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Cattle types in the Carpathian Basin in the Late Medieval and Early Modern Ages

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Abstract

During the Late Middle Ages the intensive export of livestock increased according to contemporaneous written sources. Tax records show the custom duties paid after the huge numbers of animals. On the basis of this information we get a compact picture about the importance of this activity. Cattle trade as shown in the academic literature, was widespread in the territory of the Carpathian Basin and beyond. The export of livestock was not limited to cattle, but was also extanded to other domestic species e. g. horses, sheep and pigs. In romantic history, supported by the awakening national self-awareness in Hungary at the turn of the 19th and 20th centuries, the iconic significance of the large, long-horned and light grey cattle consolidated. Unfortunately no archaeological finds could support the medieval appearance of these animals. Osteological evidence of these large, long-horned cattle are yet to be found. This archaeozoological aspect of Cattle trade is still to be developed. To date our perceptions have relied on the generalization of a concept in the historical interpretation of this large-scale economic activity. Research has usually focused on trade itself and not the subjects: the animals. In this paper the author presents new scientific approaches to the theme, using geometric morphometrics in the analysis of cattle bones.

Introduction and historic overview

According to written sources the importance of Hungary emerged in the Trans-European livestock trade from the 14th century onwards[1]. In this period, when demand for meat increased in the urbanized western- and central parts of Europe, that region was supplied by livestock from the peripheral parts. Hungary was a very important resource and transit area of this trading activity especially towards southern Germany, and northern Italy. Some cities (Buda, Pest, Székesfehérvár, Szeged) changed to centers of redistribution and markets in livestock trade,[2] while others (Vác, Nagymaros, Dunaföldvár) earned importance due to their ferries across the Danube. After a trip to Vienna across Hungary the animals had to be stall-fed[3] before being moved on towards regional markets.

On the basis of descriptions and customs records,[4] the bulk of the livestock was made up by cattle of various sizes, shapes and colours.[5] During the 16th century the diversity of exported

1 Belényessy 1956, 52; Bársony 1984, 362; Blanchard 1984; Bartosiewicz 1995a; Kubinyi 2009, 366.
2 Kubinyi 2009, 393.41
3 Nagy 2008, 272.
4 Velics – Kammerer 1890; Kubinyi 2009, 367; Bartosiewicz 1995/b, 80.
5 Velics – Kammerer 1890, 97; Vörös 2004, 210; Bartosiewicz 2002, 95.

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cattle seems to show some uniformization.[6] The demand in central European markets and the long cattle droves basically influenced the ways of breeding. Albeit the emergence of the Hungarian Grey cattle has not yet been clarified in the archaeological record, it seems inseparable from this complex process. The long-horned cattle of primigenius cranial type eventually became a trade mark of cattle trade in Hungary.[7]

Cattle exports oscillated, but continued during the 16 th–17th century Ottoman Turkish occupation of the country,[8] as is shown in tax-rolls and customs records. Supporting this activity the Pasha of Buda, Sokoli Mustafa guaranteed safe passage for cattle merchants through the ferry of Vác in 1576 and this guarantee was confirmed by Pasha Ali in 1582.[9]

Trading was supported by both Christian Europe and the Sublime Porte in Istanbul in the hope of lucrative tax revenues.[10] More than a million *akche* customs income was collected only on cattle transit at the ferry of Vác by Ottoman authorities in the 1560s.[11]

Thanks to the huge demand, new breeding centers were included in the trading system (e.g. in Transylvania, Moldva, Podolia).[12] Selective breeding and the broad variability of cattle types were a perfect basis for the emergence of new types such as the putative ancestor of the Hungarian Grey breed.[13] Intensive livestock trade started to decline during the 17 th–18th century, and this time imported dairy cattle breeds also began appearing in the Carpathian Basin.[14]

This paper presents preliminary results of a research project[15] which is focused on the morphometric differences between late medieval and early modern cattle metapodials from several archaeological sites from Hungary. The purpose of the research is to find osteological evidence of variability in cattle in the concerned archaeological periods.

The research hypotheses are established on the probable variability of cattle types by geographical and/or social regions. The main research questions are:

- Did intensive export generate homogeneous stocks of cattle over the regions or the regional differences continued to exist throughout the centuries?
- How can we isolate possibly different stocks on the basis of the morphological and osteometrical differences between metapodials?
- Is there any chance to complete this task, without using costly analytical methods such as aDNA or isotope analysis on large samples? How can we define possible morphological groups without these sensitive analytical methods?

6 Bartosiewicz 1995b, 81; Vörös 2004, 207.
7 Bartosiewicz 1997, 50.
8 Fekete 1944, 231.
9 Vass 1983, 100; Gaál 1966, 473; Veress – Dunka 2003, 44.
10 Veress – Dunka 2003, 44.
11 Velics – Kammerer 1890, 260.
12 Vörös 2004, 213.
13 Bartosiewicz 1997, 50; Vörös 2004, 214; Csippán 2009, 195.
14 Bartosiewicz 1993, 56.
15 This research project was materialized by the maintance of the Hungarian Scientific Foundation (OTKA – PD115261) and the János Bolyai Scholarship of the Hungarian Academy of Sciences (HAS) with additional funding from the project KMOP-4.2.1/B-10-2011-0002.

To gain historical informations on these animals the possible way is to turn to contemporaneous written sources. If these documentary sources offer information about the homogenity of cattle stocks from the Early Modern Age, we hypotesize, that these phenomena were also general in the Carpathian Basin. If the contemporaneous demand had a feedback effect on improving beef supplies, so the large cattle type(s) would become generally common in the region and the reflected in archaeological finds. (Animal bones from the household rubbish offer primary evidence of everyday meat-eating processes rather than trade). If uniformisation can be demonstrated, it could be attributed to the slow formation of a possible trademark such the appearance of the Hungarian cattle. It may be the result of intending to breed a recognizable product: *"magnos cornutos boves Hungaricos qui sunt omnes coloris ejér, szöjke"*.[16]

Contemporaneous tax-rolls and customs records reveal, however, that the general uniformization of the animals is a false hypothesis. The first counterargument is the huge number of the exported animals. Some written sources talk about tens of thousands of live cattle annually driven across the Danube between 15th and 16th century,[17] although the intensity of livestock export somewhat oscillated during Ottoman Turkish occupation.[18]

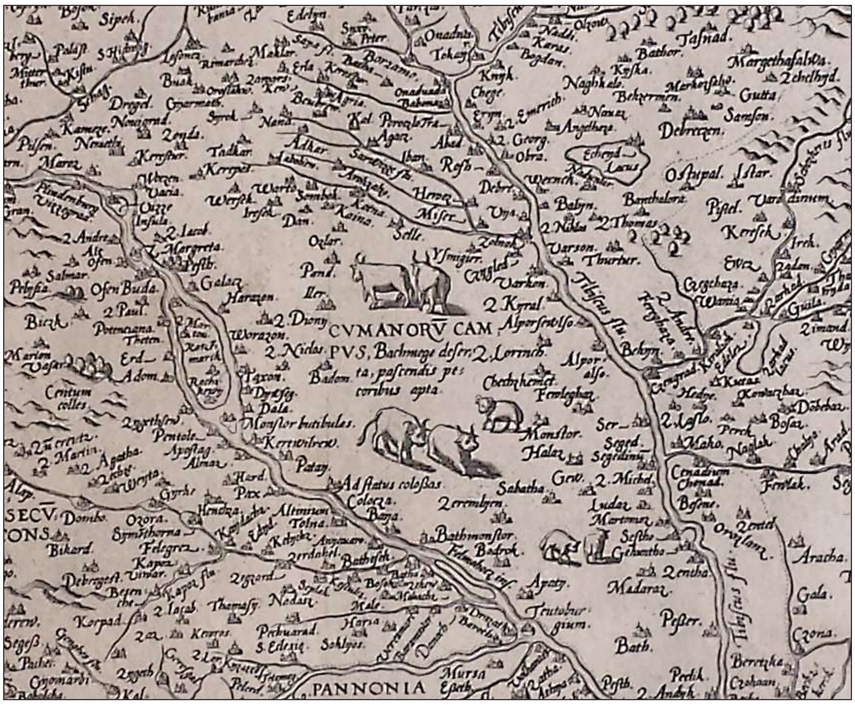


Fig. 1. Map of the Hungarian Kingdom by Wolfgang Lazius (1552)

But what do we know about the morphology of late medieval and early modern cattle? The picture of these animals is incomplete. In the written sources some clues are available e.g. *black cow with her brindle calf,*[19] and pictorial representations imply a silhouette of these cattle in general. Vörös noticed, that six basic colors of cattle were generally mentioned in the 16th–18th century: white, blond, raddle, brown, black and blue.[20] The map of the Hungarian Kingdom in

16 Milhoffer 1904, 74.; Bartosiewicz 2002, 95.
17 Milhoffer 1904, 74.
18 Káldy-Nagy 1970, 87.
19 Velics – Kammerer 1890, 97.
20 Vörös 2004, 210.

the book *Regni Hungariae Descriptio vera* by Wolfgang Lazius (1552) showed spunky, shorter horned type of cattle in the area of the town Kecskemét, a market town famous for its animal husbandry *(Fig. 1)*. Other illustrations in a map by János Zsámboky (1571) seem to be suggestive of a larger type of cattle *(Fig. 2)*.

Fig. 2. Map of the Hungarian Kingdom by János Zsámboky (1571)

In a third contemporaneous map*, Nova totius Ungariae descriptio accurata et diligens desumpta* by Mathias Zündt (1567), yet another type, a medium-long horned cattle was shown along with their herders. This representation, however, also highlights the unreliability of stature estimations based on such pictures, the body sizes of cattle and dogs were obviously different from each other *(Fig. 3)*.

Fig. 3. Map of the Hungarian Kingdom by Mathias Zündt (1567)

As much as may be seen, pictorial and written sources indicate various types of cattle during the archaeological periods focal to this paper. Moreover in the maps shown here these animals are invariably located in the central area of the country, the plains renowned for their animal husbandry. Several, but at least two types of cattle have been reported in various archaeozoological publications during the Hungarian Middle Ages, spanning from the 11th–13th century Árpád period until the subsequent late medieval times.[21]

Osteological evidence from this area confirmed this variability of cattle breeds. Nyerges and Bartosiewicz published data on these morphological groups from the late medieval village of Szentkirály.[22]

In general – on the basis of Matolcsi's work – the newly published data fit the average withers heights characteristic of these periods.[23] The minimum was shown in the 9th–14th century, but body size was increasing during the late medieval and early modern periods *(Fig. 4)*. This process seems like a rapid change, some researchers therefore presumed a possible change of cattle stocks at the end of the Middle Ages.[24]

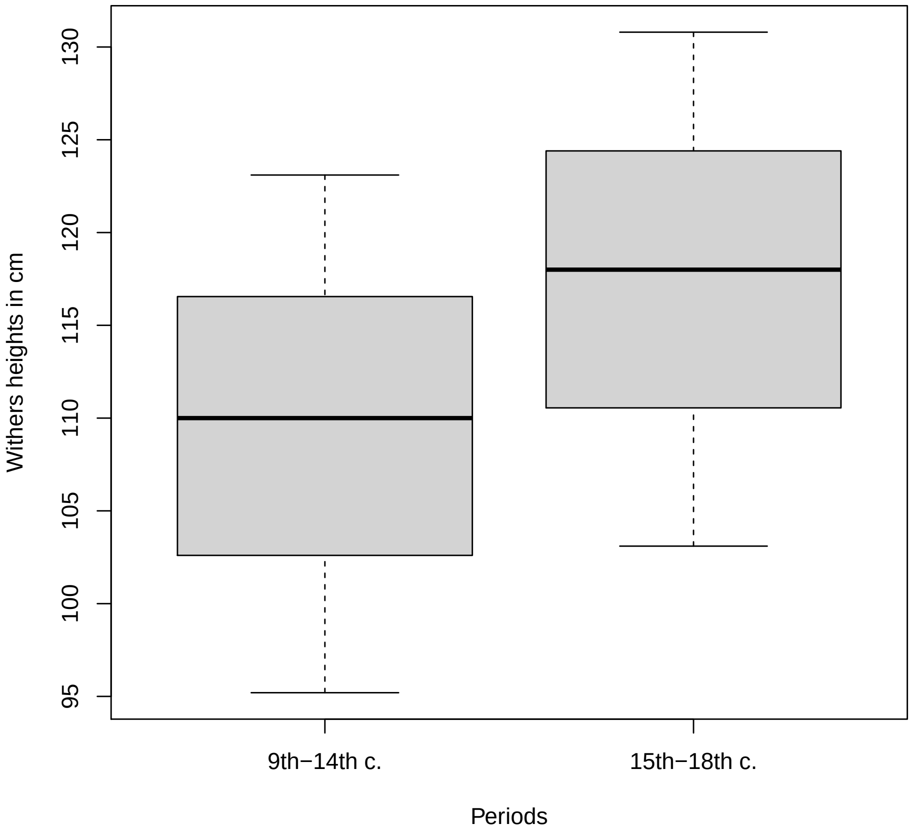


Fig. 4. Differences in withers heights early (9th–14th c.) and late (15th–16th c.) medieval cattle after Matolcsi 1986.

21 Matolcsi 1968, 26.; Vörös 1992, 233; Nyerges 2004, 528.
22 Nyerges – Bartosiewicz 2006, 335.
23 Matolcsi 1968, 12.
24 Nyerges – Bartosiewicz 2006, 336.; Lyublyanovics 2015, 229.; Vörös 2002, 344.

However it is quite possible, that significant numbers of regional cattle stocks were concentrated in the country in transit as a result of the rapid increase in animal exports. This process may have caused higher variability, but on the other hand, may have provided a genetic basis for the emergence of new types with larger body size.[25]

Method and material

Method

The main methodological problem of the concept of continuous size growth is the one-sided approach of the available data, which focuses mainly on withers heights estimates, as linear distance measurements are highly correlated with size, because long bone lengths are highly correlated with stature. This means that the comparison of measurements emphasized the same dimension: the variability in withers heights reflected variability in bone lengths but was insufficient for the fine-grain separation of cattle types.

In addition, the archaeozoological material originates from culturally filtered deposits, influenced by taphonomic processes, thus it cannot reflect exactly the contemporaneous breeding and trading processes. Excavated assemblages usually mirror everyday meat-eating habits which included only a small part of the actual animal stock. The measurable and comparable data – originating from adult animals – showed that the excavated bones, usually came from cows, representing only a very thin layer of all animal stocks in the discussed periods. Therefore, during the comparison between various data, in addition to age, a preliminary separation by sex should receive a higher priority, given the high degree of sexual dimorphism in cattle.[26]

Interpretating the number of cattle phenotypes during the Hungarian Middle Ages is problematic. On the basis of conventional archaeozoological methods, this question is hard to tackle.

One of the possible answers can be expected from the analysis of the aDNA. Genetic research showed clear differences between cattle bone samples from various archaeological sites. But the problem is the level of comparison. Without any preliminary concept of classification, these results probably will show only the tautological differences, but not the similarities.

Thus, first of all we have to define the criteria for possible groups using a method based on a skeletal element, which comes to light very often and carries a lot of decoded and comparable information (e. g. withers height, age, sex): the metapodials.[27]

Metapodials (the fused *metacarpus III-IV.* and *metatarsus III-IV.*) bear rich information (see above) on the animals, which strongly depends on the form of exploitation and/or breed-related characteristics.[28] A more sophisticated method was sought to retrieve morphometric information from these bones. Geometric morphometry (**GM**), supported by powerful statistical methods such as Principal Component Analysis (**PCA**) and Cluster Analysis (Ward method) offer appropriate solutions.

25 Bartosiewicz 1997, 50.
26 Bartosiewicz 1984, 142.
27 Fhionnghaile et al. 2015, 78.
28 Bartosiewicz 2008, 159.

Fhionnghaile et al. have already carried out multivariate morphometric analyses of cattle metapodials in Hungary. Those authors, however authors used different hardware and software in their analysis, and focused only on two recent cattle breeds in Europe.[29] On the basis of their results we can hypotesize, that the form of exploitation and morphological differences between the body shape of various cattle can be reflected in the shape of metapodials. These bones adapt to the way cattle were kept and used, and may even show deformities in metapodials as well as in the carpal and tarsal bones and phalanges of the animals.[30] Therefore preliminary observation and the separation of bones showing symptoms of degenerative disease are also important before the analysis.

GM originates from evolutionary biology and paleontology, where it is used to separate groups of similar, but different species on the basis of exact, non-conventional metric data. The basic idea of GM originated from D'Arcy Thompson in 1917 who expressed changes in shape in organisms by transforming the data into coordinates establishing diagnostic points on them in order to describe the characteristics of the shape.[31]

As the first step in GM analyses the researcher has to define diagnostic (general and identifiable) points (landmarks) on each individual to be compared, which describe the characteristics of their shape. Today, the analysis of shape is either based on the configurations of such landmarks or on the analysis of outlines (either open or closed).[32] The in-depth evaluation of these homologous diagnostic points would not be possible without suitable computer applications and methodology.

The definition of landmarks needs to meet five criteria, after by Zelditch et al.[33]

- homologous anatomical loci
- unaltered topological positions relative to other landmarks
- provision of adequate coverage of the morphology
- repeatable and reliable occurrences
- falling within the same plane

The topological variations of these landmarks form the basis of comparison. The parameters of the object can be split by size and shape. The size of the bone is represented by the centroid and absolute size itself. The centroid is the geometric center of the shape, which is described by the landmarks and the size of it is the square root of the summed squared distances of landmarks from the centroid.[34] The centroid size depends on the distances of all landmarks from the centroid of the object. Centroid sizes thus typify the objects.[35] The rare coordinates are calibrated using the centralization method of superimposition (General

29 Fhionnghaile et al. 2015.
30 Bartosiewicz 2008, 159.
31 Bookstein 1991, 2; Mitteroecker – Gunz 2009, 236.
32 Adams et al. 2013, 7.
33 Zelditch et al. 2004, 25.
34 Zelditch et al. 2004, 60.
35 Slice 2007, 3; Mitteroecker – Gunz 2009, 236.

Procrustes Analysis – GPA), which determines the geometric centroid as a standard common unit, re-scales the coordinates and determines the mean of the shapes of an individual.[36] Another advantage of the GPA is, that the method can exclude extreme measurement bias. The comparison between individual forms is based on the common mean of shapes, which is more-or-less independent from real, absolute size. To eliminate this proper of landmarks, the PCA is an obvious method, because with the reduction of dimensions the data become more manageable. On the other hand the geometric interpretation of landmarks as coordinates makes it easy to visualize the real differences between the individuals using a thin-plate spline interpolation of a coordinate grid.[37] In this case all of the landmarks are presumably homologous, so they are placed on the homologue position, but all other points are interpolated from one form to another.

GM became a well known method in archaeology as well, used in physical anthropology, ceramics typology and for lithic materials.[38] Borel et al. reminded in their work, that the classical approach based on only two measurements (greatest length and greatest breadth) is not sufficient for the precise description of stone tools and does not meet the requirements of reliable comparison. The variability of real shape can not be described by only these measurements. Using GM in archaeology, therefore, has another advantage: it pinpoints correspondences between the form, technology and function of stone tools.[39] Similarly to the problem of traditional stone tool analysis – using only two absolute metrical dimensions – the situation is the same with the morphological comparison of metapodials that serve as a basis in the estimation of withers heights.[40]

Using GM on cattle metapodials has some criteria:

- For the analysis we need clear and focused pictures of each bone taken from the same distance and angle.[41]
- Because the high degree of secondary sexual dimorphism in cattle, before the GM analysis we have to separate cows, oxen and bulls on the basis of the greatest length of a bone and breadth of proximal epiphysis, using the methods developed by Nobis.[42]
- Finally we have to compare the archaeological data with measurements taken on present-day cattle of various, known forms of exploitation to help understanding differences and similarities in the archaeological data.

36 Adams et al. 2004, 6–7; Rohlf 1999.

37 Bookstein 1991, 26.

38 Cardillo, 2010, 325.; Borel et al. 2016; In this research project I am using only 2D morphometric methods, but 3D methods also available in GM.

39 Borel et al. 2016, 2.

40 Because withers height estimation is based on the greatest length and the greatest breadth of the proximal ephipysis of the metapodials. (See Nobis 1954; Matolcsi 1970)

41 This is a general criterion in GM, therefore I was using an EPSON PERFECTION 2004 PHOTO flatbed scanner with a light tent.

42 Nobis 1954.

Material

This paper examines three archaeological assemblages from the sites of Akalacs village, Révfalu village and the town of Vác.[43] All of these sites are dated to the late medieval period (15th-16th century), but represent different types of settlement.

Akalacs[44] was a late medieval village located on the left bank of the Danube, not far from the ferry at Dunaföldvár across the Danube. The village was abandoned at the time of Ottoman Turkish occupation in the 16th century.[45]

As shown by its Hungarian name, Révfalu (Ferry-village) was an important ferry settlement during the Late Middle Ages.[46] In contrast to Akalacs, this village remained a relevant crossing point on the Danube in late medieval-early modern age cattle export, directed towards markets in Northern-Italy.[47]

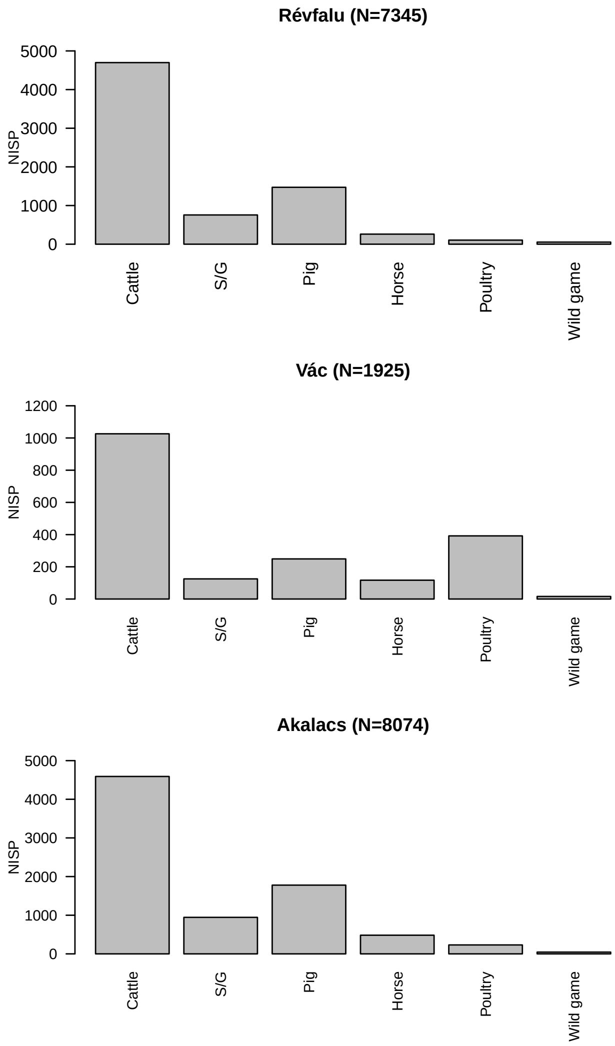


Fig. 5. Taxonomic distribution of bone animal materials from Révfalu, Vác and Akalacs.

43 The sites were excavated by Zsófia Ács (HNM-CNCH), Orsolya Mészáros (HNM-CNCH, ELTE), Gábor Wilhelm (Katona József Museum, Kecskemét), many thanks are due for their help.

44 Paks-Cseresznyés (M6–TO18).

45 Oláh et al. 2010, 204.

46 Pányos – Rosta 2015, 256.

47 Bartosiewicz 1999, 48.

And finally three estates in the center of the town of Vác, which was the most important ferry across the Danube, during the middle ages and under Ottoman Turkish occupation.[48] All three settlements were located in or near the focus of late medieval- early modern age cattle trade.

The animal bone materials from these sites were rich and well preserved[49] and all of representing a general 14–16th century Christian pattern, where beef dominated in everyday meat-consumption *(Fig. 5)*.

Unfortunately only **42** metacarpals[50] originated from the aforementioned sites, so they were complemented with **8** metacarpals from Castle of Szolnok an Early Modern site published by Bökönyi (1974)[51] and **18** metacarpals from present-day Hungarian Grey cattle from the HMA.[52] On one hand the later samples originate from a different period. On the other, they come from a well-known modern breed. Therefore they have a potential to show clear and interpretable differences and/or homologies during the analysis, thereby increasing the validity of results.

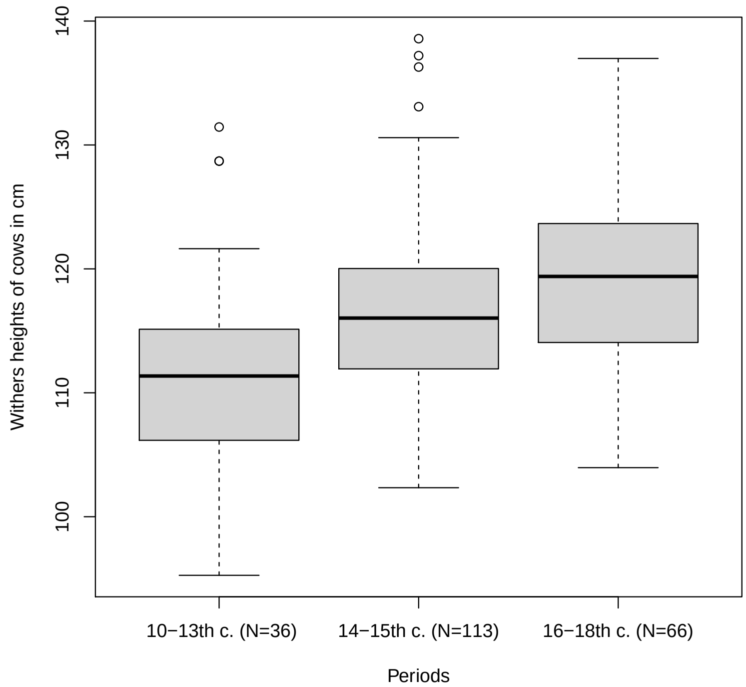


Fig. 6. Increase the withers heights of cows between the 10th to 18th century.

Using the conventional withers height based comparison the Late Medieval samples fit the characteristic of the period calculated by Matocsi 1968.[53] The average of withers heights of cows show a significant increase between the 10th to 18th century on the basis of sites listed in the Appendix *(Fig 6)*.[54]

48 Bartosiewicz 1995/a

49 All animal bone materials were identified by the author, but as of today only the finds from Vác-Piac utca have been published.

50 Sample sizes: Akalacs n=**32**, Vác n=**5**, Révfalu n=**5**

51 Bökönyi 1974, 471.

52 I have to thank Andrea Kőrösi, who provided access to Hungarian Grey metapodia in the Osteological Collection of the Hungarian Museum of Agriculture.

53 Matolcsi 1970.

54 List of the cited sites see on the Appendix.

The distribution of withers heights per samples shows significant differences in the case of the Early Modern Age and Hungarian Grey material, but in the case of Late Medieval sites, the differences are possibly due to the differences in sample size *(Fig. 7).*

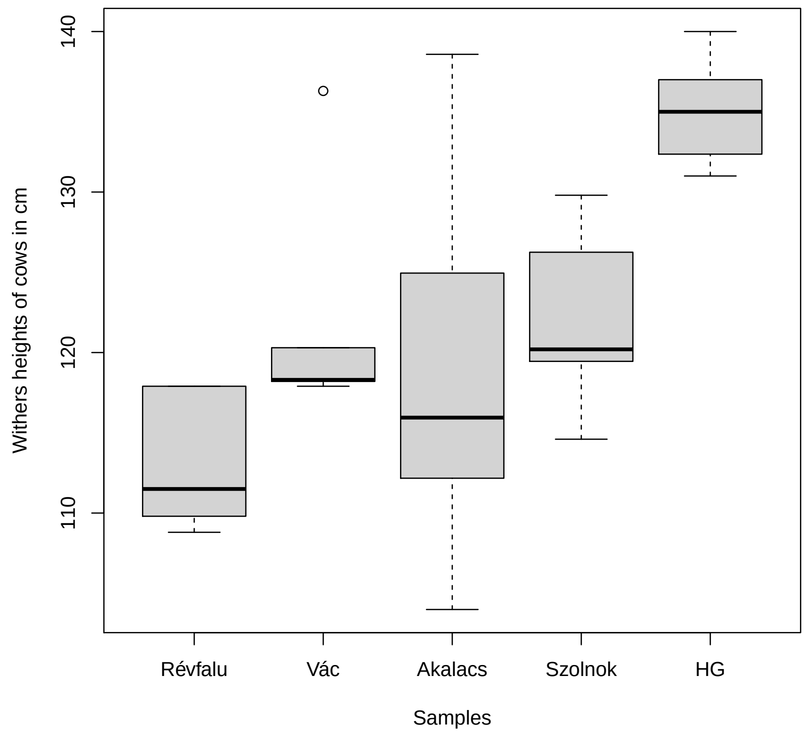


Fig. 7. Box-plot showing the distribution of withers heights in the studied samples.

Withers heights from the three Late Medieval sites show a more-or-less normal distribution with a slight positive skew. The mean value is **118** cm, accompanied by a relatively broad range (**100 – 140** cm, SD=**8.136**). The high difference between the extremes of the range might mean several types of cattle. However, these types cannot be distinguished from each other on the basis of withers heights alone *(Fig. 8).*

The morphometric analysis included only the complete, undamaged metacarpals from the rich materials described above. The analysis was made using the *geomorph* package for the statistical software *R*[55] developed by Adams et al.[56] During the recording of the data – for the sake of comparability – only the left side oriented bones were recorded. This means that metacarpals from the right side were mirrored horizontally, for the sake of the analysis. Without this process the number of the comparable elements would have been a lot smaller. Landmarks were determined on the basis of works by Bignon et al.[57] and Fhionnghaile et al.[58] Twenty-nine landmarks were defined on all complete metacarpals. As in addition to two points on the diaphysis two others on the border of distal and proximal epiphyses of the bones could not be located consistently due to the lack of concrete morphological features, these points are defined as semi-landmarks *(Fig. 9).*

55 R Core Team (2016). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL: https://www.R-project.org/

56 Adams – Otárola-Castillo 2013; Adams et al. 2016.

57 Bignon et al. 2005, 379.

58 Fhionnghaile et al. 2015, 75.

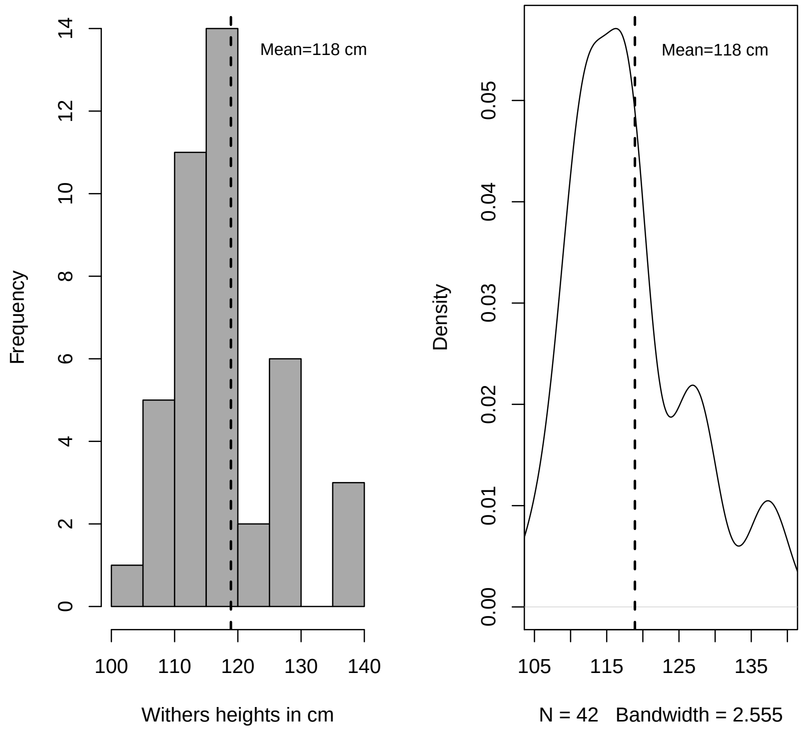


Fig. 8. Distribution of the cattle withers heights from the three Late Medieval sites.

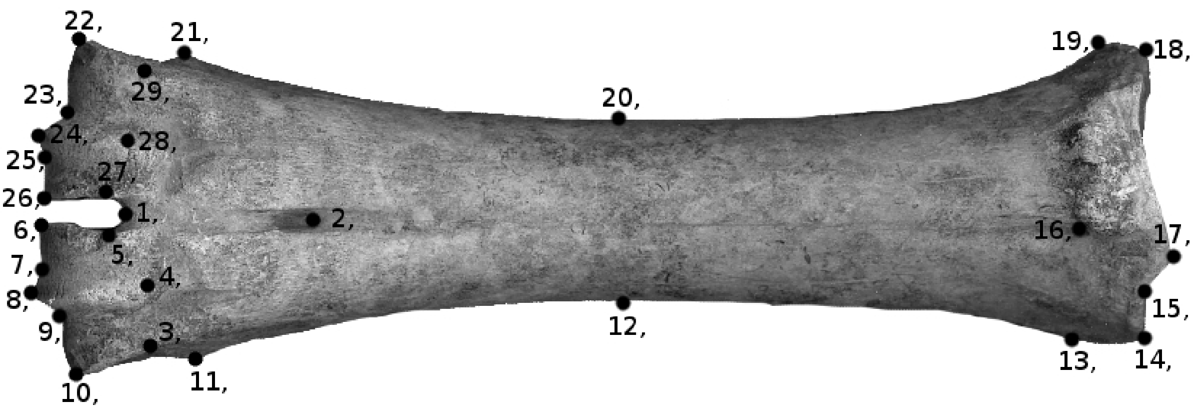


Fig. 9. Cattle metacarpal with the 23 landmarks and 6 semilandmarks on the diaphysis.

After recording the landmarks we get a cumulative topological graph of the coordinates of all landmarks on each individual bones *(Fig. 10).* These point clouds are calibrated by the General Procrustes Analysis (**GPA**), on the basis of Procrustes distances, which normalize (center and scale) the incidental mistakes of the data-recoding process. The resulting differences show the real variability in the shape of the bones. Because the real form of the individual equal the summation of shape and size.[59] This superimposition also helps defining the centroids of the raw coordinates

59 Borel et al. 2016, 2.

(Fig. 11). In order to excluse allometric correspondences – this is means that metacarpal proportions strongly depend on withers height[60] – we have to make an allometric analysis on the basis of the coordinates and the size of the calculated centroids *(Fig. 12).* [61] The allometric analysis shows relatively strong correspondences between the size and shape variations of the individual metacarpals, therefore the statistical analysis of allometry-free data is needed to obtain size-adjusted residuals.[62]

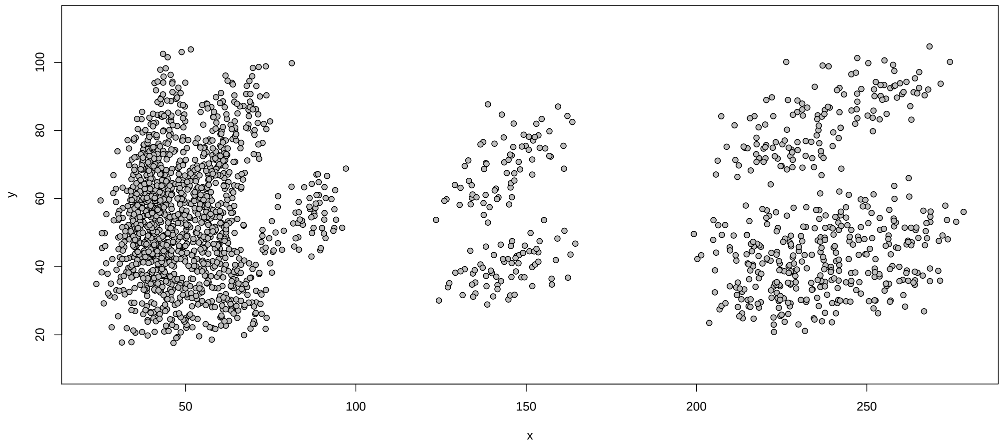


Fig. 10. Raw coordinates of the landmarks of all specimens.

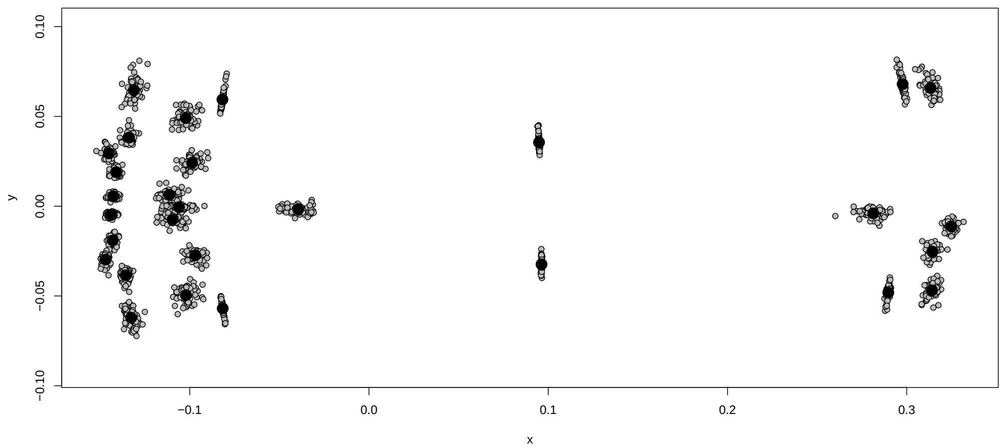


Fig. 11. Results after the General Procrustes superposition.

These data have already been pre-screened for the statistical comparison using Principal Component Analysis (**PCA**), but extreme individuals could strongly influence the results of the PCA. Against these possibilities the extreme individuals were filtered using an outlier analysis on the basis of the Procrustes Distances from the mean. The outlier analysis shows clearly the difference between the most inordinate specimens mirrored by the Procrsutes distance from the meanshape. The lowest value shows the closest, the highest value shows the farthest individual. The median (solid line) shows the most prevalent distance *(Fig. 13–14).* According to the results of the multiplied outlier analysis **7** metacarpals[63] closed out from the following parts of the research.

60 Reitz – Wing 1999, 67-71; Bartosiewicz 1987, 356–357.
61 Sherratt 2014, 19.
62 This was neccessary produced by the software package.
63 **5** pcs from Akalacs and **2** pcs from Hungarian Greys.

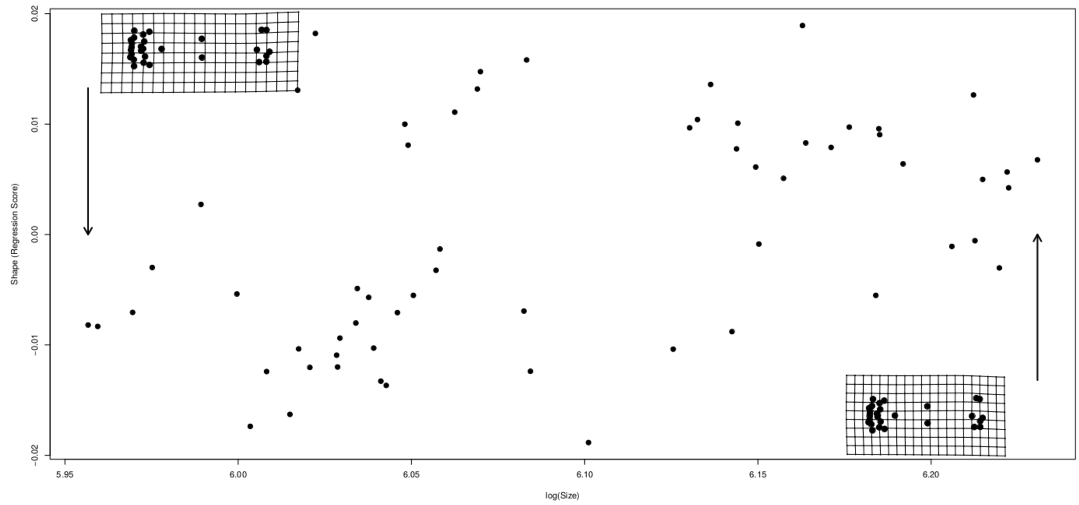


Fig. 12. Allometric correspondences between the variability of shape and size in metacarpals.

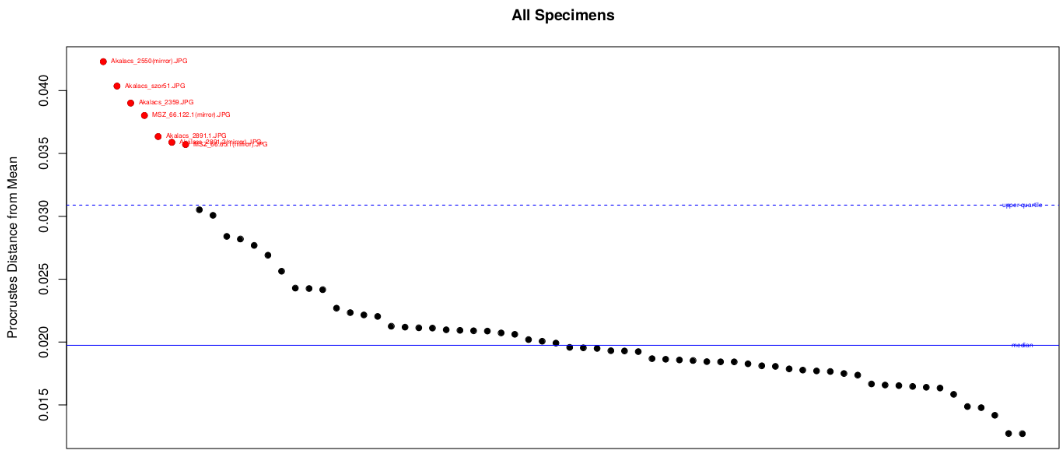


Fig. 13. Residual values of the outlier analysis on the basis of the Procrustes distances from the mean.

Results

As a result of the PCA has clearly shown, that some of the metacarpals from same locations define more-or-less separated groups in some cases, but these groups strongly overlap each other within the 95% confidence interval (CI) *(Fig. 15–16).*

The first PC encompasses most of the total variance (**34%**), which means, that the most important differences between the metacarpals are shown by the slenderness of the diaphysis and also the spread of the distal epiphysis, so the key landmarks of discriminative value are located in these areas of metacarpal bones.

Over against the groups of locations more valid morphometrical groups were outlined by the PCA. In order to clarify these groups the Ward hierarchical clustering was used. The correct number of clusters was determined choosing **30** different indices of clustering criteria (Hartigan, Ratkowsky, Duda, Gap etc.) to be used by the *NbClust* package in R.[64] (see Appendix) On the basis of these indices four different groups of PCA loadings can be described *(Fig. 17)*.

64 Charrad et al. 2014.

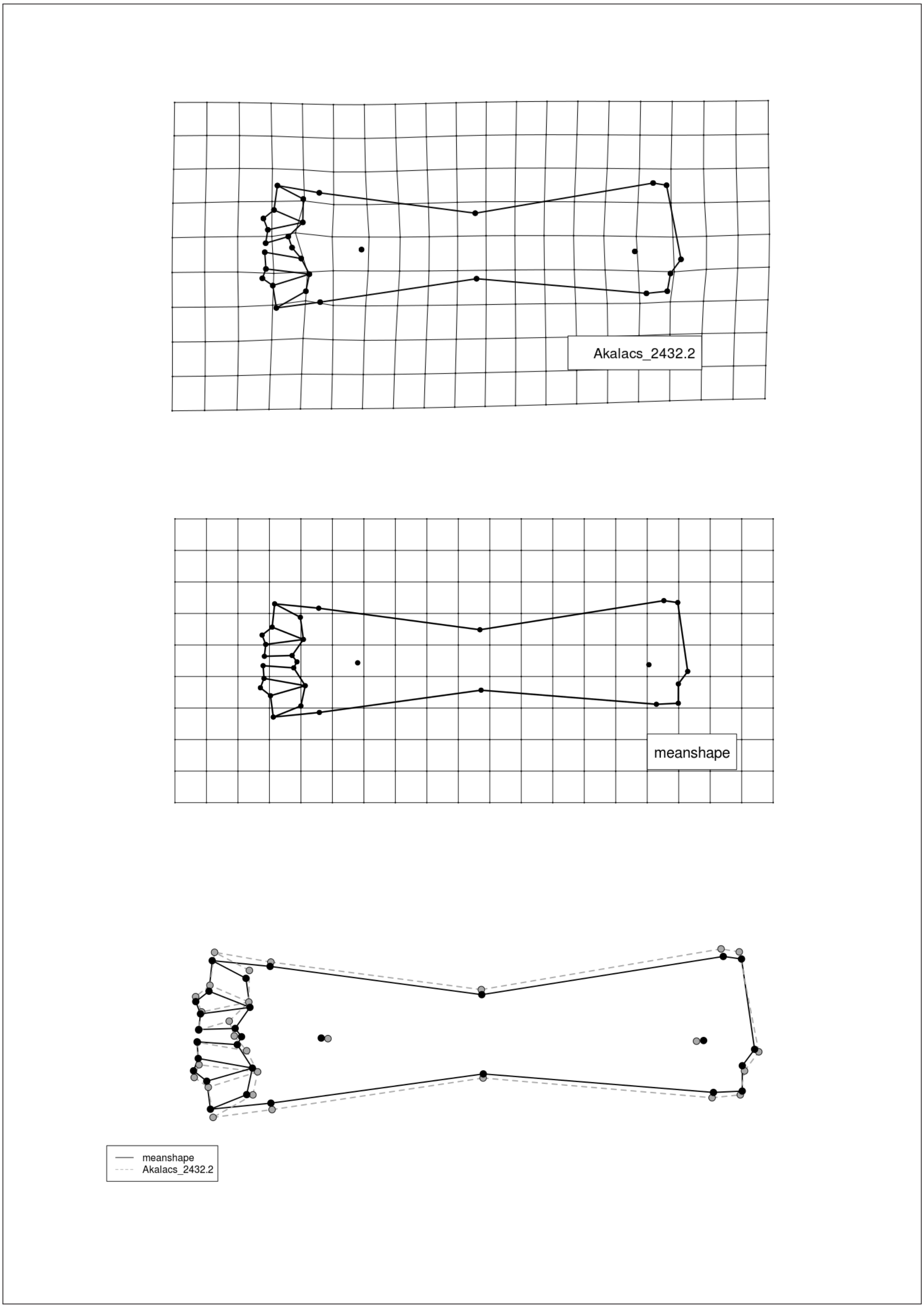


Fig. 14. Differences between the farest individual and the meanshape.

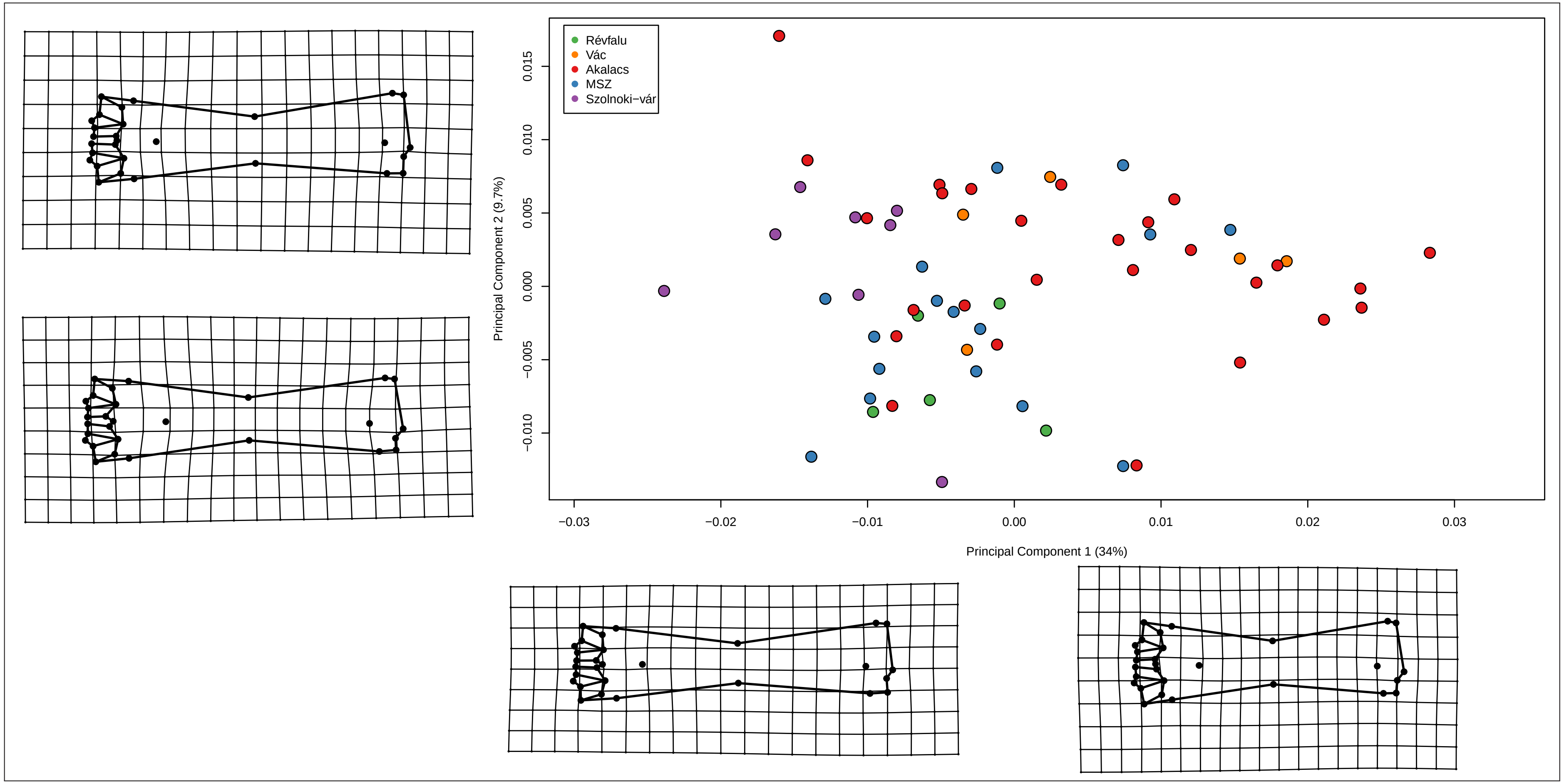


Fig. 15. Results of the PCA with respect of the extreme formations of metacarpals.

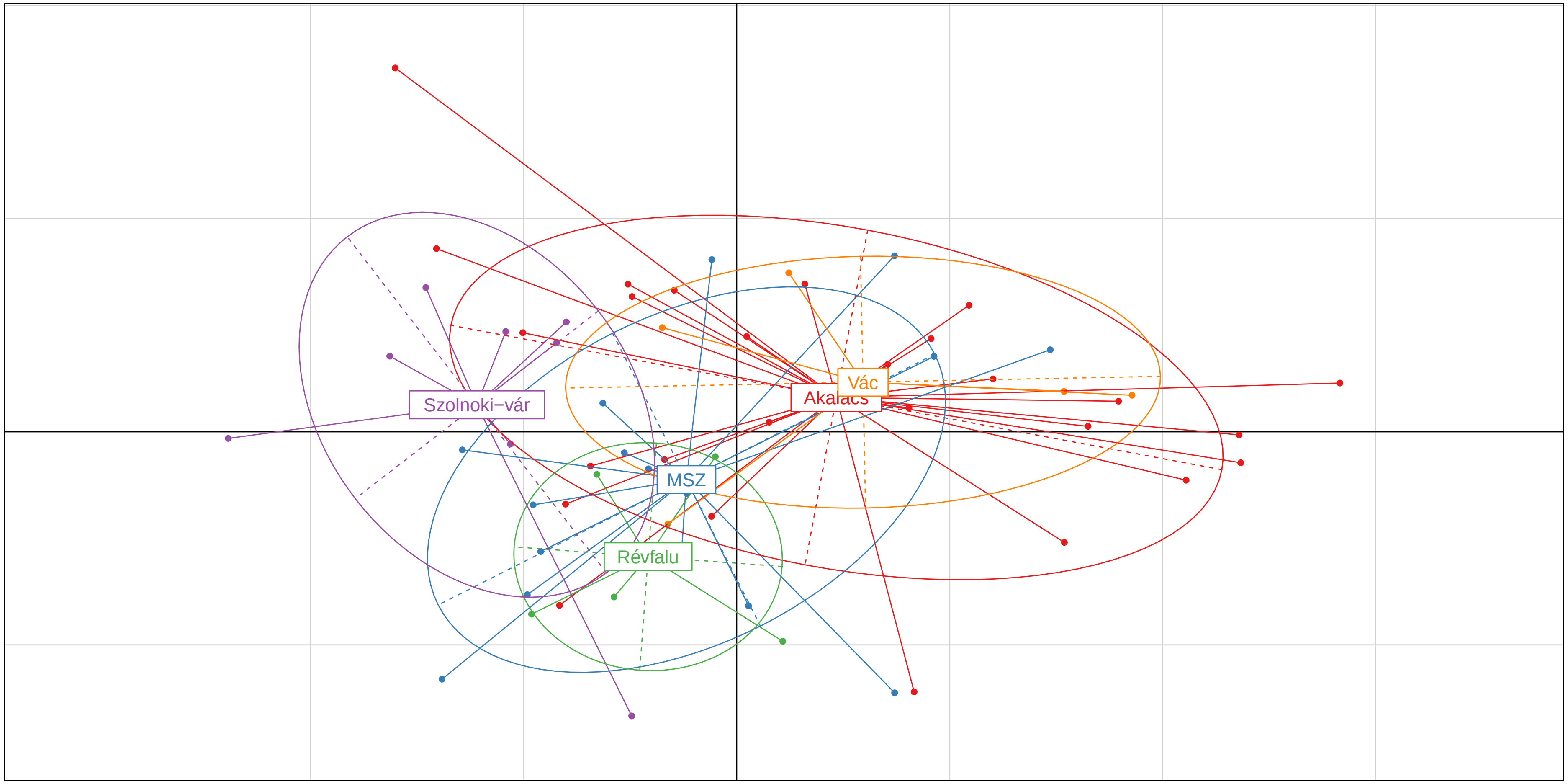
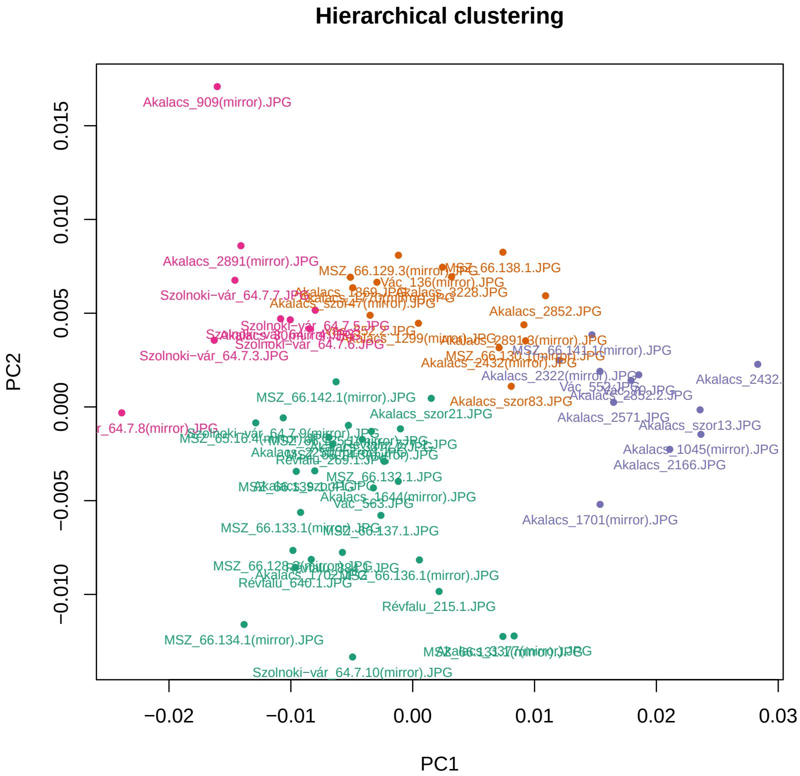


Fig. 16. Results of the PCA showing hulls of 95% CI for each sample.



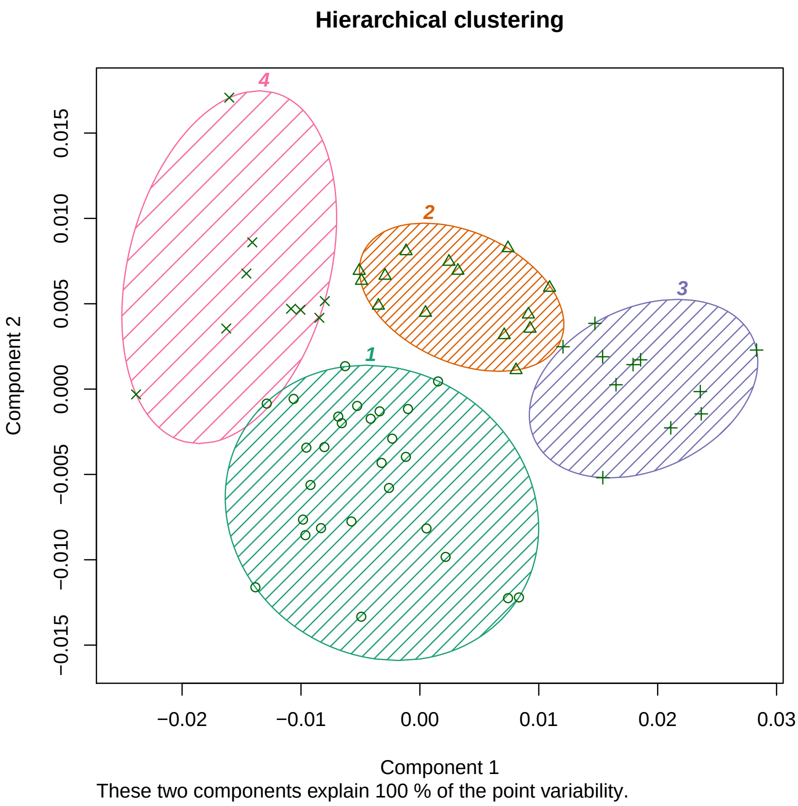


Fig. 17. Hierarchical clustering (Ward method) showing separated groups of PCA loadings.

The groups are separated by – as discussed above – modifications of the distal epiphysis, which is reflected by the PC2 axis (see *Fig. 15*). These variations depend on the assymetry of the epiphyseal surfaces, which correspond to two possibilities: *a) the strain of the bone in working animals*[65] and *b) the natural weight and age of the individuals.*[66]

The individuals with larger body size have different bone formation processes than the smaller, gracile animals, although this difference is not only shown by the slenderness of metacarpals (the proportion of smallest diaphysis breadth to the greatest length of bone), but also appears in the shape of both the distal and proximal epiphyses of the bones. These factors can strongly influence the shape of metacarpals and withers heights in relation with the phenotype of the individuals. In the case of the Hungarian Greys, the only homogeneous, modern breed used in the comparison almost all individuals were classified within the same group. The position of these metacarpals – independently of group affiliation – is always located in the center of the PC1 axis. This phenomenon indicates the possible characteristics of the metacarpals of this breed. It is also significant that the individuals from the Castle of Szolnok and most individuals from Akalacs are well separated and positioned oppositing each other. The five metacarpals from Révfalu seem absorbed in the group of the Hungarian Greys, while the five specimens from Vác are absorbed in the group of the Akalacs metacarpals.

Late Medieval sites and the clustered groups of individuals from these sites can be compared according to the changes in withers heights during the periods between 10th–18th centuries *(Fig. 18).*[67]

Size distributions by site doesn't show a strong overlap in the clustered material. Although cluster No. 1 overlaps with the value obtained for Révfalu the small number of metacarpals in the latter sample precludes meaningful conclusion. Cluster No. 2 includes almost the half of the large sample of Akalacs and a few individuals from Vác. The others from this numerous samples positioned on the two other cluster groups. The plot also clearly shows, that these groups do not correspond to withers height alone, so we can not rule out permanently the effect of allometry.

Conclusion

During the Late Middle and Early Modern Ages the withers heights of cattle increased, which phenomenon was probably related in subtle ways to the intensive livestock export to urban markets in Central Europe. This high demand inspired the spread of good quality beef as well as large bodied types of cattle in the territory of the Hungarian Kingdom.[68] The separation of presumed types is impossible on the basis of withers heights alone, because the range of the observed withers heights in these periods is very broad. It is for this reason that geometric morphometrics was used for attempting to distinguish between presumed cattle forms. During the GM analysis **42** metacarpals of cows were used from three different Late Medieval sites (Akalacs, Vác, Révfalu) **8** from an Early Modern site (Castle of Szolnok), and **18** from recent

65 These osteological anomalies were closed out before the analysis.

66 Fhionnghaile et al. 2015, 75.

67 Only the Late Medieval samples included in this compare.

68 Bartosiewicz 1997–1998, 41–42.

Hungarian Grey cows. As a result of the analysis four different groups of metacarpal formations were separated. The main differences between these groups are expressed in the slenderness of the metacarpal bones and the surface (de)formation of the distal epiphysis of individuals.

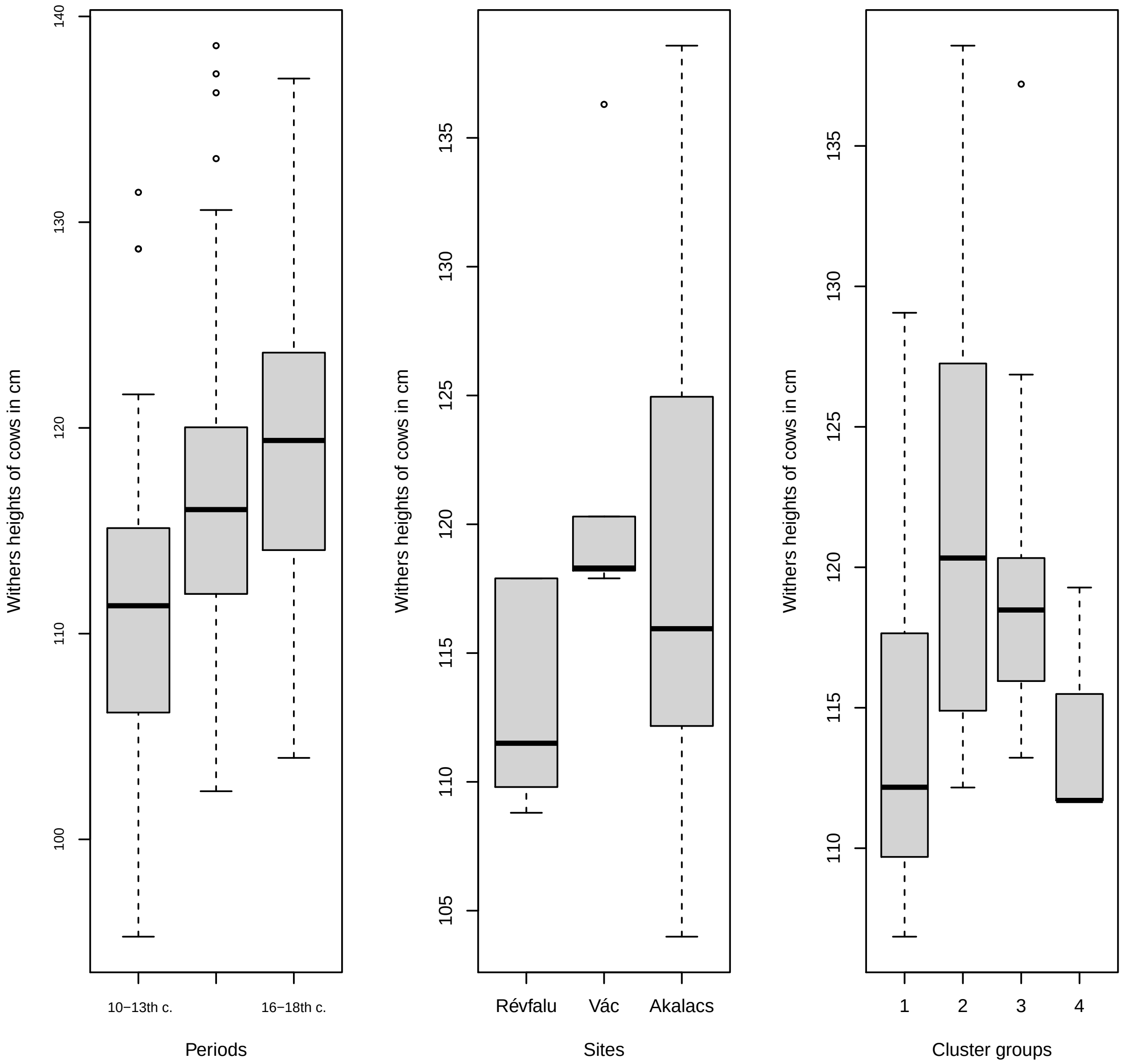


Fig. 18. Comparisons between withers heights of periods, the sites and the clusters received

Some of the groups correspond to the assemblages from various sites or the modern breed. Highly bred Hungarian Grey cows composed a well defined group, although some individuals fell into another group. It is a significant phenomenon that the individuals from the Castle of Szolnok and most individuals from Akalacs are positioned well separated and opposite site from each other and the metacarpals from Vác and Révfalu absorbed on the groups above. On the basis of preliminary morphometric analysis these groups possibly represent different forms of metacarpals of possibly different cattle in the investigated periods. For more specific information, however, more individuals need to be analysed using the geometric morphometric method, extending these investigations to the metatarsals and more samples as well. Increasing sample sizes may also improve chances of monitoring secondary sexual dimorphism in metapodials as well as the possible effects of draught work on these bones, affecting phenotypic shape.

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Appendix

Landmark definition based on anatomical orientation of metacarpals

1. Incisura intertrochlearis (middle point)
2. Foramen nutriticum along the canalis metacarpi distalis
3. Proximal extremity of the trochlea capitis metacarpalis IV. pars abaxialis
4. Proximal extremity of the crista glenoidalis lateralis
5. Proximal extremity of the trochlea capitis metacarpalis IV. pars axialis
6. Distal extremity of the trochlea capitis metacarpalis IV. pars axialis
7. Trochlea ossis metacarpalis IV. pars axialis
8. Distal extremity of the crista glenoidalis lateralis
9. Trochlea ossis metacarpalis IV. pars abaxialis
10. Distal extremity of the trochlea capitis metacarpalis IV. pars abaxialis
11. Lateral point of the distal metaphysis
12. Margo lateralis (middle point)
13. Os metacarpale V.
14. Lateral extermity of the facies articularis proximalis
15. Facies articularis proximalis
16. Foramen nutriticum along the canalis metacarpi proximalis
17. Proximal extremity at the fusion line between metacarpalia III. and IV.
18. Medial extermity of the facies articularis proximalis
19. Medial extermity of the margo medialis
20. Margo medialis (middle point)
21. Medial point of the distal metaphysis
22. Distal extremity of the trochlea capitis metacarpalis III. pars abaxialis
23. Trochlea ossis metacarpalis III. pars abaxialis
24. Distal extremity of the crista glenoidalis medialis
25. Trochlea ossis metacarpalis III. pars axialis

26. Distal extremity of the trochlea capitis metacarpalis III. pars axialis
27. Proximal extremity of the trochlea capitis metacarpalis III. pars axialis
28. Proximal extremity of the crista glenoidalis medialis
29. Proximal extremity of the trochlea capitis metacarpalis III. pars abaxialis

Generalized Procrustes Analysis with Partial Procrustes Superimposition

23 fixed landmarks, 6 semilandmarks (sliders), 2-dimensional landmarks, 6 GPA iterations to converge, Minimized squared Procrustes Distance used

Consensus (mean) Configuration

	X	Y
[1,]	-0.10631892	-0.0005366958
[2,]	-0.03952934	-0.0016527035
[3,]	-0.10217603	-0.0490524564
[4,]	-0.09733811	-0.0267990444
[5,]	-0.11004300	-0.0071589570
[6,]	-0.14382229	-0.0047752171
[7,]	-0.14286546	-0.0187183360
[8,]	-0.14679562	-0.0290972476
[9,]	-0.13570385	-0.0378225675
[10,]	-0.13264034	-0.0613305286
[11,]	-0.08181999	-0.0562405580
[12,]	0.09665832	-0.0317459827
[13,]	0.28994675	-0.0472797622
[14,]	0.31422097	-0.0461286333
[15,]	0.31428568	-0.0248438243
[16,]	0.28171394	-0.0036983074
[17,]	0.32461113	-0.0110936949
[18,]	0.31360316	0.0647670843
[19,]	0.29817864	0.0668535625
[20,]	0.09538789	0.0347691159
[21,]	-0.08255675	0.0584766018
[22,]	-0.13112896	0.0633137731
[23,]	-0.13377910	0.0376919762
[24,]	-0.14491041	0.0289471369
[25,]	-0.14091844	0.0186264142
[26,]	-0.14238074	0.0055115127
[27,]	-0.11178004	0.0064293954
[28,]	-0.09935860	0.0240959527
[29,]	-0.10274046	0.0484919907

Centroid sizes of individuals

	Centroid size
Révfalu_215.1.JPG	386.3268
Révfalu_269.1.JPG	415.4629
Révfalu_640.1.JPG	415.1804
Révfalu_777.1.JPG	391.3194
Révfalu_884.1.JPG	387.4036
Vác_136(mirror).JPG	488.7846
Vác_552.2.JPG	427.1337
Vác_552.JPG	432.2607
Vác_563.JPG	424.3441
Vác_70.JPG	423.3063
Akalacs_1045(mirror).JPG	438.4618
Akalacs_1299(mirror).JPG	417.5321
Akalacs_1644(mirror).JPG	427.6255
Akalacs_1701(mirror).JPG	498.8054
Akalacs_1702.JPG	465.2393
Akalacs_1770(mirror).JPG	418.9253
Akalacs_1869.JPG	415.0644
Akalacs_2166.JPG	432.6453
Akalacs_2250(mirror).JPG	419.5138
Akalacs_2322(mirror).JPG	423.7106
Akalacs_2432.2.JPG	412.5146
Akalacs_2432(mirror).JPG	460.6162
Akalacs_2571.JPG	462.3620
Akalacs_2852.2.JPG	429.4469
Akalacs_2852.JPG	465.8414
Akalacs_2891.3(mirror).JPG	468.4201
Akalacs_2891(mirror).JPG	409.5042
Akalacs_30(mirror).JPG	411.8500
Akalacs_3228.JPG	503.6764
Akalacs_3377.2.JPG	393.5484
Akalacs_3377(mirror).JPG	399.1140
Akalacs_909(mirror).JPG	438.9378
Akalacs_szor13.JPG	410.4178
Akalacs_szor21.JPG	403.2795
Akalacs_szor41.JPG	410.5410
Akalacs_szor47(mirror).JPG	406.7577
Akalacs_szor83.JPG	459.5699

	Centroid size
MSZ_65.14.3(mirror).JPG	472.1878
MSZ_65.16.4(mirror).JPG	484.9509
MSZ_66.128.3(mirror).JPG	468.8465
MSZ_66.129.3(mirror).JPG	508.1026
MSZ_66.130.1(mirror).JPG	478.7221
MSZ_66.131.1(mirror).JPG	466.0066
MSZ_66.132.1.JPG	475.2482
MSZ_66.133.1(mirror).JPG	499.0102
MSZ_66.134.1(mirror).JPG	502.5443
MSZ_66.135.1(mirror).JPG	500.1187
MSZ_66.136.1(mirror).JPG	485.4973
MSZ_66.137.1.JPG	485.3746
MSZ_66.138.1.JPG	481.2447
MSZ_66.139.1.JPG	495.7071
MSZ_66.141.1(mirror).JPG	474.7883
MSZ_66.142.1(mirror).JPG	503.8999
Szolnoki-vár_64.7.10(mirror).JPG	417.3607
Szolnoki-vár_64.7.3.JPG	457.3916
Szolnoki-vár_64.7.4.JPG	421.0384
Szolnoki-vár_64.7.5.JPG	422.4105
Szolnoki-vár_64.7.6.JPG	420.3864
Szolnoki-vár_64.7.7.JPG	404.8412
Szolnoki-vár_64.7.8(mirror).JPG	446.3535
Szolnoki-vár_64.7.9(mirror).JPG	438.1084

Importance of Principal Components

	PC1	PC2	PC3	PC4	PC5
Standard deviation	0.01148	0.006129	0.005379	0.00481	0.004723
Proportion of Variance	0.34010	0.096890	0.074620	0.05968	0.057530
Cumulative Proportion	0.34010	0.436990	0.511610	0.57129	0.628820
	PC6	**PC7**	**PC8**	**PC9**	**PC10**
Standard deviation	0.004196	0.003863	0.003566	0.003408	0.003225
Proportion of Variance	0.045410	0.038490	0.032790	0.029960	0.026830
Cumulative Proportion	0.674230	0.712720	0.745520	0.775480	0.802310

PCA scores

	PC1	PC2
Révfalu_215.1.JPG	0.0021658775	-0.0098313769
Révfalu_269.1.JPG	-0.0065661765	-0.0019956803
Révfalu_640.1.JPG	-0.0096286532	-0.0085580929
Révfalu_777.1.JPG	-0.0010011081	-0.0011664557
Révfalu_884.1.JPG	-0.0057574099	-0.0077536911

	PC1	PC2
Vác_136(mirror).JPG	0.0024451489	0.0074608072
Vác_552.2.JPG	-0.0034908681	0.0048886650
Vác_552.JPG	0.0153697939	0.0018961121
Vác_563.JPG	-0.0032224588	-0.0043224868
Vác_70.JPG	0.0185627172	0.0017147304
Akalacs_1045(mirror).JPG	0.0236676112	-0.0014520943
Akalacs_1299(mirror).JPG	0.0004744725	0.0044731002
Akalacs_1644(mirror).JPG	-0.0011777425	-0.0039702343
Akalacs_1701(mirror).JPG	0.0153873667	-0.0051918563
Akalacs_1702.JPG	-0.0083160970	-0.0081460977
Akalacs_1770(mirror).JPG	-0.0029299334	0.0066412676
Akalacs_1869.JPG	-0.0051011381	0.0069280904
Akalacs_2166.JPG	0.0211033030	-0.0022721190
Akalacs_2250(mirror).JPG	-0.0068648643	-0.0016097294
Akalacs_2322(mirror).JPG	0.0120382217	0.0024812625
Akalacs_2432.2.JPG	0.0283195045	0.0022876608
Akalacs_2432(mirror).JPG	0.0070967188	0.0031648698
Akalacs_2571.JPG	0.0164966995	0.0002547871
Akalacs_2852.2.JPG	0.0179321032	0.0014333672
Akalacs_2852.JPG	0.0109068683	0.0059348470
Akalacs_2891.3(mirror).JPG	0.0091279338	0.0043729683
Akalacs_2891(mirror).JPG	-0.0140961778	0.0085963922
Akalacs_30(mirror).JPG	-0.0100417603	0.0046489581
Akalacs_3228.JPG	0.0031995083	0.0069345269
Akalacs_3377.2.JPG	-0.0033853030	-0.0013031167
Akalacs_3377(mirror).JPG	0.0083321185	-0.0122041829
Akalacs_909(mirror).JPG	-0.0160289663	0.0170737744
Akalacs_szor13.JPG	0.0235871328	-0.0001458529
Akalacs_szor21.JPG	0.0015293161	0.0004505045
Akalacs_szor41.JPG	-0.0080347001	-0.0033975550
Akalacs_szor47(mirror).JPG	-0.0049118623	0.0063456119
Akalacs_szor83.JPG	0.0080889409	0.0011129600
MSZ_65.14.3(mirror).JPG	-0.0041355892	-0.0017381534
MSZ_65.16.4(mirror).JPG	-0.0128792140	-0.0008488394
MSZ_66.128.3(mirror).JPG	-0.0098289715	-0.0076449603
MSZ_66.129.3(mirror).JPG	-0.0011620437	0.0080815750
MSZ_66.130.1(mirror).JPG	0.0092656911	0.0035393862
MSZ_66.131.1(mirror).JPG	0.0074163531	-0.0122498918
MSZ_66.132.1.JPG	-0.0023251696	-0.0029016368
MSZ_66.133.1(mirror).JPG	-0.0091993513	-0.0056197565
MSZ_66.134.1(mirror).JPG	-0.0138346430	-0.0116110478
MSZ_66.135.1(mirror).JPG	-0.0052736441	-0.0009850409
MSZ_66.136.1(mirror).JPG	0.0005576680	-0.0081643897

	PC1	PC2
MSZ_66.137.1.JPG	-0.0025961259	-0.0057933802
MSZ_66.138.1.JPG	0.0074120979	0.0082583086
MSZ_66.139.1.JPG	-0.0095500632	-0.0034297601
MSZ_66.141.1(mirror).JPG	0.0147218294	0.0038494813
MSZ_66.142.1(mirror).JPG	-0.0062834600	0.0013444538
Szolnoki-vár_64.7.10(mirror).JPG	-0.0049292459	-0.0133347292
Szolnoki-vár_64.7.3.JPG	-0.0162869613	0.0035490840
Szolnoki-vár_64.7.4.JPG	-0.0108381930	0.0047060858
Szolnoki-vár_64.7.5.JPG	-0.0079961462	0.0051548779
Szolnoki-vár_64.7.6.JPG	-0.0084523628	0.0041770643
Szolnoki-vár_64.7.7.JPG	-0.0145907153	0.0067709876
Szolnoki-vár_64.7.8(mirror).JPG	-0.0238685259	-0.0003112202
Szolnoki-vár_64.7.9(mirror).JPG	-0.0106193512	-0.0005731397

Clustering indices

	KL	**CH**	**Hartigan**	**CCC**	**Scott**
Number_clusters	4.0000	10.000	4.0000	10.0000	4.0000
Value_Index	5.7518	70.004	16.2413	-2.0422	48.2844
	Marriot	**TrCovW**	**TraceW**	**Friedman**	**Rubin**
Number_clusters	4	3	4e+00	9.0000	4.0000
Value_Index	0	0	8e-04	5.1369	-0.2993
	Cindex	**DB**	**Silhouette**	**Duda**	**PseudoT2**
Number_clusters	10.0000	6.0000	5.0000	2.000	2.0000
Value_Index	0.2164	0.8086	0.4038	0.313	50.4905
	Beale	**Ratkowsky**	**Ball**	**PtBiserial**	**Gap**
Number_clusters	2.0000	4.000	3.0000	5.0000	2.0000
Value_Index	2.1038	0.424	0.0015	0.5556	-0.1409
	Frey	**McClain**	**Gamma**	**Gplus**	**Tau**
Number_clusters	1	2.0000	10.0000	10.0000	4.0000
Value_Index	NA	0.5485	0.9133	7.1393	288.3164
	Dunn	**Hubert**	**SDindex**	**Dindex**	**SDbw**
Number_clusters	5.0000	0	5.0000	0	9.0000
Value_Index	0.1519	0	245.5409	0	0.1263

Cluster groups

ID	Cluster	Withers Height
Révfalu215.1	1	109.20
Révfalu269.1	1	117.65
Révfalu640.1	1	118.25
Révfalu777.1	1	111.01
Révfalu884.1	1	109.69
Vác563	1	118.15
Akalacs1644(mirror)	1	117.59
Akalacs1702	1	129.06
Akalacs2250(mirror)	1	115.94
Akalacs3377.2	1	106.85
Akalacs3377(mirror)	1	108.68
Akalacsszor21	1	109.88
Akalacsszor41	1	112.17
MSZ65.14.3(mirror)	1	131.39
MSZ65.16.4(mirror)	1	132.36
MSZ66.128.3(mirror)	1	138.00
MSZ66.131.1(mirror)	1	131.00
MSZ66.132.1	1	137.00
MSZ66.133.1(mirror)	1	137.00
MSZ66.134.1(mirror)	1	137.00
MSZ66.135.1(mirror)	1	135.00
MSZ66.136.1(mirror)	1	134.00
MSZ66.137.1	1	140.00
MSZ66.139.1	1	135.00
MSZ66.142.1(mirror)	1	138.00
Szolnok-vár64.7.10(mirror)	1	119.08
Szolnoki-vár64.7.9(mirror)	1	125.40
Vác136(mirror)	2	136.30
Vác552.2	2	120.33
Akalacs1299(mirror)	2	114.22
Akalacs1770(mirror)	2	115.57
Akalacs1869	2	112.82
Akalacs2432(mirror)	2	126.30
Akalacs2852	2	128.21
Akalacs2891.3(mirror)	2	117.00
Akalacs3228	2	138.57
Akalacsszor47(mirror)	2	112.16
Akalacsszor83	2	125.38
MSZ66.129.3(mirror)	2	138.00
MSZ66.130.1(mirror)	2	134.00
MSZ66.138.1	2	132.00

ID	Cluster	Withers Height
Vác552	3	120.33
Vác70	3	117.88
Akalacs1045(mirror)	3	119.89
Akalacs1701(mirror)	3	137.20
Akalacs2166	3	119.08
Akalacs2322(mirror)	3	115.95
Akalacs2432.2	3	113.86
Akalacs2571	3	126.86
Akalacs2852.2	3	117.83
Akalacsszor13	3	113.22
MSZ66.141.1(mirror)	3	137.00
Akalacs2891(mirror)	4	111.70
Akalacs30(mirror)	4	111.70
Akalacs909(mirror)	4	119.28
Szolnoki-vár64.7.3	4	129.76
Szolnoki-vár64.7.4	4	120.57
Szolnoki-vár64.7.5	4	119.82
Szolnoki-vár64.7.6	4	119.82
Szolnoki-vár64.7.7	4	114.61
Szolnoki-vár64.7.8(mirror)	4	127.13

List of sites for the summary of withers height calculations

10th–13th century

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16th-18th century

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