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# An osteometrical method for sexing cattle bones: the metacarpals from 17th century Carnide, Lisbon, Portugal

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(with 8 figures and 2 tables)

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## Abstract

Measurements taken on 47 complete and 44 distal fragments of cattle metacarpals from 17th century AD Carnide, Lisbon, separate into two groups. Comparison with 21 ancient DNA sexed specimens and modern specimens of known sex (seven Barrosã cows and a Barrosã bull), indicates that the Carnide metacarpals probably belonged to both cows and bulls/oxen. We use the 47 complete metacarpals as a "sexed reference sample" in order to find which measurements generally taken by zooarchaeologists on the distal metacarpal help separate males from females. Widths appear to be most useful. The modern Barrosã cattle in our collection, selected for their meat, have wider metacarpals than the ones from Carnide; the latter were perhaps more generalist animals.

**Keywords**: Cattle, metacarpals, aDNA, osteometry, sexing.

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## Introduction

One of the principal aims of zooarchaeology – the study of animal remains found on archaeological sites – is to understand the nature of the relation between man and animals in the past. Hunters probably related to male animals in a different way from female animals. Farmers no doubt always treated their male livestock differently from females, depending in part upon the nature of the economy – meat, milk, power. Hence to be able to determine the sex ratios of the animals represented in archaeological sites can be very useful. The ratio of "male animals to female animals" can help to interpret hunting and husbandry strategies. Two examples of this can be found in studies undertaken by Erich Pucher (Pucher 2004; Pucher & Engl 1997). At two Austrian sites, Middle Neolithic Melk-Winden and the Late Neolithic lake dwelling in Mondsee, he noted a clear preponderance of cows. At the second of these two sites he also found that most of the cows were slaughtered as young adults suggesting that milk production was not important in the Late Neolithic. Animal size too is an important variable that the zooarchaeologist needs to consider, but sex and size may be difficult to disentangle in the often very fragmentary archaeological remains of animals. Chronological changes in the average size of animals are also interesting and in a lineage of domestic livestock it is generally assumed that an increase in size reflects animal improvement. Size increases occurred in cattle for example in many parts of the Roman Empire and subsequently in Medieval/Post-Medieval times in various parts of Europe (see for example Matolsci 1970; Teichert 1984; Audoin-Rouzeau 1995; Albarella 1997a, b; Davis 1997; Peters 1998; Davis & Beckett 1999; Breuer *et al.* 2001; Forest & Rodet-Belarbi 2002; Schlumbaum *et al.* 2003; Davis 2008; Thomas *et al.* 2013). However, many mammals like cattle (goat, red and fallow deer are other well-known examples) exhibit considerable sexual dimorphism with males being larger than females. This means that an average size difference between two samples may simply be due to their different sexual composition. One sample with more males will be larger than another with more females. The importance of this in zooarchaeology was emphasized by Zeder (2001) and Weinstock (2006).

In these strongly sexually dimorphic mammals the differences in certain parts of some bones can be great enough to enable a metrical separation of the sexes. This seems to be particularly the case in bones of the forelimb that have to support heavy appendages such as horns and antlers in males. Hence one can estimate the sex ratio within a sample. According to Telldahl *et al.* (2012), *"Metacarpals exhibit a more marked dimorphism between the sexes than metatarsals".* Some time ago, Higham (1969) showed how measurements like the width of the cattle metacarpal are very sexually dimorphic and he was able to obtain almost complete separation between metacarpals of cows and steers. As Guintard & Borvon (2009) emphasize, within a population there generally exists what they term "biological continuity" between the measurements of males and those of females and it is rare, even in large samples, to find complete separation of sexes when their measurements are plotted as a scatter diagram. Studies of cattle metacarpals by Guintard and his colleagues (see for example Guintard 1998; Guintard & Borvon 2009), have greatly improved our understanding of the relation between shape, sex and breed. Male metacarpals tend to be more robust than those of females as do those of meat breeds like the Charolais compared to milk breeds. Unfortunately many, often most, metacarpals found on archaeological sites are fragmented and it can be difficult to estimate the slenderness or robustness of the metacarpal when one only has its distal part. Molecular geneticists are now helping, and using molecular techniques, the sex of ancient cattle remains can be identified with genetic markers (SVENSSON *et al.* 2008; SVENSSON *et al*. 2008; TELLDAHL *et al*. 2012). These studies also show that the genetic results for sexing match those inferred from the measurements. Use of similar genetic methods (described below) revealed the sex of 21 metacarpals from 15th century Beja in southern Portugal (DAVIS *et al*. 2012).

In 2012 and 2013 Ana CAESSA and Nuno MOTA of the Lisbon Centre for Archaeology (CAL), excavated 71 out of an estimated total of 136 silos in the Largo do Coreto (bandstand square), Carnide, Lisbon. They contained late 16th and early 17th century domestic waste – and much table and kitchen ware. Carnide, is now a suburb of Lisbon, some 7 kms from its centre, but 300 years ago it was a village that supplied Lisbon with garden and agricultural produce (CAESSA & MOTA 2013). The large collection of faunal remains they uncovered included 47 complete and 44 distal metacarpals of cattle. Nearly all belonged to different animals and they provide an opportunity to make detailed osteometrical studies. Ancient DNA analyses of the Carnide metacarpals are currently underway and so it is hoped we shall be able to improve our ability to sex these bones.

Our aims are to a) determine the sex of the 47 complete metacarpals from Carnide by comparing them to the ancient DNA sexed bones from 15th century Beja, Portugal (DAVIS *et al*. 2012); Degerbøl's early Holocene aurochsen of known sex (he studied whole skeletons that could be sexed by the size/form of their horns) from Denmark (DEGERBØL & FREDSKILD 1970) and the modern Portuguese Barrosã reference metacarpals from our herds (kept by one of us; AS), b) try and discern changes over time and c) use these 47 specimens as a "sexed reference sample" to discover, as we tried to do several years ago (DAVIS *et al*. 2012), which measurements taken on the distal metacarpal could prove most useful to sex isolated distal fragments.

## Material and methods

The 47 complete metacarpals and the 44 distal metacarpals studied here (Table 1) are being studied by CD and SJMD and form part of a long term investigation of livestock in Portugal from late Pleistocene to modern times.

A slowly growing collection of Barrosã skeletons comes from the herds kept by one of us (AS) at Freixo do Meio, Montemor-o-Novo, Alentejo and at Cruzetinhas, Parreira, Chamusca, Ribatejo. This collection now comprises skeletons of seven cows and a single bull. The Barrosã breed originates from the Minho in the far north-west of Portugal, and was originally a generalist animal used for both meat and milk as well as its power. It is famous for its meat (GOUVEIA *et al*. 2001) and is one of 14 native breeds of Portuguese cattle. The ones reared by AS (the source of the eight skeletons in the LARC collection) are primarily meat animals.

Measurements were taken with vernier callipers to the nearest tenth of a millimetre following the recommendations in von den Driesch (1976) and Davis (1996). These include the measurements, mostly of the distal end, commonly taken by zooarchaeologists such as the widths and depths of the condyles, distal width and, where possible, the shaft width and total length of the bone. The manner in which measurements were taken is also shown in the sketches inserted in each figure. Measurements, in tenths of a millimetre, of the Carnide and Barrosã metacarpals are provided in Tables 1 and 2.

Besides the eight modern Barrosãs of known sex, 21 of the 44 15$^{th}$ century Beja metacarpals had been sexed as part of a previous study (Davis *et al*. 2012). We therefore now have two sexed reference collections with which to compare (as well as the Danish aurochsen). The molecular sexing is based on a single nucleotide polymorphism distinguishing between males and females; the SNP is located in the two homologous genes ZFX and ZFY, on the X and Y chromosome respectively (Aasen & Medrano 1990). Thus it is possible to differentiate between males and females. In position 243 both males and females have a Thymine (T) on the ZFX gene, but males carry a Cytosoine (C) instead of a T on ZFY (Werner *et al*. 2004). The use of a SNP for sex identification is especially suitable for ancient DNA since only a short fragment needs to be analyzed, as fragment size is correlated to success rate in work with ancient DNA (Malmström *et al.* 2007). Pyrosequencing was used to genotype the Beja cattle for this position and the sex for each individual was confirmed by several independent genotypings (Davis *et al*. 2012).

## Results and discussion

### Cows *versus* bulls

Figure 1 (modified from fig. 12 of Davis 2008) is a stacked histogram which includes a plot of the distal widths (BFd) of the Carnide metacarpals (both the complete and the distal fragments; several were too damaged to be included) and the modern Barrosã specimens alongside previously published ones (Davis 2008; Davis *et al*. 2012) from Moslem Alcáçova de Santarém and Silves (Algarve) and 15$^{th}$ century AD Beja – 21 of these having been sexed via molecular genetics as described above. As can be seen in Fig. 1 just above the Beja sample – they comprised 13 males (6 complete and 7 distal parts) and 8 females (4 complete and 4 distal parts). Our reason for being interested in the sex of the Beja specimens was quite simply that we wanted to be able to demonstrate that the average size increase of cattle between Moslem and Christian times in southern Portugal was a real increase in size and not one due to a change in the sex ratio. In other words both females and males increased in size. Prior to obtaining the results of the genetic studies it was suspected that the two peaks at both Santarém and Beja represented the two sexes – the small ones the cows and the large ones the bulls/

Table 1. Measurements in tenths of a millimetre of the cattle metacarpals from 17th century Carnide, Lisbon. All metacarpals had fused distal epiphyses and therefore belonged to adult animals. They are ordered in ascending distal width. Key: ID – ‘access’ identification number; Crate – container number; Bag – bag number; UE – stratigraphic unit; GL, Bp, BFd, Dd and SD are measurements according to VON DEN DRIESCH (1978); WCM, DEM, WCL and DEL are measurements according to DAVIS (1996); Side – side of the animal (generally only for complete bones); Sex-inferred – the sex of the animal as inferred from the scatter diagram (Figure 4) of GL vs (4.7 x BFd) – GL. Metacarpals with ‘asymmetry’ in the ‘notes’ column are cases where one condyle is significantly wider than the other and may represent a stress induced arthropathy. Two metacarpals have small notches indented in the shaft and were presumably used as anvils for serrating scythes.

| ID | Crate | Bag | UE | GL | Bp | BFd | Dd | WCM | DEM | WCL | DEL | SD | notes | Side | Sex-inferred |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 35 | 40 | 9 | 24234 | – | – | – | – | 318 | 265 | – | – | 363 | – | R | – |
| 267 | 37 | 18 | 2453 | – | – | – | 333 | 294 | 244 | – | 269 | – | – | – | – |
| 283 | 35 | 12 | 2466 | – | – | – | 351 | – | – | 336 | 254 | – | – | – | – |
| 353 | 47 | 4 | 24255 | – | – | – | – | – | – | 287 | – | – | – | – | – |
| 97 | 29 | 5 | 1529 | 2035 | – | – | – | – | – | – | 237 | 326 | GL = approx | – | – |
| 184 | 10 | 4 | 2823 | – | – | – | – | – | – | 315 | 226 | – | WCL = approx | R | – |
| 204 | 18 | 3 | 2410 | 1873 | 491 | 527 | 286 | 255 | 215 | 250 | 201 | 285 | – | L | F |
| 189 | 10 | 13 | 2467 | – | – | 533 | 288 | 249 | 224 | 257 | 213 | – | – | R | – |
| 44 | 31 | 5 | 2833 | 1666 | 503 | 535 | – | 266 | 217 | 259 | 203 | 285 | – | R | F? |
| 94 | 36 | 16 | 2458 | 1920 | 523 | 539 | 292 | 260 | 214 | 249 | 203 | 283 | – | R | F |
| 5 | 51 | 4 | 4234 | 1966 | 524 | 552 | 296 | 263 | 221 | 257 | 210 | 304 | – | L | F |
| 119 | 22 | 7 | 2875 | 1783 | 502 | 552 | 284 | 266 | 216 | 263 | 199 | 291 | – | R | F |
| 190 | 10 | 11 | 2465 | – | – | 574 | 304 | 281 | 241 | 270 | 225 | – | Dd = approx | – | – |
| 103 | 26 | 10 | 2853 | 1843 | 562 | 575 | 317 | 278 | 241 | 265 | 223 | 308 | – | R | F |
| 138 | 25 | 10 | 24005 | 1869 | 538 | 576 | 316 | 282 | 246 | 265 | 230 | 337 | – | R | F |
| 68 | 38 | 12 | 2497 | 1963 | 578 | 579 | 313 | 276 | 246 | 277 | 225 | 303 | – | L | F |
| 101 | 26 | 5 | 24003 | 2005 | 556 | 579 | 313 | 286 | 243 | 270 | 228 | 326 | – | R | F |
| 90 | 36 | 6 | 2427 | – | – | 580 | 303 | 280 | 227 | 277 | 221 | – | Dd & WCL = approx | R | – |
| 64 | 30 | 14 | 2829 | 2049 | 558 | 581 | 319 | 281 | 244 | 269 | 224 | 317 | – | R | F |
| 80 | 37 | 15 | 2497 | 1945 | 568 | 581 | 320 | 287 | 242 | 269 | 226 | 331 | – | R | F |
| 125 | 23 | 4 | 2873 | 2032 | 596 | 583 | 318 | 289 | 248 | 270 | 233 | 339 | – | R | F |
| 27 | 49 | 10 | 4248 | – | – | 589 | 317 | 279 | 243 | 275 | 230 | – | – | R | – |
| 41 | 40 | 3 | 2818 | 1943 | 598 | 593 | 328 | 290 | 247 | 279 | 235 | 338 | – | R | F |
| 30 | 47 | 1 | 24256 | – | – | 593 | 321 | 287 | 246 | 283 | 224 | – | ?Anvil | – | – |
| 31 | 42 | 12 | 24247 | – | – | 597 | 319 | 282 | 239 | 284 | 229 | – | – | R | – |
| 172 | 2 | 10 | 24003 | – | – | 598 | 311 | 291 | 244 | 283 | 226 | – | – | R | – |
| 162 | 2 | 5 | 24003 | 2087 | 581 | 599 | 332 | 288 | 257 | 284 | 245 | 341 | 162 & 163 from same animal? | L | F |
| 95 | 30 | 1 | 2855 | 2058 | – | 599 | 319 | 286 | 242 | 280 | 227 | 349 | SD = approx | – | F |
| 255 | 4 | 6 | 2497 | 2037 | 585 | 599 | 312 | 293 | 238 | 276 | 222 | 332 | Slight asymmetry | R | F |
| 163 | 2 | 5 | 24003 | 2095 | 586 | 600 | 340 | 284 | 259 | 281 | 245 | 330 | 162 & 163 from same animal? | R | F |
| 79 | 29 | 6 | 1529 | 2063 | 585 | 604 | 328 | 290 | 247 | 282 | 232 | 319 | – | R | F |
| 175 | 3 | 7 | 2461 | – | – | 605 | 323 | 289 | 247 | 284 | 230 | – | – | – | – |

Table 1. Continued.

| ID | Crate | Bag | UE | GL | Bp | BFd | Dd | WCM | DEM | WCL | DEL | SD | notes | Side | Sex-inferred |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 193 | 11 | 17 | 2497 | 2042 | 585 | 606 | 327 | 292 | 246 | 290 | 231 | 312 | – | L | F |
| 182 | 9 | 7 | 24010 | – | – | 607 | 319 | 294 | 238 | 283 | 222 | – | – | R | – |
| 203 | 18 | 6 | 2869 | – | – | 607 | 324 | 285 | 242 | 288 | 223 | – | – | R | – |
| 181 | 9 | 10 | 4112 | 2004 | 575 | 608 | 319 | 288 | 239 | 286 | 231 | 363 | – | R | F |
| 198 | 14 | 5 | 24009 | – | – | 609 | 301 | 291 | 236 | 289 | 222 | – | Dd = approx | – | – |
| 183 | 9 | 7 | 24010 | – | – | 615 | 314 | 299 | 235 | 285 | 221 | – | – | – | – |
| 256 | 7 | 18 | 2438 | 1825 | 554 | 616 | – | 283 | 229 | 310 | 213 | 333 | Slight asym.; DEM = approx | L | M |
| 96 | 29 | 5 | 1529 | 1852 | 583 | 622 | 310 | 294 | – | 315 | 231 | 329 | DEM = 24–25 Asymmetric | L | M |
| 61 | 32 | 7 | 2855 | 2087 | 589 | 624 | 329 | 298 | 256 | 300 | 242 | 331 | – | L | F |
| 91 | 37 | 10 | 1529 | – | – | 624 | 345 | 289 | 245 | 306 | 262 | 359 | – | R | – |
| 144 | 1 | 12 | 2418 | – | – | 625 | 305 | 297 | 239 | 300 | 220 | – | – | R | – |
| 43 | 34 | 6 | 4107 | 1885 | 603 | 625 | 308 | 299 | 237 | 302 | 224 | 370 | Same animal as 42? | L | M |
| 42 | 34 | 6 | 4107 | – | – | 626 | 312 | 300 | 240 | 301 | 223 | – | Same animal as 43? | R | – |
| 201 | 17 | 7 | 2449 | – | – | 629 | 318 | 303 | 245 | 301 | 232 | – | BFd = approx | – | – |
| 92 | 47 | 5 | 24247 | – | – | 640 | 327 | 308 | 254 | 306 | 238 | – | – | – | – |
| 249 | 21 | 17 | 2801 | 1887 | 626 | 641 | 328 | 316 | 249 | 296 | 227 | 346 | – | R | M |
| 93 | 37 | 5 | 2410 | – | – | 648 | 330 | 310 | 260 | 302 | 243 | – | – | – | – |
| 109 | 27 | 3 | 2874 | 1945 | 620 | 648 | 336 | 317 | 255 | 299 | 237 | 376 | ? Male | L | M |
| 112 | 28 | 6 | 2465 | 1900 | 615 | 651 | 318 | 312 | 254 | 312 | 236 | 376 | GL & Dd = approx | L | M |
| 20 | 53 | 2 | 2857 | – | – | 652 | 318 | 308 | 220 | 316 | 240 | – | – | R | – |
| 251 | 20 | 6 | 2801 | 1954 | 605 | 652 | 336 | 319 | 254 | 304 | 234 | 345 | SD = approx | R | M |
| 208 | 21 | 2 | 2839 | 1982 | 613 | 656 | 332 | 310 | 258 | 313 | 244 | 351 | Slightly asymmetric | L | M |
| 123 | 23 | 3 | 2875 | 2053 | 640 | 661 | 337 | 322 | 258 | 311 | 239 | 388 | – | L | M |
| 171 | 3 | 13 | 2426 | – | – | 665 | 318 | 314 | 253 | 316 | 240 | – | – | R | – |
| 37 | 29 | 11 | 2857 | – | – | 671 | 332 | 317 | 249 | 321 | 236 | – | ?Asymmetric | R | – |
| 266 | 38 | 2 | 2438 | – | – | 671 | 335 | 332 | 261 | 315 | 251 | – | BFd & WCM = approx | – | – |
| 186 | 8 | 12 | 2435 | – | – | 672 | 339 | 332 | 256 | 324 | 242 | – | ?Asymmetric | – | – |
| 192 | 11 | 17 | 2497 | 2054 | 634 | 673 | 341 | 327 | 266 | 311 | 254 | 364 | – | R | M |
| 113 | 28 | 6 | 2465 | 2062 | 637 | 674 | 339 | 329 | 265 | 312 | 253 | 388 | – | R | M |
| 32 | 42 | 12 | 24247 | – | – | 674 | 328 | 328 | 273 | 323 | 234 | – | Asymmetric | R | – |
| 202 | 18 | 6 | 2869 | 1996 | 657 | 674 | 340 | 322 | 268 | 318 | 250 | 384 | side uncertain | L | M |
| 263 | 39 | 21 | 2438 | – | – | 678 | – | – | – | – | – | – | – | – | – |
| 38 | 29 | 11 | 2857 | – | – | 679 | 347 | 324 | 253 | 333 | 266 | – | – | R | – |
| 60 | 48 | 5 | 24265 | 2119 | 664 | 681 | 354 | 332 | 277 | 314 | 261 | 399 | – | R | M |
| 26 | 51 | 3 | 4250 | – | – | 683 | – | – | – | – | – | – | BFd = approx | R | – |
| 252 | 21 | 1 | 2491 | – | – | 684 | 332 | 343 | 258 | 320 | 245 | – | Asymmetric; Dd = approx | – | – |
| 142 | 25 | 6 | 24005 | – | – | 686 | 341 | 331 | 259 | 333 | 246 | 388 | SD = approx | R | – |
| 170 | 1 | 14 | 24005 | 2027 | 666 | 688 | 359 | 332 | 285 | 321 | 265 | 394 | – | L | M |
| 116 | 28 | 3 | 2831 | – | – | 689 | 337 | 326 | 266 | 339 | 262 | – | – | R | – |
| 84 | 35 | 9 | 24247 | 1993 | 643 | 695 | – | 347 | 260 | 315 | 229 | 362 | WTM & WTL = approx ? Male | R | M |

Table 1. Continued.

| ID | Crate | Bag | UE | GL | Bp | BFd | Dd | WCM | DEM | WCL | DEL | SD | notes | Side | Sex-inferred |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 77 | 30 | 11 | 1520 | 2030 | 660 | 699 | 351 | 353 | 274 | 332 | 249 | 381 | ? Male | R | M |
| 21 | 53 | 2 | 2857 | – | – | 700 | – | 364 | – | 315 | – | – | WCM = approx | R | – |
| 205 | 18 | 3 | 2410 | – | – | 701 | 338 | 344 | 268 | 329 | 254 | – | Asymmetric | R | – |
| 83 | 35 | 9 | 24247 | 2073 | 691 | 702 | 365 | 328 | 276 | 335 | 255 | 387 | ? Male! | L | M |
| 36 | 49 | 8 | 4209 | – | – | 706 | 359 | 346 | 279 | 336 | 257 | – | – | R | – |
| 82 | 35 | 9 | 24247 | 2028 | 684 | 710 | 350 | 341 | 273 | 335 | 260 | 410 | ? Male! | L | M |
| 104 | 26 | 10 | 2853 | – | – | 711 | 361 | 338 | 273 | 348 | 285 | – | Anvil | – | – |
| 110 | 15 | 4 | 24017 | – | – | 712 | 357 | 343 | 278 | 330 | 264 | – | – | – | – |
| 139 | 25 | 7 | 24003 | 2014 | 651 | 713 | 355 | 350 | 283 | 347 | 261 | 384 | – | R | M |
| 195 | 11 | 12 | 2499 | 2111 | 694 | 718 | 347 | 346 | 276 | 330 | 263 | 399 | – | R | M |
| 250 | 21 | 17 | 2801 | – | – | 718 | 350 | 341 | 283 | 336 | 270 | – | – | R | – |
| 2 | 5 | 8 | 2465 | 2075 | 707 | 719 | 366 | 349 | 281 | 339 | 259 | 382 | – | R | M |
| 107 | 27 | 4 | 2874 | – | – | 721 | 360 | 351 | 281 | 340 | 262 | – | – | – | – |
| 191 | 11 | 17 | 2497 | – | – | 724 | 368 | 344 | 289 | 352 | 269 | – | – | R | – |
| 111 | 28 | 6 | 2465 | 2053 | – | 726 | 375 | 350 | 281 | 349 | 259 | 413 | GL = approx | R | M |
| 63 | 52 | 5 | 1318 | 2106 | 643 | 732 | 353 | 353 | 273 | 364 | 259 | 409 | Slight asymmetry | R | M |
| 81 | 35 | 9 | 24247 | 2132 | 718 | 735 | 384 | 356 | 287 | 345 | 262 | 394 | ? Male! | L | M |
| 259 | 7 | 17 | 2438 | – | – | 742 | 362 | 355 | 286 | 359 | 274 | – | ?Asymmetric; Dd = approx | – | – |
| 209 | 21 | 3 | 2833 | 1975 | 665 | 746 | 368 | 382 | 308 | 324 | 271 | 382 | – | L | M |
| 40 | 31 | 3 | 2835 | – | – | 754 | 382 | 372 | 306 | 346 | 294 | – | – | R | – |
| 260 | 4 | 29 | 2410 | – | – | 757 | – | 365 | 280 | 359 | 256 | – | Asymmetric; DEM = approx | – | – |
| 405 | 6 | 16 | 1529 | – | – | 757 | 380 | 367 | 280 | 375 | 260 | – | Distal end very splayed | R | – |
| 24 | 50 | 1 | 24021 | – | – | 758 | – | 384 | 278 | 347 | 254 | – | Asymmetric WTM = approx | R | – |
| 22 | 47 | 12 | 24263 | – | – | 791 | – | 391 | 279 | 382 | 256 | – | – | R | – |

Table 2. Measurements in tenths of a millimetre of the modern Barrosã cattle metacarpals from Freixo do Meio herds in the Alentejo and Ribatejo now in the Laboratório de Arqueociências (LARC) reference collection. They all belonged to adult animals and have fully fused distal epiphyses. Key: Cat Nº – LARC accession number; GL, Bp, BFd, Dd and SD are measurements taken according to VON DEN DRIESCH (1978); WCM, DEM, WCL and DEL are measurements taken according to DAVIS (1996).

| Cat Nº | GL | Bp | BFd | Dd | WCM | DEM | WCL | DEL | SD | Sex |
|---|---|---|---|---|---|---|---|---|---|---|
| 2300 | 1799 | 536 | 575 | 298 | 274 | 219 | 267 | 200 | 334 | f |
| 2491 | 1916 | 543 | 597 | 303 | 293 | 231 | 278 | 216 | 309 | f |
| 2638 | 1935 | 595 | 626 | 330 | 300 | 246 | 300 | 228 | 351 | f |
| 2701 | 1926 | 557 | 571 | 318 | 278 | 240 | 264 | 220 | 297 | f |
| 2702 | 1957 | 610 | 618 | 338 | 294 | 252 | 277 | 243 | 356 | f |
| 2725 | 2023 | 602 | 623 | 332 | 289 | 246 | 289 | 229 | 371 | f |
| 2726 | 2064 | 616 | 647 | 329 | 306 | 244 | 295 | 237 | 378 | f |
| 2730 | 2047 | 706 | 727 | 370 | 354 | 283 | 334 | 271 | 450 | m |

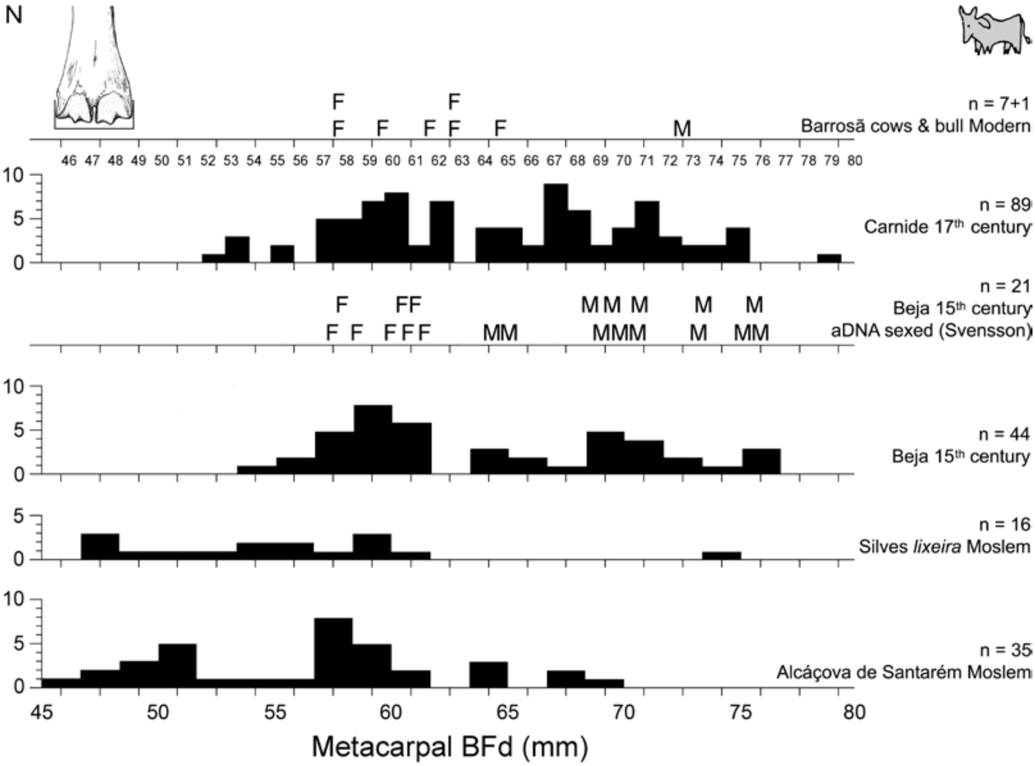


Fig. 1. Variation of cattle size in southern Portugal in Moslem and Christian periods as represented by metacarpal distal widths (BFd) from Alcáçova de Santarém, Silves *lixeira* (rubbish pit), the 15th century Beja silos and the 17th century Carnide silos. These stacked histograms are adapted from fig. 12 in Davis (2008). "n" refers to sample size. Note that the larger samples from Moslem Santarém and 15th century Beja show a bimodal distribution of their widths, which, it was presumed, represent the two sexes. For Beja, this presumption was corroborated by aDNA sexing results for 21 of the 44 metacarpals shown above (see Davis *et al.* 2012), M being male and F female. On the top axis are the 7 Barrosã cows (F) and single Barrosã bull (M). It was concluded that the bimodality at both Beja and Santarém reflects the differences in widths of metacarpals between the sexes and therefore the size increase of cattle between Moslem and Christian periods was a real one and not one due to a change of the sex-ratios over time. Note also the apparent wider spread of the male plots. Perhaps some were work animals with splayed distal ends.

oxen. It was therefore gratifying to see that indeed the genetics appeared to corroborate the osteometrically based hypothesis (in Davis 2008). We were therefore able to confirm that the Christians in Portugal improved the local cattle or perhaps even introduced new breeding stock. The similarity between the BFd plots for 15th century Beja and that now obtained for 17th century Carnide is also interesting and furthermore confirms our suggestion that cattle in Christian Portugal were indeed larger and presumably improved. The next task was therefore to further study the data – given our much larger sample of metacarpals, especially complete ones – to obtain an even clearer separation of the sexes.

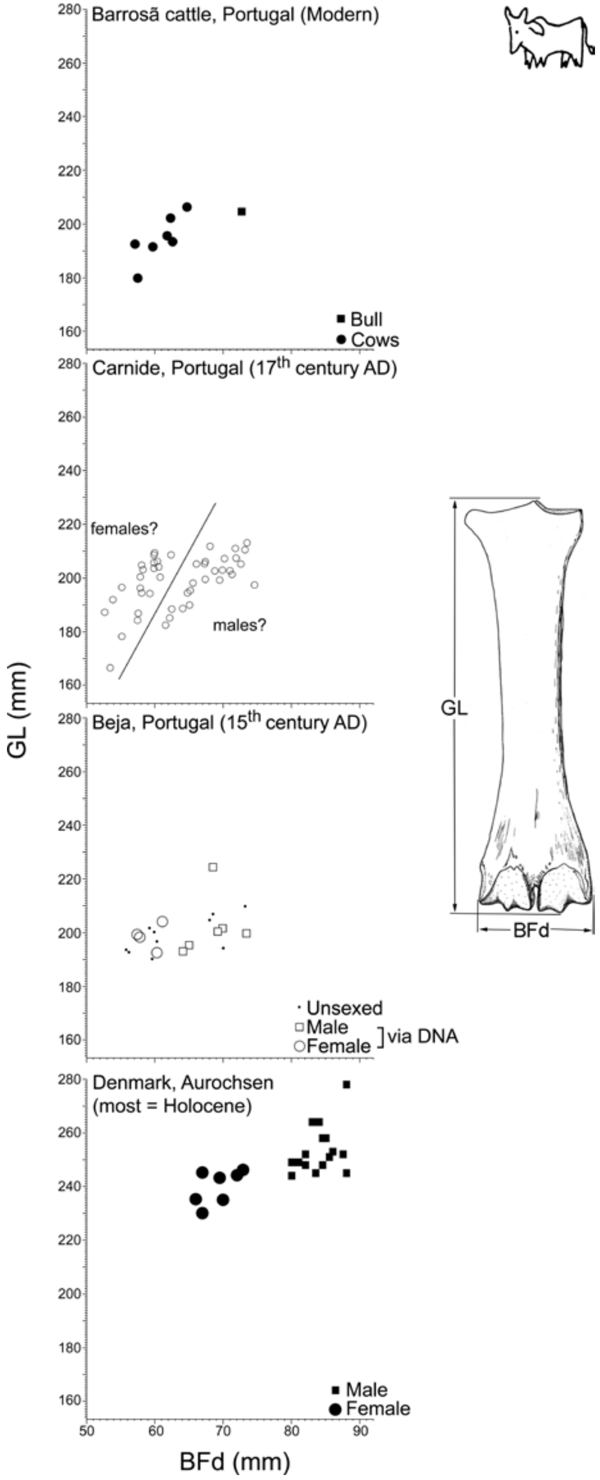


Fig. 2. Scatter plots of aurochs and cattle metacarpal greatest length (GL) against distal width (BFd). From bottom to top: the measurements from the early Holocene of Denmark (DEGERBØL & FREDSKILD 1970); the aDNA sexed and unsexed ones from Beja (from DAVIS *et al.* 2012); the Carnide metacarpals; the seven modern Barrosã cows and single modern Barrosã bull. Given the distribution of males and females from Denmark, Beja and the modern Barrosãs, it seems most likely that the two apparently separated clouds of points at Carnide are the females (to the left) and males (to the right).

Figure 2 represents such an attempt where we try to "pull apart" the BFd measurements for the complete metacarpals at Carnide by plotting this measurement against the total length of the bone (GL). Note the line that separates the two groups at Carnide. Comparing these with the aDNA sexed Beja metacarpals and the Danish aurochsen (Degerbøl & Fredskild 1970) reinforces the idea that the specimens to the left of the line at Carnide probably belonged to females and the ones to the right probably belonged to males. This sexual division is confirmed by the 7 cows and single bull from our collection of modern Barrosã cattle.

Figures 1 and 2 are simple plots of bone size – width and length. Indexes can sometimes offer a means to separate biological samples into taxon and sex for example. One example is shown in Fig. 3 which considers the shaft width (SD) in relation to length and the distal width also in relation to length, *i. e.*, the overall shape of the bone. For the sample from Carnide a line has been drawn that may separate the "sexes" as inferred from the previous figure (*i. e.*, the plot of GL *vs.* BFd). There is admittedly a degree of circular reasoning here, which depends whether or not the gap in Fig. 2 correctly separates the sexes. To highlight the need for caution, we have added a "?". This composite graph indicates two interesting tendencies. The first is that the 15th century cattle from Beja and the 17th century cattle from Carnide appear to have rather similar distributions of shape with the line dividing the sexes remaining very approximately in the same position. The Danish aurochsen seem to lie a little to the left. One might deduce that while size has changed in the course of time – aurochsen were considerably larger than domestic cattle – it is possible that the distal ends of aurochsen metacarpals were slightly less splayed. Splaying of the distal ends of this bone could reflect heavy workloads/stress in life and aurochsen, being wild, were not work animals by definition! It is also quite likely that many, perhaps most, of the males at Carnide were castrates used for work purposes. It is also difficult to understand why the farmers there would have kept (or even been able to keep given their potential aggressiveness) so many bulls (*i. e.*, entire males). Perhaps they were fighting bulls. The small sample of Barrosã cattle indicates that both cows and the single bull have shifted upwards and to the right. In other words both their metacarpal shaft widths and distal widths are greater relative to their lengths. The Barrosã from AS' herds are animals selected for increased meat yield presumably resulting in a broader-boned skeleton. Guintard (1994) shows in his figure 1 the clear exaggerated breadth in the metacarpals of the Charolais – *"une race de boucherie excellente"* (Diffloth 1909: p. 298). When selection specifically for higher meat yield and presumably power too, occurred in northern Portugal remains unknown since we have yet to study archaeological remains of cattle from northern Portugal. If both the 17th century Carnide sample and the modern Barrosãs are representative of the general conformation of cattle several centuries ago and today then one could speculate that selection for such "specialist" meat breeds is a rather recent occurrence. One could also speculate that until the very recent past cattle were more "generalist" animals valued not only for their meat and hides, but also for their milk and power.

While the simple scatter of plots of metacarpal length (GL) versus distal width (BFd) in Fig. 2 does, at least at Carnide and in the Danish aurochsen, show two reasonably clearly

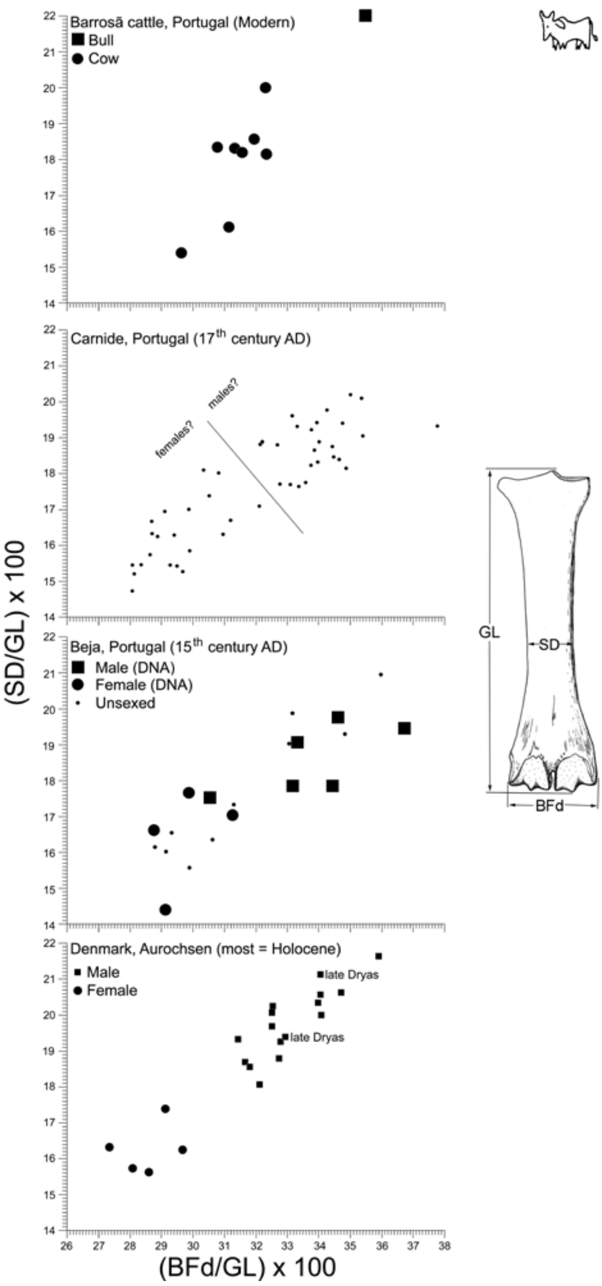


Fig. 3. Scatter plots of the four samples in Fig. 2 but here two indexes are plotted. The "y" axis is the minimum shaft width (SD) divided by GL and the "x" axis is BFd divided by GL. Again, the sexes of aurochsen and modern Barrosãs separate. At Beja a male specimen falls among the females and may have belonged to a castrate; it has a very long shaft. The Carnide metacarpals may separate into two clouds – presumed females on the lower left and presumed males on the upper right. Confirmation of their sexual identity awaits genetical analyses. Note an apparent shift to the right of the dividing line between sexes over time. This may reflect increased splaying of these bones, perhaps due to increased weight of the animals and/or increasing use of cattle for their power.

separated clouds of dispersion which probably represent the sexes, can we produce a plot that is easier to interpret? For the "x" axis, John WATSON (personal communication) has pointed out that by multiplying BFd by 4.7 and then subtracting the result from GL the line dividing males from females becomes vertical (Fig. 4). The aDNA sexed specimens from

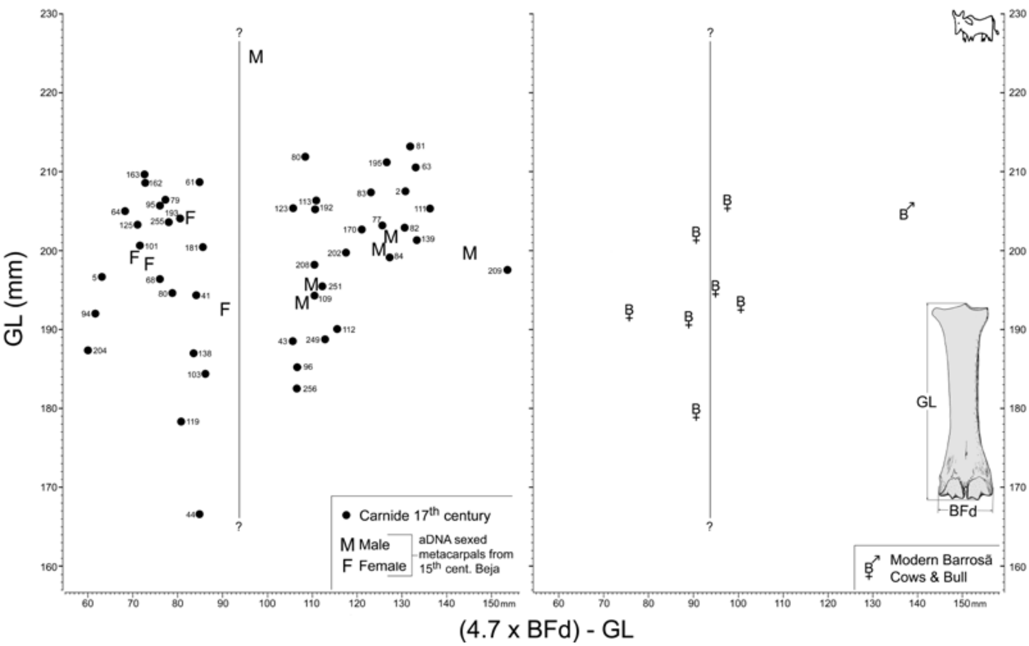


Fig. 4. A plot of GL against the value obtained by multiplying BFd by 4.7 and then subtracting the result from GL (WATSON pers. comm.). This has the effect of rotating the intersex dividing line (as in Fig. 3) so that it becomes vertical and has a value around 91 to 97mm. On the left graph are the Carnide metacarpals shown as dots and the 10 aDNA sexed ones from Beja (DAVIS *et al*. 2012). It is clear that the Carnide specimens form two distinct clouds – presumably the females on the left and the males on the right. On the right graph are the seven modern Barrosã cows and the single Barrosã bull. These have shifted to the right in comparison with the Carnide and Beja specimens – *i. e.*, they have wider values for BFd or are more splayed.

Beja (M and F) are also plotted on this graph and these indicate rather clearly that the left hand scatter shows the females and the right hand one the males. The seven modern Barrosã cows and single Barrosã bull are also plotted and are shown on the right side. These Barrosã cattle also show a left – right separation of the sexes although of interest is the apparent shift of both sexes to the right. In other words the modern Barrosã cattle have wider distal metacarpals as we have already observed in Figures 1 and 3. One could even go further and speculate that the cattle at Carnide and Beja were milk and/or all-purpose cattle. Did the Carnide cattle supply 17th century Lisbon with milk and dairy products? An answer to this question may come from studies in progress of their pattern of age-at-slaughter.

## Earlier cattle metacarpals from Portugal

Unfortunately complete cattle metacarpals are not very common in the earlier sites in Portugal. A plot of [(4.7 × BFd) − GL] against GL for the three main levels, Iron Age, Roman and Moslem at Santarém shown in Fig. 5, is unclear. Perhaps partly due to the

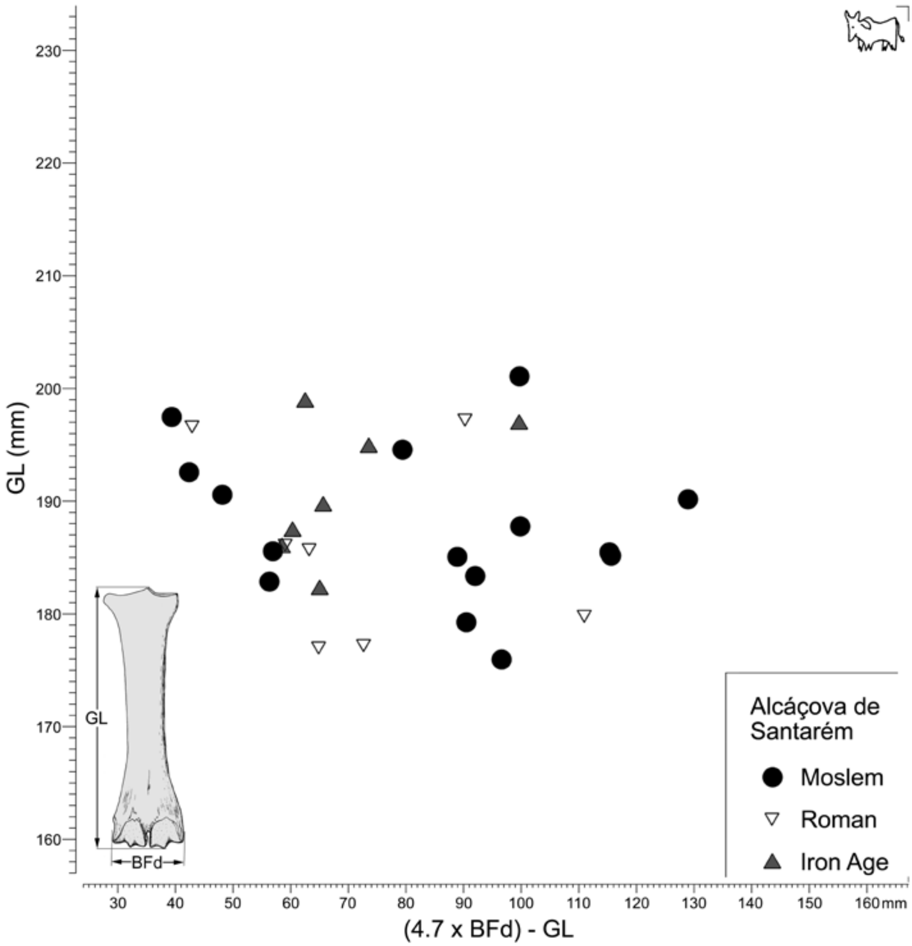


Fig. 5. The complete cattle metacarpals from Iron Age, Roman and Moslem period levels at Alcáçova de Santarém (DAVIS 2006) plotted in the same way as in Fig. 4. Here there is no very clear separation of sexes, but if we remove the two specimens in the centre – one Iron Age, the other Moslem period – it is possible that a vertical line crossing the x axis at approximately 75 to 85 mm may separate the sexes. If this is correct then these cattle were even less splayed than those from later times. Note also that the sex ratio of adult cattle may have changed between Roman and Moslem times with more males kept to maturity in the Moslem period.

smallness of these samples, there is no clear space separating presumed females from presumed males. However, it is possible that a line through the "x" axis at 75 mm separates most males from females. If we ignore a Moslem period and an Iron Age specimen which plot out in the centre, then there is a space between what may be females and males. A separating line between 90 and 95 as indicated in the plot for Carnide would clearly be too far to the right for these earlier periods and hence it is likely that cattle in those earlier times were less robust (or at least had narrower distal metacarpals). The shift to the right

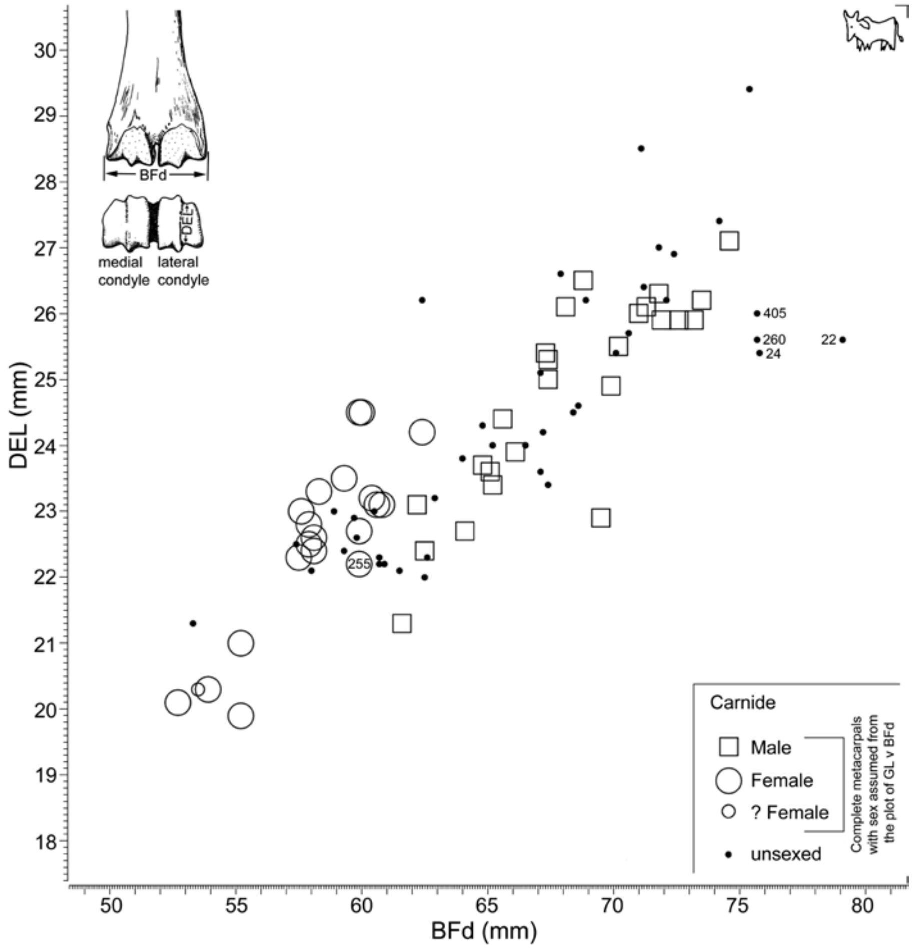


Fig. 6. An attempt to discover a metrical method to sex distal metacarpals – a plot of the depth of the lateral trochlea (DEL) versus BFd. Here the presumed male (squares) and female (circles) complete metacarpals from Carnide (see Figs 2 and 4), are shown with the distal fragments that cannot be assigned sex. The complete specimens seem to partially separate out and it is interesting that the females appear to have relatively greater values for DEL than the males.

in the course of time probably reflects selection of heavier cattle to supply heavier beeves and perhaps provide greater power. This may be a continuation of a trend we have already suggested by comparing Carnide and Beja with our modern Barrosã cattle (see above).

## Measurements of the distal ends – some speculations

If we assume that the plots in Figures 2, 3 and 4 correctly separate the females from the males among the 47 complete metacarpals from Carnide, we can use them as a "baseline" of sexed reference material to try and determine the sex of the rest of the

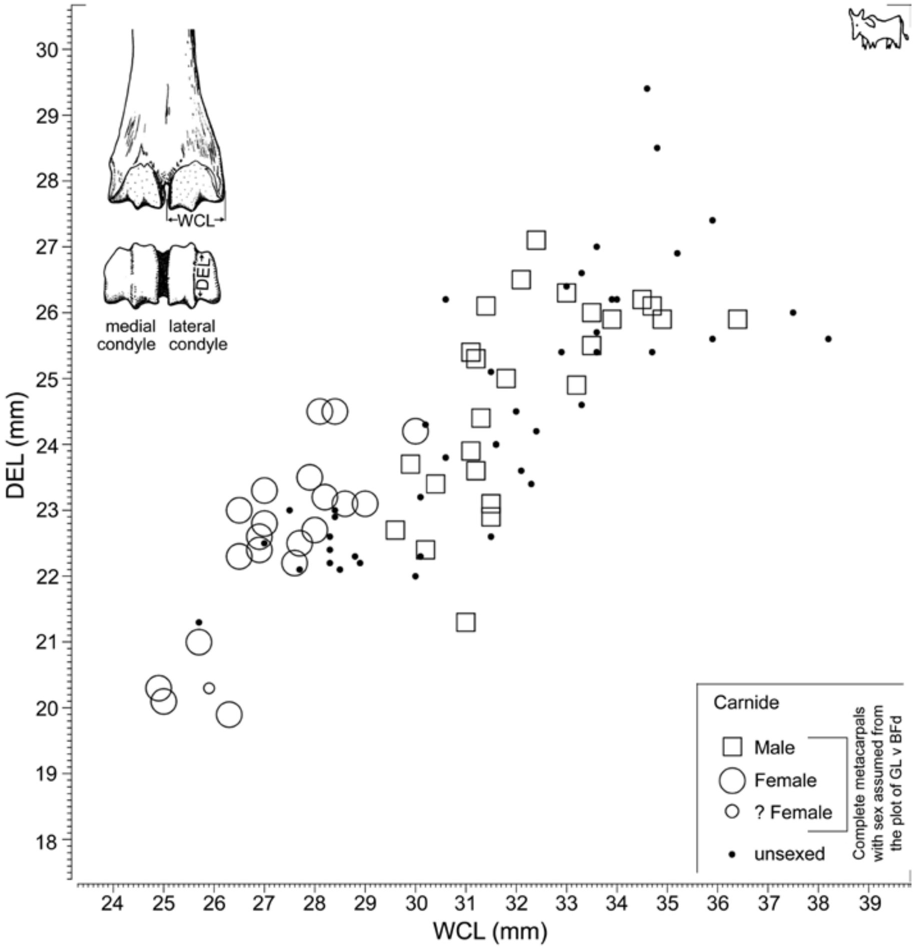


Fig. 7. An attempt to discover a metrical method to sex distal metacarpals – a plot of the depth of the lateral trochlea (DEL) versus the width of the lateral condyle (WCL). Here the presumed male (squares) and female (circles) complete metacarpals from Carnide (see Figs 2 and 4), are shown with the distal fragments that cannot be assigned sex. The complete specimens seem to partially separate out, but there is some overlap, especially of DEL. Note again that females show a tendency to have relatively larger DEL values.

metacarpals – the distal ends that lack their shafts and proximal ends. An ability to sex distal metacarpals would be very useful since archaeological metapodials are generally broken, and there are few large collections of well documented modern cattle skeletons from single breeds in museum collections. Several years ago we attempted to do just this but with a much smaller "baseline". Then we only had 21 aDNA sexed metacarpals, of which a mere 10 were complete. We did suggest (DAVIS *et al*. 2012) that perhaps the best separators of the sexes are BFd and WCL while WCM provides reasonable separation. SD, DEL and DEM also provided some separation but with overlap.

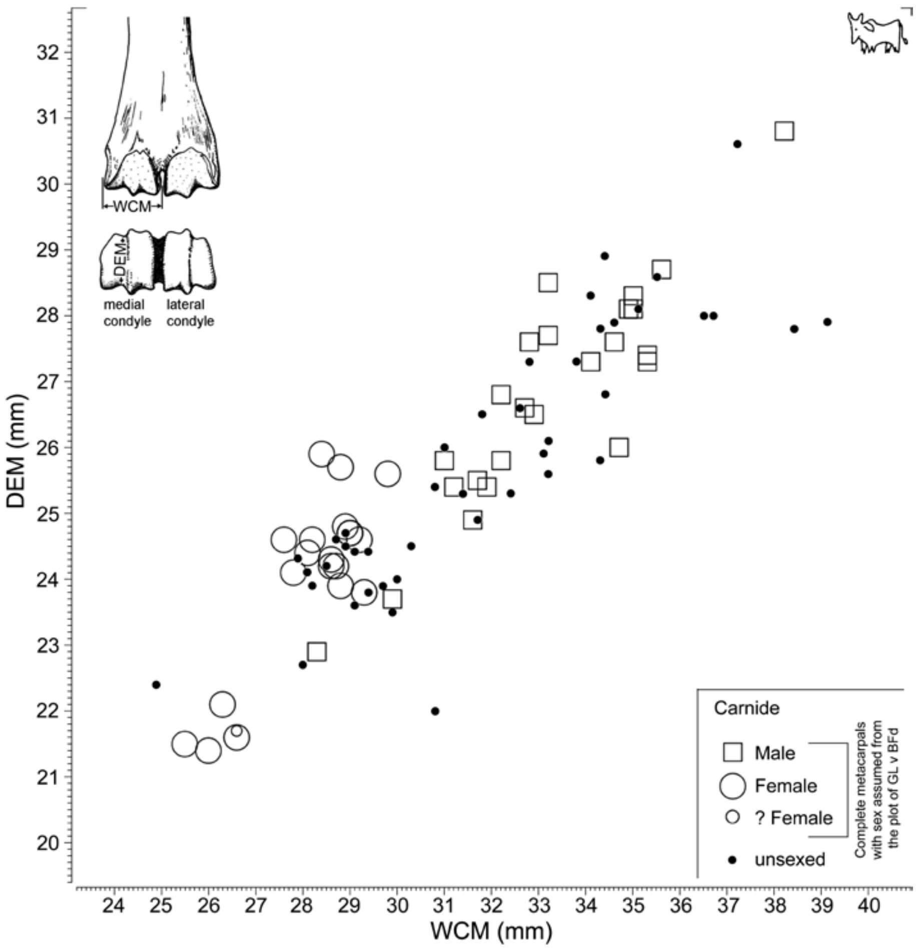


Fig. 8. An attempt to discover a metrical method to sex distal metacarpals – a plot of the depth of the medial trochlea (DEM) versus the width of the medial condyle (WCM). Here the presumed male (squares) and female (circles) complete metacarpals from Carnide (see Figs 2 and 4), are shown with the distal fragments that cannot be assigned sex. The complete specimens seem to partially separate out, but there is some overlap. Note especially the two presumed males that fall among the females.

Figures 6, 7 and 8 are scatter diagrams of some of these measurements. In these diagrams, the males and females (the complete metacarpals) were "sexed" on the basis of where they plot in Figures 2 and 4 and are shown as open squares and open circles respectively. The plots of the distal fragments, which of course cannot be sexed, are shown as small black dots. Our suggestions of 2012 seem to hold true with BFd and WCL certainly indicating almost complete separation of the sexes. The equivalent of WCL on the medial condyle, WCM, may hold promise but Fig. 8 shows two female-like "males". Again, both DEL and DEM seem to be far less useful.

Two factors that may confuse these plots are castration and stress induced changes:

a) Castration. Especially if performed early in the life of the males, castration delays epiphysial closure and results in longer limb bones (HOBDAY 1914; HIGHAM & MESSAGE 1969; SILBERBERG & SILBERBERG 1971) and early farmers were well acquainted with this practise (see for example, FITZHERBERT 1534/1882: p. 67). We suspected that one of the very long metacarpals at Beja (arrowed in some of the figures of DAVIS *et al.* 2012) may have been castrated. This specimen is also the one at the top of the Beja graph in Fig. 2 and the top of Fig. 4 (the longest "M"). We wonder if some of the longer metacarpals at Carnide like specimens 80, 81, 195 and 63 were steers. And as mentioned above, the probability that many, perhaps most of the male cattle at Carnide were castrates needs to be considered. Why keep so many bulls?

b) Stress. Stress in life can cause splaying of the distal ends of the metacarpals – the condyles become wider (BARTOSIEWICZ *et al*. 1997). Sometimes only one condyle is splayed causing assymetry of the distal end of the bones. Several of the Carnide metacarpals do indeed exhibit splaying and we wonder if, for example, some of the specimens on the far right of the figures belonged to work animals. The specimen on the far right of Fig. 3 has a WCM of 38.2 mm while WCL is only 32.4 mm. Of the four on the far right of Fig. 6 (Nºs 405, 260, 24, and 22) three were noted as having asymmetrical distal ends – *i. e.*, with one condyle considerably wider than the other. At least one of the probable female specimens (255) was noted to be slightly asymmetrical. This should not come as a surprise as OLIVEIRA MARQUES (1968) writes that the Quadrangular, or Chariot plough, which became widespread in 14$^{th}$ and 15$^{th}$ and especially 16$^{th}$ century Portugal, was pulled by oxen *or cows*. Further studies of the effects of stress on limb bones are needed. For example we need to know whether stress causes splaying of both condyles or just one. In order to induce changes does stress need to commence early in the animal's life or can these changes happen suddenly in later life?

## Sex ratios

We shall for the time being assume that the graphs plotted here separate the cows from the bulls/castrates. All metacarpals measured and plotted in these diagrams have fully fused epiphyses and so belonged to adult animals. Once fused, we cannot of course determine their age in any greater detail than "adult". Let us at least see what the sex ratio was for the adult cattle at Carnide and then try and discern any changes in this ratio over time in Portugal and how this might reflect the nature of the cattle economy or strategy for keeping cattle. Figures 2, 3 and 4 indicate that for the complete metacarpals there were 21 cows and 25 bulls/castrates. Figures 6, 7 and 8 which include the distal fragments also indicate a rather similar female:male ratio of approximately 39:50; 42:56 and 40:48. Farmers generally slaughter most males for meat and only keep a few for reproduction. Hence the adult females greatly outnumber the males – the pattern we may see (samples are small) in the Iron Age and Roman period at Alcáçova de Santarém (Fig. 5). But here in Carnide as well as perhaps the Moslem period at Alcáçova de Santarém, we have, if anything, the opposite with more adult males/oxen than cows! Carnide was and is not far from Lisbon. Are we seeing here animals slaughtered locally with the better "beeves" sent on foot into Lisbon for slaughter? Thus we need to understand why in both Moslem Santarém and 17th century Carnide we have more adult bulls/oxen than adult cows! There are many possible explanations. Put quite simply one could imagine that at both these places in Moslem and Christian times, the economy was geared more for the production of beef and power. Carnide was an agricultural region supplying Lisbon (Caessa & Mota 2013) and so perhaps many of the males had served locally for ploughing and were subsequently slaughtered when past their prime and consumed locally. But what became of the missing adult cows? Were these good milkers sent to Lisbon for local dairy production?

## Conclusions

The adult metacarpals from 17th century Carnide and 15th century Beja were of similar shape and size but were slightly larger and more robust than Iron Age to Moslem period Portuguese cattle.

These Iron Age to 17th century Portuguese cattle were slightly slenderer than our modern Barrosã animals. This difference may reflect selection for heavier carcasses – the Barrosã kept by one of us (AS) are essentially a meat herd.

The predominance of adult males over adult females at 17th century Carnide is difficult to understand in terms of slaughter strategy and the kind of economy that was practised there. Were these fighting bulls?

In order to separate the sexes via metacarpal measurements, the Carnide sample of 47 complete bones indicates a likely complete separation of sexes by plotting GL against BFd and an oblique dividing line can be drawn. And by plotting GL against [(4.7 × BFd) − GL] the dividing line becomes vertical. Other measurements such as SD, DEL, WCL and WCM may serve to partly separate the sexes.

The measurements of the Carnide cattle metacarpals should serve as a baseline for comparing remains of cattle metacarpals from other sites and other periods in the Iberian Peninsula. It is hoped to further these studies if and when the analyses of their ancient DNA succeed.

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## References

AASEN, E. & MEDRANO, J.F. (1990): Amplification of the ZFY and ZFX genes for sex identification in humans, cattle, sheep and goats. – Biotechnology (NY), **8**: 1279–1281.

ALBARELLA, U. (1997a): Size, power, wool and veal: zooarchaeological evidence for late medieval innovations. – In: DE BOE, G. & VERHAEGHE, F.: Environment and subsistence in Medieval Europe (I.A.P. Rapporten 9). – pp. 19–30, Zellik (Instituut voor het Archeologisch Patrimonium).

ALBARELLA, U. (1997b): Shape variation of cattle metapodials: age, sex or breed? Some examples from mediaeval and postmediaeval sites. – Anthropozoologica, **25–26**: 37–47.

AUDOIN-ROUZEAU, F. (1995): Compter et mesurer les os animaux. Pour une histoire de l'élevage et de l'alimentation en Europe de l'Antiquité aux Temps Modernes. – Histoire & Mesure, **10**: 277–312.

BARTOSIEWICZ, L., VAN NEER, W. & LENTACKER, A. (1997): Draught cattle: their osteological identification and history. – Annales du Musée Royal de l'Afrique Centrale, Sciences Zoologiques, **281**: 147 pp.

BREUER, G., REHAZEK, A. & STOPP, B. (2001): Veränderung der Körpergrösse von Haustieren aus Fundstellen der Nordschweiz von der Spätlatènezeit bis ins Frühmittelalter. – Jahresberichte aus Augst und Kaiseraugst, **22**: 161–178.

CAESSA, A. & MOTA, N. (2013): Redescobrindo a história de Carnide: a intervenção arqueológica no largo do coreto e envolvente. – In: ARNAUD, J.M., MARTINS, A. & NEVES, C. (eds): Arqueologia em Portugal: 150 Anos. – pp. 1025–1032, Lisboa (Associação dos Arqueólogos Portugueses).

DAVIS, S.J.M. (1996): Measurements of a group of adult female Shetland sheep skeletons from a single flock: a baseline for zooarchaeologists. – Journal of Archaeological Science, **23**: 593–612.

DAVIS, S.J.M. (1997): The Agricultural Revolution in England: some zoo-archaeological evidence. – Anthropozoologica, **25–26**: 413–428.

DAVIS, S.J.M. (2006): Faunal remains from Alcáçova de Santarém, Portugal. – Trabalhos de Arqueologia Lisboa, **43**: 11–144.

DAVIS, S.J.M. (2008): Zooarchaeological evidence for Moslem and Christian improvements of sheep and cattle in Portugal. – Journal of Archaeological Science, **35**/4: 991–1010.

DAVIS, S.J.M. & BECKETT, J. (1999): Animal husbandry and agricultural improvement: the archaeological evidence from animal bones and teeth. – Rural History: Economy, Society, Culture, **10**: 1–17.

DAVIS, S.J.M., SVENSSON, E.M., ALBARELLA, U., DETRY, C., GÖTHERSTRÖM, A., PIRES, A.E. & GINJA, C. (2012): Molecular and osteometric sexing of cattle metacarpals: a case study from 15th century AD Beja, Portugal. – Journal of Archaeological Science, **39**/5: 1445–1454.

DEGERBØL, M. & FREDSKILD, B. (1970): The Urus (*Bos primigenius* Bojanus) and Neolithic domesticated cattle (*Bos taurus domesticus* LINNÉ) in Denmark with a revision of Bos-remains from the kitchen middens: zoological and palynological investigations. – Det Kongelige Danske Videnskabernes Selskab Biologiske Skrifter, **17**/1: 234 pp.

DIFFLOTH, P. (1909): Races bovines, France – étranger. Encyclopédie agricole, publiée par une réunion d'ingénieurs agronomes sous la direction de G. WÉRY. – 474 pp., Paris (Baillière et fils).

FITZHERBERT, Sir A. (1534/1882): The boke of husbandry. Reprinted from the edition of 1534 and edited with an introduction, notes, and glossarial index by the Rev. Walter W. SKEAT, M.A. – xxx+167 pp., London (Trübner & Co.).

FOREST, V. & RODET-BELARBI, I. (2002): À propos de la corpulence des bovins en France durant les périodes historiques. – Gallia, **59**: 273–306.

GOUVEIA, A., LEITE, J.V. & DANTAS, R. (2001): Raça Barrosã. – 108 pp., Braga (AMIBA – Associação dos Criadores de Bovinos de Raça Barrosã).

GUINTARD, C. (1994): Le métapode: un bon marqueur génétique. – In: ROULIÈRE-LAMBERT, M.-J. (ed.): Aurochs, le retour , aurochs, vaches & autres bovins de la préhistoire à nos jours. – pp. 201–202, Lons-le-Saunier (Centre Jurassien du Patrimoine).

GUINTARD, C. (1998): Ostéométrie des métapodes de bovins. – Revue Médecin Vétérinaire, **149**/7: 751–770.

GUINTARD, C. & BORVON, A. (2009): Sexer les métapodes de bovins: proposition de méthodologie appliquée aux métacarpes. Exemple des sites archéologiques médiévaux d'Andone (Charente, X–XIe siècles) et de Montsoreau (Maine-et-Loire, XIe siècle). – Bulletin de la Société des sciences naturelles de l'Ouest de la France, Nouvelle série, **31**/3: 123–137.

HIGHAM, C.F.W. (1969): The metrical attributes of two samples of modern bovine bones. – Journal of Zoology, **157**: 63–74.

HIGHAM, C.F.W. & MESSAGE, M. (1969): An assessment of a prehistoric technique of bovine husbandry. – In: BROTHWELL, D. & HIGGS, E. (eds): Science in archaeology. – pp. 315–330, London (Thames and Hudson).

HOBDAY, Sir F.T.G. (1914): Castration, including cryptorchids and caponing, and ovariotomy. 2nd edition. – xvi+162 pp., Edinburgh & London (W. & A. K. Johnston).

MALMSTRÖM, H., SVENSSON, E.M., GILBERT, M.T.P., WILLERSLEV, E., GÖTHERSTRÖM, A. & HOLMLUND, G. (2007): More on contamination: The use of asymmetric molecular behavior to identify authentic ancient human DNA. – Molecular Biology and Evolution, **24**: 998–1004.

MATOLSCI, J. (1970): Historische Erforschung der Körpergrösse des Rindes auf Grund von ungarischem Knochenmaterial. – Zeitschrift für Tierzüchtung und Züchtungsbiologie, **87**: 89–137.

OLIVEIRA MARQUES, A.H. de (1968): Introdução à Historia da Agricultura em Portugal, A questão cerealífera durante a Idade Média. 2a. Edição. – 350 pp., Lisboa (Edições Cosmos).

PUCHER, E. (2004): Der mittelneolithische Tierknochenkomplex von Melk-Winden (Niederösterreich). – Annalen Naturhistorische Museum Wien, Serie A, **105**: 363–403

PUCHER, E. & ENGL, K. (1997): Materialien 1. Die Pfahlbaustationen des Mondsees. Tierknochenfunde. – Mitteilungen der Prähistorischen Kommission der Österreichischen Akademie der Wissenschaften, **33**: 9–152.

PETERS, J. (1998): Römische Tierhaltung und Tierzucht. Eine Synthese aus archäozoologischer Untersuchung und schriftlich-bildlicher Überlieferung (Passauer Universitätsschriften zur Archäologie, 5). – 444 pp., Rahden/Westf. (Maria Leidorf).

SCHLUMBAUM, A., STOPP, B., BREUER, G., REHAZEK, A., BLATTER, R., TURGAY, M. & SCHIBLER, J. (2003): Combining archaeozoology and molecular genetics: the reason behind the changes in cattle size between 150 BC and 700 AD in Northern Switzerland. – Antiquity, Project Gallery. https://www.antiquity.ac.uk/projgall/schlumbaum298/ [last accessed 12.10.2017]

SILBERBERG, M. & SILBERBERG, R. (1971): Steroid hormones and bone. – In: BOURNE, G.H. (ed.): The biochemistry and physiology of bone. Vol. III. 2nd ed. – pp. 401–484, London & New York (Academic Press).

SVENSSON, E. & GÖTHERSTRÖM, A. (2008): Temporal fluctuations of Y-chromosomal variation in *Bos taurus*. – Biology Letters, **4**: 752–754.

SVENSSON, E.M., GÖTHERSTRÖM, A. & VRETEMARK, M. (2008): A DNA test for sex identification in cattle confirms osteometric results. – Journal of Archaeological Science, **35**/4: 942–946.

TEICHERT, M. (1984): Size variation in cattle from Germania Romana and Germania libera. – In: GRIGSON, C. & CLUTTON-BROCK, J. (eds): Animals and archaeology: **4**. Husbandry in Europe. – British Archaeological Reports, International Series, **227**: 93103.

TELLDAHL, Y., SVENSSON, E.M., GÖTHERSTRÖM, A. & STORÅ, J. (2012): Osteometric and molecular sexing of cattle metapodia. – Journal of Archaeological Science, **39**: 121–127

THOMAS, R., HOLMES, M. & MORRIS, J. (2013): "So bigge as bigge may be": tracking size and shape change in domestic livestock in London (AD 1220–1900). – Journal of Archaeological Science, **40**/8: 3309–3325.

VON DEN DRIESCH, A. (1976): A guide to the measurement of animal bones from archaeological sites. – Peabody Museum Bulletin, **1**: 148 pp.

WEINSTOCK, J. (2006): Environment, body size and sexual dimorphism in Late Glacial reindeer. – In: RUSCILLO, D. (ed.): Recent advances in ageing and sexing animal bones. Proceedings of the 9th conference of the International Council of Archaeozoology, Durham, August 2002. – pp. 247–253, Oxford (Oxbow Books).

WERNER, F.A., DURSTEWITZ, G., HABERMANN, F.A., THALLER, G., KRAMER, W., KOLLERS, S., BUITKAMP, J., GEORGES, M., BREM, G., MOSNER, J. & FRIES, R. (2004): Detection and characterization of SNPs useful for identity control and parentage testing in major European dairy breeds. – Animal Genetics, **35**: 44–49.

ZEDER, M. (2001): A Metrical Analysis of a collection of modern goats (*Capra hircus aegagrus* and *Capra hircus hircus*) from Iran and Iraq: implications for the study of caprine domestication. – Journal of Archaeological Science, **28**: 61–79.