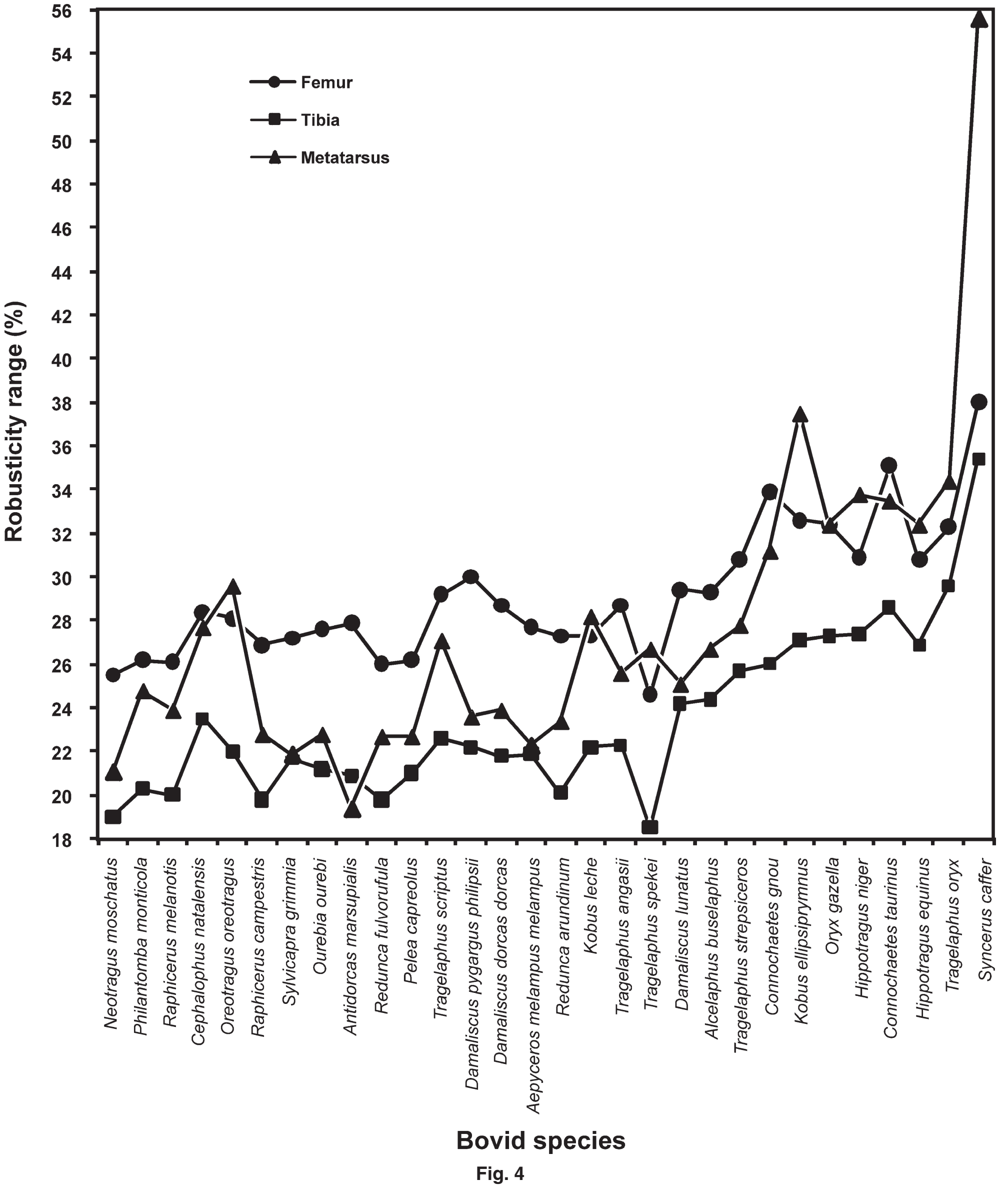

Fig. 4

Comparison of robusticity means: femur, tibia and metatarsal.

on the range of the robusticity indices calculated as an abundance of, for example, males in a group may have led to an inflated robusticity.

Animal and human exercise studies by Forwood and Burr (1993) revealed that exercise can add small amounts of bone mass to the adult skeleton, although the main function of bone is to conserve or maintain existing bone. Exercise intensity will inevitably differ in zoo- and wild-born individuals depending on the zoo enclosure size and suitability for free movement of a specific species. O'Connor (2004), Higham (1968) and Davis (1981) substantiate this by skeletal measurements that show a diminishing skeletal robusticity in zoo animals. The study by Riesenfeld (1978), however, indicated that domestication had no significant effect on robusticity of the metatarsals of different mammalian species. Unfortunately very little information is available on the origins of the animals used in this study.

The indices are indicative of the robusticity of the specific bone. There are, however, a few species which showed no overlap with other species and where the animal could be identified purely on their index values if the bovid size class were known. In the Bov III class the metatarsal robusticity index will clearly identify waterbuck as it had the highest robusticity value. Sitatunga had the smallest robusticity values of the femur and tibia, with very little overlap (especially on the tibia), if at all. These two indices are therefore very important indicators for this species. Buffalo showed the most robust bones of all the species. In all three indices it showed almost no overlap. These robusticity values can therefore be an important element in the identification of buffalo remains.

There are various publications (*e.g.*, Biewener,1989; Bertram and Biewener, 1992) that refer to the concept of large mammals (>100 kg), for example buffalo, reducing their locomotor performance and altering the bone shape. These changes in turn maintain constant safety factors such as ultimate bone stress and peak functional stress. Smaller mammals, on the other hand (<100 kg), such as springbok, compensate for their increasing body mass by straightening both the fore-and hind limbs.

A variety of external factors may have influenced the data collection and results obtained. These include the small sample sizes, and the fact that male and female specimens had to be combined. This pooling of the sexes may therefore give an ambiguous reflection, if the majority of a sample was of a specific sex. The ideal would have been to separate the sexes, but unfortunately no other samples are available. It is therefore of extreme importance that the current collections should be maintained and expanded, in order to increase opportunities for future osteometric research.

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