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Índices/Contents

Archaeofauna 25 (2016): 33-78

The size of domestic cattle, sheep, goats and pigs in the Czech Neolithic and Eneolithic Periods: Temporal variations and their causes

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ABSTRACT: Osteometric data were analysed from the main domestic animals existing in central Europe during the Neolithic and Eneolithic (Chalcolithic) periods, specifically cattle (*Bos taurus*), sheep (*Ovis aries*), goats (*Capra hircus*), and pigs (*Sus domesticus*). The results are based on a combined evaluation of selected dental and postcranial measurements (in total nearly 1100 measured values) obtained from archaeological material from the Bohemian and Moravian (Czech Republic) Lengyel and Eneolithic periods (4700-2200 BC, including Moravian Painted Ware, Funnelbeaker, Baden-Řivnáč, and Bell-Beaker Cultures for example) and adjacent Neolithic and Early Bronze Age cultures (Linear and Stroked Pottery, Únětice). Results on the animals´ body size and their variation over time are presented, and possible interpretations of the secular changes in size are discussed in detail. Apart from the general, well known trend showing a reduction in cattle size over time, some anomalies were found. Based on osteometric comparisons, there are indications of cross-breeding between wild and domestic forms and/or the local domestication of cattle in the Bohemian Řivnáč Culture (3200-2800 BC), and of pigs in the Proto-Eneolithic to Funnelbeaker Cultures (4300-3350 BC). The observed body-size increase in sheep in the territory of the Czech Republic during the Early-Middle Eneolithic corresponds to the previously hypothesised importation of a new breed throughout Europe during the second half of the 4th millennium BC.

KEYWORDS: OSTEOMETRY, BODY MASS, DOMESTICATION, CROSS-BREEDING, CHALCOLITHIC, *Bos taurus, Ovis aries, Capra hircus, Sus domesticus*, AUROCHS, WILD BOAR

RESUMEN: Este trabajo analiza datos osteométricos de los principales animales domésticos centroeuropeos durante el Neolítico y Eneolítico (Calcolítico) como la vaca (*Bos taurus*), la oveja (*Ovis aries*), la cabra (*Capra hircus*) y el cerdo (*Sus domesticus*). Los resultados se basan en cerca de 1.100 medidas dentarias y postcraneales obtenidos a partir de materiales arqueológicos de Bohemia y Moravia (República Checa) en culturas como la de Lengyel y otras calcolíticas en un rango de entre 4700-2200 a. C. En ellas están presentes horizontes de las cerámicas pintadas de Moravia, cultura de los vasos de embudo (TBK), cultura de Baden, así como el Campaniforme, además de otras culturas adyacentes como la de Cerámica a Bandas (LBK), la de Cerámicas impresas (Stichbandkeramik, STK) y la de Únětice. Se presentan datos sobre tallas corporales y su variación diacrónica valorando pormenorizadamente las posibles causas de los cambios seculares detectados. Además de una bien constatada tendencia referida a la progresiva reducción de la talla del vacuno con el tiempo, se detectan una serie de anomalías. De este modo, se especula sobre posibles cruces habidos entre el vacuno doméstico y salvaje o una posible domesticación local del uro en la cultura Bohemia de Řivnáč (3200-2800 a.C.), así como del cerdo en las culturas Proto-Eneolíticas y de cerámica de embudo (4300-3350 a.C.). El incremento de talla del ovino en el territorio de la república Checa durante el Eneolítico Antiguo y Medio, en cambio, refuerza la postulada importación de una nueva raza de oveja en Europa durante la segunda mitad del cuarto milenio a.C.

PALABRAS CLAVE: OSTEOMETRÍA, MASA CORPORAL, DOMESTICACIÓN, CRUZAMIENTO, CALCOLÍTICO, *Bos taurus, Ovis aries, Capra hircus, Sus domesticus*, URO, JABALÍ

INTRODUCTION

There is a relatively large amount of archaeozoological data, analyses and results available from the area of central Europe, but very little is known internationally about the Bohemian and Moravian regions. For instance, a synthesis by Bökönyi (1974) does not include any locality from the Czech Eneolithic, a synthesis by Benecke (1994) includes only four localities, and a survey by Glass (1991) only two localities. A short overview including the selective evaluation of the size of domestic animals was written by Peške (1994). Detailed synthetic studies analysing breeding and hunting in the Czech Republic during the early agricultural period have appeared only recently (Roblíčková, 2003a, b; Kyselý, 2010a, 2012; Kovačiková *et al*., 2012). The work presented here tries to partly fill this gap using selection of so far unpublished osteometric analyses of the author (Kyselý, 2010a), based on a synthetic study of 140 archaeozoological collections originating from 104 Lengyel and Eneolithic settlements, about half of which provided measurement data for the analyses presented below. Thus, this work expands on the knowledge of animal breeding in the Czech lands outlined in the previous study analysing the paleoeconomic situation in the Lengyel and Eneolithic periods (Kyselý, 2012).

This study is based on the measurements of bones and subsequent analyses of the obtained osteometric data. Morphological signs and other characteristics are only marginally taken into account. However, the results can be applied on a broader scale, because the size of animals is related to their genetic background, breed origin, zootechnical interventions, economic utilization and their role in the life of people.

AIMS

The basic aims of the study are

(1) to provide a large set of metric data documenting a variety of skeletal dimensions, body size and variability in body size of domestic cattle, sheep/goats and pigs from the Czech territory during the Lengyel and Eneolithic periods;

(2) to detect the changes in the size of these animals over time;

(3) to provide interpretations of found secular changes.

MATERIAL AND METHODS

Terms and acronyms

Taxonomic nomenclature of domestic mammals follows Gentry *et al*. (2004). Archaeological cultures and periods and their absolute dating follow local, Bohemian and Moravian chronology and terminology (Podborský, 1993; Jiráň & Venclová, 2013-2014; see Figure 2). Acronyms of measurements are after Driesch (1976).

B = breadth

BBC = Bell-Beaker C.

BC = before Christ calib.

Bd = distal breadth

BO = Bohemia

Bos indet. = undetermined form of cattle (*Bos taurus* / *Bos primigenius*)

Bp = proximal breadth

BP = *Bos primigenius*

BT = *Bos taurus*
C. = (archaeological) culture
CA = *calcaneus*
CH = *Capra hircus*
CR = the Czech Republic
CWC = Corded Ware C.
En./ Eneolithic = Chalcolithic or Copper Age (*sensu* Bohemian and Moravian chronology)
GAC = Globular Amphora C.
GB = greatest breadth
GL = greatest length
H_2 = heritability
inf. = inferior
KHD = Kutná Hora-Denemark site (east Bohemia)
L = length
LBK = Linear Pottery C. (Linearbandkeramik)
LGK = Lengyel C.
M1, M3 = *molar 1*, *molar 3*
MMK = Moravian Painted Ware C.
MO = Moravia
MTC = *metacarpus*
mtDNA = mitochondrial DNA
MTT = *metatarsus*
NISP = number of identified specimens
OA = *Ovis aries*
O/C = *Ovis* / *Capra*
P1 = *premolar 1*
prox. = proximal
Řivnáč C. = local Bohemian Middle Eneolithic culture (derived from Baden C.)
SS = *Sus scrofa*
SSD = *Sus domesticus*
STK = Stroked Pottery C. (Stichbandkeramik)
Sus indet. = undetermined form of pig (*Sus domesticus* / *Sus scrofa*)
TRB = Funnelbeaker C. (Trichterbecherkultur)
WH = the withers height

Thematic and temporo-spatial definition

The study is limited to typical farm mammals; cattle, sheep, goats and pigs, that played a substantial role in European prehistoric husbandry and were interrelated. Dogs and horses have been analysed morphometrically elsewhere (Kyselý, 2010a; Kyselý & Peške, 2016). In the Czech lands, domestic fowl has not been reliably documented in the studied period (Kyselý, 2010b). In the studied region some of the domestic mammals had, and still have, wild ancestors with which they could potentially have been cross-bred. Some of the comparisons also include osteometric data from bones of these wild forms. These concern aurochs, which were still quite common in the region in the Neolithic and Eneolithic periods (Kyselý, 2005, 2008 a, b, 2012), and wild boar, which were common in all Holocene periods (Kyselý, 2005).

The work compares osteometric data obtained as part of the study of archaeozoological finds from the Czech Republic (CR). The majority of the data used here comes from the localities of Bohemia (the western part of CR), especially its central and northern parts. This region is mostly surrounded by medium-sized mountains, which result in its partial isolation (Figure 1). A smaller dataset comes from southern Moravia (the eastern part of CR), which is open to the relatively warmer Pannonia lowland and which is part of a north-south migration corridor. However, the distance between the two regions and their geographical and climatic differences are not great. Relatively stable temperatures, a climate without dramatic changes and similar vegetation are assumed within the studied period. The evaluated time span includes the Holocene climatic optimum, with a temperature probably slightly higher than nowadays (Ložek, 1973; Dreslerová *et al.*, 2007). All the localities included come from the lowland regions, the altitudinal span being only c. 160-300 m above sea level (Figure 1).

As in Kyselý (2010a, 2012), the study is focused on the Lengyel and Eneolithic periods, i.e. c. 4700-2200 BC. Nevertheless, to detect broader tendencies, available data representing the preceding Neolithic cultures (LBK, STK) and the immediately following Early Bronze Age culture (Únětice C.) are also included - thus the work comprises nearly 4000 years of history (c. 5600-1700 BC). The Lengyel and Eneolithic periods in the given region include 11 archaeological cultures or their subphases (for the cultures represented in CR see Table 1 and Figure 2). In terms of the number of settlement localities as well as the amount of osteometric data, the TRB and Řivnáč Cultures are the best-represented (i.e. the Early and Middle Eneolithic, c. 3800-2800 BC). Other archaeological cultures present in the Czech Republic are, in terms of the quantity of

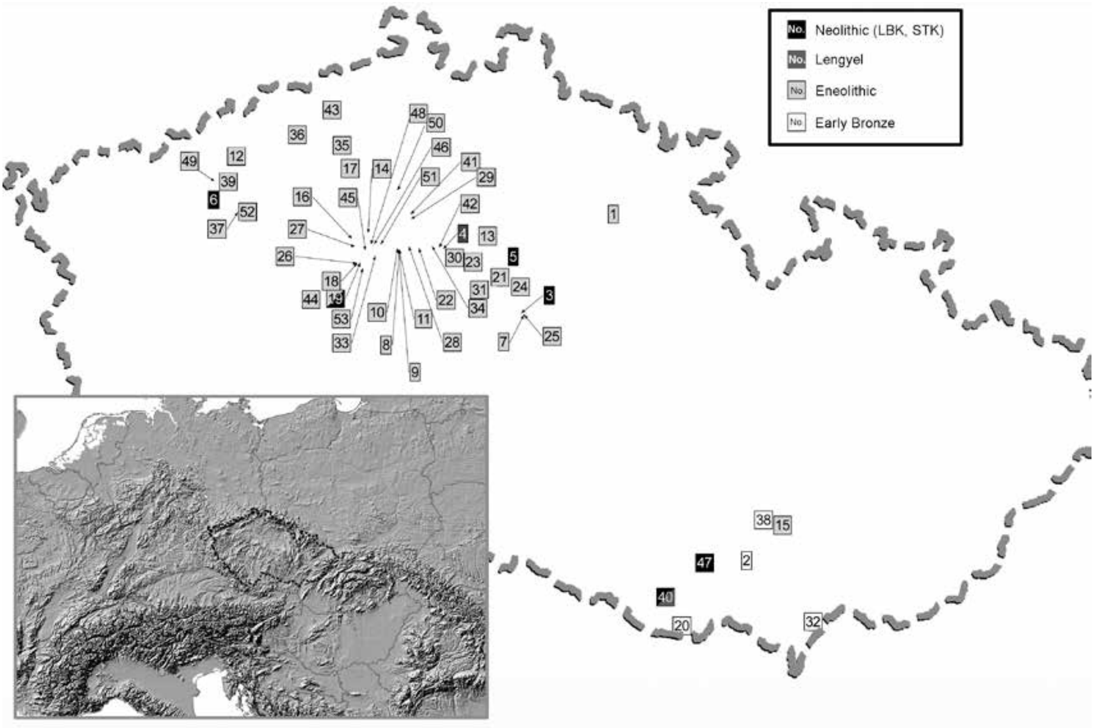

FIGURE 1

Map of the Czech Republic with localities which provided osteometric data for the study. Localities are sorted according to main archaeological periods. Locality codes correspond to those used in Table 1. The position of the Czech Republic in the Central European geomorphological situation is shown in Figure inset. Broken lines = state border of CR. Image by R. Kyselý with using geographical map from http://www.eea.europa.eu/.

osteometric data, represented less or only rarely, or are not represented at all (e.g. Corded Ware C.).

Localities, data and taphonomy

The localities that provided the data for the analyses presented here (Figures 3-29) are given in Table 1 and Figure 1. Most of them are part of the synthesis by Kyselý (2010a), which includes osteometric data representing the majority of the processed Lengyel and Eneolithic material thus far obtained through archaeological excavations in the territory of the Czech Republic. Methodological uniformity is largely ensured by the fact that the data were mostly obtained, or at least were methodologically treated, by the author himself. The primary osteometric data, the survey on fauna, quantifications and other data related to the material and localities are included in Kyselý (2010a) and other source studies cited in Table 1. Unlike in the source works, small corrections have been made including the re-interpretation of the status (domestic / wild / indet.) of some finds. Newly obtained data from the well-known Neolithic locality Bylany are also included.

Only selected measurements were analysed. Of the total amount of collected osteometric data nearly 1100 data (measuring) representing c. 900 finds from 53 localities (Table 1) have been used. The amount of data in individual animal species and single dimensions differ: a total of c. 730 metric values for cattle have been analysed, c. 110 for sheep/goats and c. 230 for pigs. In the graphs, the material is mostly presented in the form of primary osteometric values (points). These primary data could also be tested statistically. However, in the case of the relatively extensive material from sites at Makotřasy, Chotěbudice and Hostivice-Sadová (Clason, 1985; Kovačiková *et al*., 2012) the primary data were not published, and therefore only the available histograms or boxplots are used here.

site code	site name	region	period / phase	culture (stage)	source of primary osteometric data	source of further information	osteometric data used **		
correspond to Figure 1		*	see Figure 2	see Figure 2 *			*Bos*	O/C	*Sus*
1	Benátky	BO	Eneolithic early	TRB-Baalberge	Kyselý, 2010a	Kyselý, 2012	X		
2	Blučina-Cezavy	MO	Bronze	Únětice C.	Roblíčková, 2003b, 2004	Roblíčková, 2003a	X	X	
3	Bylany	BO	Neolithic (pre-Lengyel)	LBK	R. Kyselý, unpublished	Peške et al., 1998	X		X
4	Čelákovice	BO	Lengyel	LGK (late phase)	Kyselý, 2010a	Kyselý, 2012	X		X
5	Choťánky	BO	Neolithic (pre-Lengyel)	STK	R. Kyselý, unpublished		X	X	X
6	Chotěbudice	BO	Neolithic (pre-Lengyel)	LBK	Kovačiková et al., 2012		x***		
7	Cimburk	BO	Eneolithic early	TRB-Baalberge	Kyselý, 2010a	Peške, 2000; Kyselý, 2012	X		X
7	Cimburk	BO	Eneolithic early/middle	TRB-Baalberge + Boleráz phase	Kyselý, 2010a	Peške, 2000; Kyselý, 2012	X		X
8	Ďáblice-K Letňanům	BO	Proto-Eneolithic	Jordanów C. (late phase)	Kyselý, 2010a	Kyselý, 2007a, 2012	X	X	X
9	Ďáblice-K lomu	BO	Eneolithic middle	Řivnáč C.	Kyselý, 2010a	Kyselý, 2007b, 2012	X		X
10	Ďáblice-křižovníci	BO	Eneolithic early	TRB-Siřem	Kyselý, 2010a	Kyselý, 2012	X		
11	Ďáblice-Legionářů	BO	Proto-Eneolithic	Jordanów C. (late phase)	Kyselý, 2010a	Kyselý, 2009, 2012	X		X
11	Ďáblice-Legionářů	BO	Eneolithic Proto-/early	Jordanów C. (late phase) / TRB	Kyselý, 2010a	Kyselý, 2009, 2012	X	X	
12	Droužkovice	BO	Proto-Eneolithic	Jordanów C. (Schussenried)	Kyselý, 2010a	Kyselý, 2012	X		
13	Dvory-Liduška	BO	Eneolithic early	TRB	Kyselý, 2010a	Kyselý, 2012	X		
14	Holubice	BO	Eneolithic middle	Řivnáč C.	Kyselý, 2010a	Kyselý, 2012	X		X
15	Holubice II	MO	Eneolithic late	BBC	Peške, 1985a		X	X	
16	Homolka	BO	Eneolithic middle	Řivnáč C. (middle phase)	Ambros, 1968; Bogucki, 1979		X	X	X
17	Hostěnice	BO	Eneolithic early	TRB-Salzmünde	Kyselý, 2010a	Kyselý, 2012, 2013	X	X	X
18	Hostivice-Litovice	BO	Eneolithic early	TRB-Baalberge	Kyselý, 2002a	Kyselý, 2012	X		
19	Hostivice-Sadová	BO	Neolithic (pre-Lengyel)	LBK	Kovačiková et al., 2012		x***		
19	Hostivice-Sadová	BO	Eneolithic early	TRB	Kyselý, 2010a	Kyselý, 2012	X		X
20	Hrádek	MO	Bronze	Únětice C.	Roblíčková, 2003b, 2004	Roblíčková, 2003a	X		
21	Hradenín	BO	Eneolithic middle	Řivnáč C.	Kyselý, 2010a	Kyselý, 2012	X	X	
22	Jenštejn	BO	Proto-Eneolithic	Jordanów C. (phase Jenštejn)	Beech, 1995		X		X
23	Klučov	BO	Eneolithic middle	GAC	Kyselý, 2010a	Kyselý, 2008d, 2012	X		X
23	Klučov	BO	Eneolithic middle	Řivnáč C. (early phase)	Kyselý, 2010a	Kyselý, 2008d, 2012	X		X
24	Kolín (bypass)	BO	Eneolithic middle	řivnáč starší	Dobeš et al., 2013		X		
25	Kutná Hora-Denemark	BO	Eneolithic middle	Řivnáč C. (middle-late phase)	Kyselý, 2008b	Kyselý, 2008a, 2012	X	X	X
26	Litovice	BO	Eneolithic early	TRB	Kyselý, 2010a	Kyselý, 2012	X	X	X
26	Litovice	BO	Eneolithic middle	Řivnáč C.	Kyselý, 2010a	Kyselý, 2012	X		X
27	Makotřasy	BO	Eneolithic early	TRB-Siřem	Clason, 1985		x***		
28	Miškovice	BO	Eneolithic middle	Řivnáč C. (early phase)	Kyselý, 2010a	Kyselý, 2012, Ernée et al. 2007	X	X	X
29	Mlékojedy	BO	Eneolithic early	TRB-Baalberge	Kyselý, 2010a	Kyselý, 2012	X		
29	Mlékojedy	BO	Eneolithic middle	Baden C. (phase II)	Kyselý, 2010a	Kyselý, 2012			X
30	Mochov	BO	Eneolithic early	TRB-Salzmünde	Kyselý, 2010a	Kyselý, 2012	X	X	X
31	Molitorov	BO	Eneolithic early	TRB	Kyselý, 2010a	Kyselý, 2012			X
32	Moravská Nová Ves	MO	Bronze	Únětice C.	Roblíčková, 2003b, 2004	Roblíčková, 2003a	X	X	
33	Nebušice	BO	Proto-Eneolithic	Jordanów C. (Schussenried)	Kyselý, 2010a	Kyselý, 2012	X		X
34	Ostrov-Zápy	BO	Eneolithic middle	Řivnáč C.	Kyselý, 2010a	Kyselý, 2012	X	X	X
35	Prosmyky	BO	Eneolithic early	TRB	Kyselý, 2010a	Kyselý, 2012	X		X
36	Radovesice	BO	Eneolithic late	BBC	Beech, 1993		X		
37	Siřem	BO	Eneolithic early	TRB-Siřem	Kyselý, 2010a	Kyselý, 2012; Likovský & Kyselý, 2008			X
38	Šlapanice	MO	Bronze	Únětice C.	Roblíčková, 2003b, 2004	Roblíčková, 2003a	X	X	X
39	Soběsuky	BO	Eneolithic middle	Řivnáč C.	Kyselý, 2010a	Kyselý, 2012	X	X	X
40	Těšetice-Kyjovice	MO	Neolithic (pre-Lengyel)	LBK	Dreslerová, 2006		X	X	X
40	Těšetice-Kyjovice	MO	Lengyel	LGK (MMK-Ia)	Dreslerová, 2006		X	X	X
41	Tišice	BO	Eneolithic middle	Baden C. / Řivnáč C. (late phase)	Kyselý, 2010a	Kyselý, 2012			X
42	Toušeň-Hradišťko	BO	Eneolithic middle	Řivnáč C.	Kyselý, 2010a	Kyselý, 2012	X	X	X
43	Trmice	BO	Proto-Eneolithic	Jordanów C. (Schussenried)	Kyselý, 2010a	Kyselý, 2012	X	X	X
44	Trubín	BO	Proto-Eneolithic	Jordanów C. (Schussenried)	Kyselý, 2010a	Kyselý, 2012	X		X
45	Tuchoměřice	BO	Proto-Eneolithic	Jordanów C. (early phase)	Kyselý, 2010a	Kyselý, 2012	X	X	
45	Tuchoměřice	BO	Eneolithic middle	Řivnáč C. (early phase)	Kyselý, 2010a	Kyselý, 2012	X		
45	Tuchoměřice	BO	Eneolithic middle	Řivnáč C.	Kyselý, 2010a	Kyselý, 2012	X		X
46	Úholičky	BO	Eneolithic middle	Řivnáč C.	Kyselý, 2010a	Kyselý, 2008c, 2012		X	X
46	Úholičky	BO	Eneolithic late (+middle?)	BBC (+ Řivnáč C.?)	Kyselý, 2010a	Kyselý, 2008c, 2012			X
47	Vedrovice	MO	Neolithic (pre-Lengyel)	LBK	Nývltová-Fišáková, 2004		X	X	
48	Velké Přílepy-Skalka	BO	Eneolithic early	TRB	Kyselý, 2010a	Kyselý, 2012	X	X	
48	Velké Přílepy-Skalka	BO	Eneolithic early	TRB-Salzmünde	Kyselý, 2010a	Kyselý, 2012	X		X
48	Velké Přílepy-Skalka	BO	Eneolithic early	TRB-Siřem	Kyselý, 2010a	Kyselý, 2012	X		
48	Velké Přílepy-Skalka	BO	Eneolithic early/middle	TRB-Siřem, Salzmünde, Baden, GAC	Kyselý, 2010a	Kyselý, 2012	X	X	X
48	Velké Přílepy-Skalka	BO	Eneolithic early/middle	Baden C. (/ TRB + Boleráz)	Kyselý, 2010a	Kyselý, 2012			X
49	Vikletice	BO	Eneolithic early	TRB-Siřem	Kyselý, 2010a	Kyselý, 2002b, 2012	X	X	X
50	Vlíněves	BO	Eneolithic middle	Řivnáč C.	R. Kyselý, unpublished	Dobeš et al., 2011	X		X
51	Žalov	BO	Eneolithic middle	Řivnáč C.	Kyselý, 2010a	Kyselý, 2012	X		X
52	Želeč	BO	Proto-Eneolithic	Jordanów C. (Schussenried)	Kyselý, 2010a	Kyselý, 2012	X		
53	Zličín	BO	Eneolithic middle	Řivnáč C.	Kyselý, 2010a	Kyselý, 2012			X

TABLE 1

List of the Czech localities used in this study, arranged alphabetically. Locality codes correspond to those used in the map in Figure 1. *For acronyms see text; **Data available and used for particular taxon marked by ×, O/C = *Ovis* / *Capra*; ***Raw data not given, only histograms available.

There are geographic differences in the representation of cultures, since in Bohemia osteometric data from the Lengyel, Late Eneolithic (BBC) and Early Bronze (Únětice C.) are almost absent, while in Moravia osteometric data from the Early and Middle Eneolithic (TRB, Řivnáč, Jevišovice C.) are missing (cf. Table 1 and Figure 2). Nevertheless, all the analysed assemblages come from

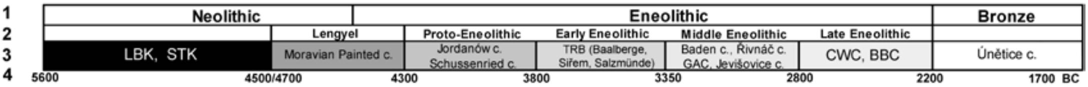

FIGURE 2

Chronology and dating of the Czech archaeological cultures and periods (after Pavlů & Zápotocká *et al*., 2013; Neustupný *et al*., 2013; Jiráň *et al*., 2013). 1 = main periods, 2 = period sub phases, 3 = archaeological cultures, 4 = dating (BC calibrated). All presented cultures except CWC and Jevišovice C. yielded osteometric data.

localities representing lowland agricultural settlements (either in flat land or on mounds or promontories). All of the material comes from sunken archaeological features; material from caves, tells, peat or underwater sites, and material from the settlement layers is not represented. Therefore, considering their similar origins, the individual samples are in the right condition to conduct taphonomic processes with comparable impacts. In general, the material is heavily fragmented as reflected in the very low number of complete long bones for example. Thus, the work has to rely on dimensions other than the lengths of long bones. With regard to strong taphonomic disintegration and reduction of skeletons and spatial distribution of the material (in many archaeological contexts, features and sites), the author expects that in most cases one individual is represented only by one bone/fragment.

As the evidence of one locality can potentially be anomalous, it is preferable for the evaluation that the results from the most analysed cultures are based on more than one locality (cf. Table 1). A particularly large number of localities are available in the case of the dominant Funnelbeaker (TRB) and Řivnáč Cultures. Nevertheless, the really numerous osteological samples are available for only a small number of localities. As one locality (sample) usually provided only a small amount of osteometric data, this study operates with units formed by the grouping (merging) of several samples (localities). The method of fusion and categorization, as well as the quantity of the data used for the analysis is obvious from individual graphic comparisons.

General remarks on the size and metric variability

The work takes into consideration the following facts, assumptions and studies:

(1) Genetically-based variability of body size and bone dimensions in conspecific populations living at the same place and time consists of several components which were for the purposes of archaeozoology clearly defined by Payne & Bull (1988). The main components are: (a) individual age, (b) sex (including castration), (c) breed/form/taxon and (d) residual individual variability. It is necessary to also take into consideration the effect of pathologies (Albarella, 1997; Bartosiewicz, 2013). The fact that sexual dimorphism in size (and dimensions of bones) is reduced in domesticated forms compared with wild forms is also taken into account (Bökönyi, 1962; Benecke, 1994; Hannah *et al*., 2005; Zeder *et al*., 2006).

(2) As well as genetic influences, the size of the body, size of bones and variability in the size is also influenced by the physical condition, diet, milking and other external conditions, and therefore are also affected by the method of feeding, human care and general management of the animals. The fact that these factors influence the growth leads from observations within zootechnology and anthropology as well as zoology. It is also well known in archaeozoology (Higham, 1969). Of course, the influence of external factors is limited. For example heritability (H^2) of the wither height in domestic ungulates is said to be high; in artiodactyls H^2 is usually between 0.5 and 0.8 depending on various factors (for cattle see Nephawe *et al*., 2004; Riley *et al*., 2007). There is only a small amount of data available on bone size heritability. On the length of cattle metacarpus and metatarsus Wilson *et al*. (1977) found that h^2 are 0.48 and 0.59. H^2 for the breadth and depth of metapodials are, based on the same study, between 0.29 and 0.65.

(3) Animals crossbred between breeds of a different body size have, on average, a body size somewhere between those of the parents. This fact is also generally valid for

farm animals. Nevertheless, it is necessary to take into consideration the possibility of the specific influence of heterosis or, on the contrary, of outbreeding depression (e.g. Johnson, 1981; Frisch, 1987). The well-known phenomenon of 'regression to the mean' (Galton, 1886) is also of general validity.

(4) The body size is reflected in the sizes of postcranial bones. The lengths of long bones of domestic animals correlate relatively well with the withers height (WH), and are used for WH estimation[1]. It is obvious that the average body weight representing the given breed/taxon is also reflected in the sizes of the bones, especially cross-sectional measurements of limb bones, as they bear the animal's weight (Uerpmann & Uerpmann, 1994; Meadow, 1999; Mendoza *et al*., 2006; Kyselý, 2008a). According to Scott (1985, 1990) and Gingerich (1990) in particular the breadths of long bones and lengths of the humerus and femur have, on the supra-specific level, a rather high correlation with an average body mass. On an intra-specific level, the correlation of dimensions of the postcranial bones with the body mass is not very high, but it is positive and in many cases statistically significant (see for example studies concerning domestic cattle: Higham, 1969; Noddle, 1973; Dikeman *et al*., 1976; Wilson *et al*., 1977; Bergström & Wijngaarden-Bakker, 1983). In palaeontology the craniodental measurements are also used for the assessment of the body size, but they are under other selection pressures and therefore their correlation with the dimensions of extremity bones and with WH is lower (Damuth, 1990; Uerpmann & Uerpmann, 1994; Mendoza *et al*., 2006). However, even the estimation of the height from extremity bones is accompanied by problems and inaccuracies, which are particularly reported in estimations based on short bones such as the talus and calcaneus and, in the case of pigs, also the metapodials (see methodical papers cited[1]). Despite these inaccuracies, selected estimations are provided in this paper as an alternative to the raw osteometric data, which helps to image the ancient breeds (Table 2).

(5) In a broader geographic frame, it is necessary to take into consideration the general clinial variability and eco-geographic principles such as Bergmann´s rule (Bergmann, 1847) or Allen´s rule (Allen, 1877). However, within the relatively small Czech territory, it did not play a significant role, and therefore it is not taken into account for the intra-regional frame.

(6) In the broader time frame it is necessary to consider domestication trends. The general tendency of body-size reduction during the course of domestication in a number of species, including cattle, sheep, goats and pigs, is widely known (e.g. Zeuner, 1963; Bökönyi, 1974; Davis, 1981; Clutton-Brock, 1999; Zeder *et al*., 2006; see also note[13]). Sophisticated and systematic breeding, based on artificial selection such as grading up and resulting in large breeds was, in the Czech lands, only applied in the 20th century AD, although occasional imports of animals of foreign breeds are recorded from the 17th century AD (Petrášek, 1972). The actual forms of the temporal trends and evolution of the animal size in the studied region are analysed in the results section.

(7) Climate models for the Czech territory reveal temperature fluctuations of a mere 1ºC and 100 mm of precipitation in the period ranging from the Neolithic to the Bronze Age (Dreslerová, 2012. Dreslerová *et al*., 2007). Natural selection could affect domestic animals but rapid changes in body size would be unlikely under such circumstances. For such reason the impact of climate, and the other natural agents has not been considered important for our study (see Kyselý & Peške, 2016).

(8) The proportions of the body and osseous dimensions also depend on various factors. The above-mentioned factors, for example sex and age, can thus result in distinctive allometries and significant morphological variability; strikingly in the case of the size of horns of domestic bovids, but pronounced allometries also occur between the pairs of dimensions, such as the length vs. breadth of extremity bones and the sizes of teeth vs.

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[1] Methods in Driesch & Boessneck, 1974; May *et al*., 1996; May & Teichert, 2001; Teichert, 2005; Rehazek & Nussbaumer, 2012.

long bones. The individual skeletal dimensions react to the above-mentioned factors differently, as described for domestic cattle, sheep and pigs in papers by Higham (1969), Bartosiewicz (1984, 1985, 1987, 2013), Payne & Bull (1988), Berteaux & Guintard (1995) and Davis (2000). For example, the higher load of the forelimbs than hind limbs may lead to size-determined allometries (Bartosiewicz, 1987, 2013). The result of the disproportional load is the fact that the breadths of the fore limb bones display more sexual dimorphism than do equivalent bones in the hind limb, which is especially apparent and well known in metacapals (described in cattle by Calkin, 1960, 1962; Higham, 1969; Bartosiewicz, 1987; Thomas, 1988; Berteaux & Guintard, 1995). The allometries, often reflecting geographical or chronological position, commonly develop during the process of domestication of animals, including European cattle, sheep/goats

A - *Bos*					**measurements (mm)**				**indices (metapodials only)**			**withers height (cm)**								
												after Fock (1966)		after Calkin (1960)			after Matolcsi (1970)			
site (see Table 1 and Figure 1)	culture (see Figure 2)*	zoological determination*	anatomy*	sex, age (C = castrate)	GL	Bp	SD	Bd	Bp/GL*100	SD/GL*100	Bd/GL*100	indices for females used	indices for males used	indices for females used	indices for castrates used	indices for males used	indices for females used	indices for castrates used	indices for males used	sexually undifferentiated index used
Vedrovice	LBK	BT	MTC	not given	not given												145.1 (index not given)***			
Prosmyky	TRB	BT	MTT		200.3	46.2	26.6	54.2	23.1	13.3	27.1	107.2	111.2	107	110	111.8	105.8	114.4	112.6	
Cimburk	Baalberge	BT	MTC		(210)			70			(33.3)	(126)	(131.3)	(125.6)	(128.7)	(131)	(127.1)	(142.2)	(132.9)	
Hostivice-Litovice	Baalberge	BT	Femur	♀ **	367	115.5	38.3	100.5												118.5
Hostivice-Litovice	Baalberge	BT	Humerus	♀ **	290	104.4	39.6	82												120.1
Hostivice-Litovice	Baalberge	BT	Radius	♀ **	267.5	83.7	41.8	74.6												115
Hostivice-Litovice	Baalberge	BT	Tibia	♀ **	329.5	99.3	40.4	64.4												113.7
Hostivice-Litovice	Baalberge	BT	MTC	♀ **	191.8	60.8	31.3	62.3	31.7	16.3	32.5	115.1	119.9	114.7	117.6	119.7	116	129.8	121.4	
Hostivice-Litovice	Baalberge	BT	MTC	♀ **	192.2	60.1	32.1	62.3	31.3	16.7	32.4	115.3	120.1	114.9	117.8	119.9	116.3	130.1	121.7	
Hostivice-Litovice	Baalberge	BT	MTT	♀ **	218.5	51	27	56.7	23.3	12.4	25.9	116.9	121.3	116.7	120	121.9	115.4	124.8	122.8	
Makotřasy	TRB-Siřem	BT	MTC	not given	two estimations of WH from Clason (1985): 123 cm and 124 cm by two MTC (after Boessneck 1956)*** which are smaller than most of other MTC found in Makotřasy															
Hostěnice	Salzmünde	BT	MTC	♀?, subad.	192.5	57	32.1	62.2	29.6	16.7	32.3	115.5	120.3	115.1	118	120.1	116.5	130.3	121.9	
Hostěnice	Salzmünde	BT	MTT		228		27.3	61.8		12	27.1	122	126.5	121.8	125.2	127.2	120.4	130.2	128.1	
Vikletice	TRB (Siřem)	BT	MTC	♂?	188.4	61.2	33.9	64.7	32.5	18	34.3	113	117.7	112.7	115.5	117.6	114	127.5	119.3	
Homolka	Řivnáč C.	BT	Tibia		329		37	60												113.5
Holubice	Řivnáč C.	BT	MTC	C?, subad?	224.2	64	35	62	28.5	15.6	27.7	134.5	140.1	134.1	137.4	139.9	135.6	151.8	141.9	
Homolka	Řivnáč C.	BT	MTT		226.5	46	28	56	20.3	12.4	24.7	121.2	125.7	121	124.3	126.4	119.6	129.3	127.2	
Homolka	Řivnáč C.	BT	MTT		226	46	26	51	20.4	11.5	22.6	120.9	125.4	120.7	124.1	126.1	119.3	129	126.9	
Toušeň-Hradišťko	Řivnáč C.	BP	MTC		230.8	74.8	38.2	72.5	32.4	16.6	31.4	138.48	144.25	138		144	139.6		146.1	
Tuchoměřice	Řivnáč C.	BT	MTC	♀	190.2	51.7		53.9	27.2		28.3	114.1	118.9	113.7	116.6	118.7	115.1	128.8	120.4	
Tuchoměřice	Řivnáč C.	BT	MTC	♀	190.6	51	27	54.2	26.8	14.2	28.4	114.4	119.1	114	116.8	118.9	115.3	129	120.6	
Tuchoměřice	Řivnáč C.	BT	MTT		(221)	42.4	24.3	51	(19.2)	(11)	(23.1)	(118.2)	(122.7)	(118)	(121.3)	(123.3)	(116.7)	(126.2)	(124.2)	
Kutná Hora-Denemark	Řivnáč C.	BP	MTT		279.5	65.5	40	74.9	23.4	14.3	26.8	149.5	155.1	149.3		156	147.6		157.1	
Klučov	Řivnáč C.	BT	Femur		(405)	124.1	38.7													(130.8)
Klučov	Řivnáč C.	BT	Humerus		328.2		38.3	90.5												135.9
Klučov	Řivnáč C.	BP	Tibia		441	117.4		76.8												152.1
Klučov	Řivnáč C.	BT	MTC	C?	219.5	62.4	36.5	63.3	28.4	16.7	28.8	131.7	137.2	131.3	134.6	137	132.8	148.6	138.9	
Klučov	Řivnáč C.	BT	MTC	C?	(219.5)		(36.7)	62.1			(28.3)	(131.7)	(137.2)	(131.3)	(134.6)	(137)	(132.8)	(148.6)	(138.9)	
Klučov	Řivnáč C.	BP	MTT		283.1	60.1	31.5	70.7	21.2	11.1	25	151.5	157.1	151.2		158	149.5		159.1	
Tuchoměřice	Řivnáč C.	BT	Humerus		311		42.6	87.1												128.8
Šlapanice	Únětice C.	BT	MTT	not given	244	51.2	30.6	64.1	21	12.5	26.3	130.5	135.4	130.3	134	136.1	128.8	139.5	137.1	
Blučina-Cezavy	Únětice C.	BT	MTC	not given, ♀?	189.1	50.7	30.2		26.8	16		113.5	118.2	113.1	115.9	118	114.4	128	119.7	
Blučina-Cezavy	Únětice C.	BT	MTT	not given	222.6	42.6	25.2	53	19.1	11.3	23.8	119.1	123.5	118.9	122.2	124.2	117.5	127.2	125.1	
Blučina-Cezavy	Únětice C.	BT	MTT	not given	213.1	46.7	29	59.1	21.9	13.6	27.7	114	118.3	113.8	117	118.9	112.5	121.8	119.8	
Blučina-Cezavy	Únětice C.	BT	MTT	not given	222.5			50.3			22.6	119	123.5	118.8	122.2	124.2	117.5	127.2	125	
Blučina-Cezavy	Únětice C.	BT	MTT	not given	214.2	43			20.1			114.6	118.9	114.4	117.6	119.5	113.1	122.4	120.4	

B - *Ovis/Capra*				**measurements (in mm)**					**withers height (cm)**			
site (see Table 1 and Figure 1)	culture (see Figure 2)*	zoological determination*	anatomy*	GL (HS)	GLl	Bp	SD	Bd	indices for *Capra* used (after Schramm, 1967)	indices for *Ovis* used (after Teichert, 1975; Tab. 4)	calculated after May & Teichert (2001; Tab. 2a), using indices for males	calculated after May & Teichert (2001; Tab. 2b), using indices for females
Vedrovice	LBK	OA	MTC	not given						82.4***		
Těšetice-Kyjovice	LBK	OA	CA	53						60.4	59.3	
Těšetice-Kyjovice	LBK	OA	CA	58						66.1	62.6	
Těšetice-Kyjovice	LBK	OA	Talus		26					59	64.1	
Choťánky	STK	OA	CA	54.6						62.2	60.4	
Těšetice-Kyjovice	MMK	CH	MTC	97		24	17	27	55.8			
Těšetice-Kyjovice	MMK	CH	MTT	104		21			55.5			
Těšetice-Kyjovice	MMK	OA	Talus		23					52.2	62.3	
Těšetice-Kyjovice	MMK	OA	Talus		24					54.4	62.9	
Těšetice-Kyjovice	MMK	OA	Talus		28					63.5	65.3	
Těšetice-Kyjovice	MMK	OA	Talus		29					65.8	65.8	
Těšetice-Kyjovice	MMK	OA	Talus		31					70.3	66.9	
Těšetice-Kyjovice	MMK	OA	Talus		32					72.6	67.4	
Jenštejn	Jordanów	OA	CA	57.6						65.7	62.4	
Velké Přílepy-Skalka	TRB	OA	Femur	181.7		45.2	17	38.3		64.1	67.7	65.8
Hostěnice	Salzmünde	OA	MTT	130.3		18.8	10.3	22.2		59.2	63	64.4
Velké Přílepy-Skalka	Siřem to GAC	O/C	Talus		31.2			20.2		70.8	67	
Toušeň-Hradišťko	Řivnáč C.	CH	MTC	129.1		28.9	19.7	32.8	74.2			
Toušeň-Hradišťko	Řivnáč C.	OA	CA	64.8						73.9	67	
Toušeň-Hradišťko	Řivnáč C.	OA	MTT	124.5		20	10.3	22.9		56.5	61.4	63.5
Toušeň-Hradišťko	Řivnáč C.	OA	Talus		33.9			22.5		76.9	68.4	
Toušeň-Hradišťko	Řivnáč C.	OA	Talus		30.9			19.6		70.1	66.9	
Homolka	Řivnáč C.	O/C	CA	65						74.1	67.1	
Homolka	Řivnáč C.	O/C	Talus		32					72.6	67.4	
Homolka	Řivnáč C.	O/C	Talus		30.5					69.2	66.7	
Homolka	Řivnáč C.	O/C	Talus		30					68	66.4	
Homolka	Řivnáč C.	O/C	Talus		28					63.5	65.3	
Homolka	Řivnáč C.	O/C	Talus		27					61.2	64.7	
Hradenín	Řivnáč C.	O/C	Talus		32.4					73.5	67.6	
Toušeň-Hradišťko	Řivnáč C.	O/C	Talus		33.8			21.9		76.7	68.3	
Úholičky	Řivnáč C.	O/C	Talus		35.3			22.1		80.1	69.1	
Holubice II	BBC	O/C	Talus		27					61.2	64.7	
Moravská Nová Ves	Únětice C.	OA	MTC	131.9						64.5	65.4	66.6
Šlapanice	Únětice C.	OA	talus		29.9					67.8	66.3	
Blučina-Cezavy	Únětice C.	OA	talus		28.1					63.7	65.3	
Blučina-Cezavy	Únětice C.	OA	talus		27.7					62.8	65.1	
Blučina-Cezavy	Únětice C.	OA	talus		27					61.2	64.7	
Blučina-Cezavy	Únětice C.	OA	talus		25.9					58.7	64.1	
Šlapanice	Únětice C.	OA	MTC	(123)		21	12			(60.1)	(62.6)	(65.2)
Šlapanice	Únětice C.	OA	MTC	(122)		21.7	13.4			(59.7)	(62.3)	(65.1)
Šlapanice	Únětice C.	OA	MTC	(121)		22.6	13.7			(59.2)	(62)	(64.9)
Šlapanice	Únětice C.	OA	MTC	(130)		(21.8)				(63.6)	(64.8)	(66.3)
Blučina-Cezavy	Únětice C.	CH	MTC	112		(24.3)	16	27.9	64.4			

C - *Sus*				**measurements (mm)**	**withers height (cm)**	
site (see Table 1 and Figure 1)	culture (see Figure 2)*	zoological determination*	anatomy*	GL or GLl	calculated after Teichert (1969)	calculated after May et al. (1996; Tab. 2b)
Těšetice-Kyjovice	LBK	SSD	Talus	36	64.4	77.7
Těšetice-Kyjovice	LBK	SSD	Talus	39	69.8	80.3
Těšetice-Kyjovice	LBK	SSD	Talus	40	71.6	81.1
Těšetice-Kyjovice	MMK	SSD	CA	75	70.1	78.3
Těšetice-Kyjovice	MMK	SS	CA	110	102.7	95
Těšetice-Kyjovice	MMK	SS	Talus	54	96.7	91.3
Těšetice-Kyjovice	MMK	SS	Talus	51	91.3	89.2
Ďáblice-K Letňanům	Jordanów (late)	SSD	Talus	42.4	75.9	83
Litovice	TRB	SS	MTC 3	(97.5)	104.5	99.4
Litovice	TRB	SSD	MTC 4	(80.7)	85	88.3
Hostivice-Sadová	TRB	SSD	Talus	40	71.6	81.1
Cimburk	Baalberge	SS	CA	109.5	102.3	94.8
Makotřasy	TRB-Siřem	SSD	not given	not given	60-78.2***	
Hostěnice	Salzmünde	SS	MTC 4	(100.4)	105.7	100.7
Hostěnice	Salzmünde	SS	MTC 3	100.6	107.8	101.3
Hostěnice	Salzmünde	SS	MTT 3	108.5	101.3	100.4
Hostěnice	Salzmünde	SS	MTT 4	120.1	106.2	101.3
Hostěnice	Salzmünde	SS	Talus	56.2	100.6	92.7
Mochov3	Salzmünde	SSD	MTC 3	75.3	80.7	85.4
Velké Přílepy-Skalka	Salzmünde	SSD	MTC 3	72.9	78.1	83.8
Velké Přílepy-Skalka	Salzmünde	SSD	MTC 3	73.4	78.7	84.1
Velké Přílepy-Skalka	Salzmünde	SSD	MTT 4	92	81.3	87.5
Velké Přílepy-Skalka	Baden (/TRB+Boleráz)	SSD	Talus	(43)	(77)	(83.4)
Tišice	Baden/Řivnáč	SSD	Talus	43.4	77.7	83.7
Miškovice	Řivnáč (early)	SSD	Talus	40.8	73	81.7
Holubice	Řivnáč C.	SSD	Talus	42.9	76.8	83.3
Homolka	Řivnáč C.	SSD	CA	81	75.7	81.4
Homolka	Řivnáč C.	SS	CA	104.5	97.6	92.6
Homolka	Řivnáč C.	SSD	Talus	44.5	79.7	84.6
Homolka	Řivnáč C.	SSD	Talus	42.5	76.1	83
Homolka	Řivnáč C.	SS	Talus	50	89.5	88.5
Homolka, hut B	Řivnáč C.	SSD	MTC 4	79.4	83.6	87.4
Homolka, hut B	Řivnáč C.	SSD	CA	83.4	77.9	82.6
Homolka, hut B	Řivnáč C.	SS	Talus	52	93.1	89.9
Ostrov-Zápy	Řivnáč C.	SSD	MTC 3	74	79.3	84.5
Ostrov-Zápy	Řivnáč C.	SSD	Talus	40.9	73.2	81.8
Soběsuky	Řivnáč C.	SSD	MTC 3	76	81.5	85.8
Soběsuky	Řivnáč C.	SSD	MTC 3	76.3	81.8	86
Toušeň-Hradišťko	Řivnáč C.	SSD	MTC 3	75	80.4	85.2
Toušeň-Hradišťko	Řivnáč C.	SSD	CA	78	72.9	79.9
Toušeň-Hradišťko	Řivnáč C.	SSD	CA	80.3	75	81.1
Toušeň-Hradišťko	Řivnáč C.	SSD	MTT 3	83.7	78.2	86.4
Toušeň-Hradišťko	Řivnáč C.	SSD	MTT 3	86.4	80.7	88
Toušeň-Hradišťko	Řivnáč C.	SSD	MTT 4	93.5	82.7	88.3
Toušeň-Hradišťko	Řivnáč C.	SS	CA	97.5	91.1	89.4
Toušeň-Hradišťko	Řivnáč C.	SS/SSD	Talus	50.7	90.8	89
Tuchoměřice	Řivnáč C.	SS	Talus	53.8	96.3	91.2
Kutná Hora-Denemark	Řivnáč C. (late)	SSD	CA	80.1	74.8	81
Kutná Hora-Denemark	Řivnáč C. (late)	SSD	CA	80.5	75.2	81.2
Kutná Hora-Denemark	Řivnáč C. (late)	SS	CA	98.2	91.7	89.7
Kutná Hora-Denemark	Řivnáč C. (late)	SS	CA	102.2	95.5	91.6
Kutná Hora-Denemark	Řivnáč C. (late)	SS	CA	111.7	104.3	95.8
Kutná Hora-Denemark	Řivnáč C. (late)	SSD	Talus	42.4	75.9	83
Kutná Hora-Denemark	Řivnáč C. (late)	SSD	Talus	47.1	84.3	86.5
Kutná Hora-Denemark	Řivnáč C. (late)	SS	Talus	53.6	95.9	91
Kutná Hora-Denemark	Řivnáč C. (late)	SS	Talus	52.8	94.5	90.5
Kutná Hora-Denemark	Řivnáč C. (late)	SS	Talus	55.3	99	92.2
Kutná Hora-Denemark	Řivnáč C. (late)	SS	Talus	55.2	98.8	92.1
Kutná Hora-Denemark	Řivnáč C. (late)	SS	Talus	55.8	99.9	92.5
Šlapanice	Únětice C.	SSD	Talus	40.3	72.1	81.3

TABLE 2

Estimations of the withers height of the Czech Neolithic, Eneolithic and Early Bronze Age cattle (sub-table A), sheep/goats (sub-table B) and pigs (sub-table C). Selected bone measurements and indices included. Grey – estimations by indices in concordance with the sex of an individual. Numbers in parentheses indicate approximate values. *For acronyms see text; **One individual (cattle no. 1 from pit 3, after Kyselý 2002a); ***Exact indices or values not given in original sources, therefore heights are not used in Figure 3, 17 and 21.

and pigs (e.g. Lasota-Moskalewska, 1980; Lasota-Moskalewska *et al*., 1987).

Methods

Those samples with questionable archaeological dating, and finds suspected of intrusion were excluded from the analyses. The dimensions were measured according to Driesch (1976).

In the graphical presentation the measured values as well as the calculated withers heights are grouped according to archaeological age and provenance, which leads to segmentation of the studied period. This segmentation (i.e. merging of the samples/localities) is individual in each graphical analysis; it was necessary because the distribution of the available metric data between the individual comparisons is sometimes highly uneven. Segmentation of the studied period (Lengyel + Eneolithic) in the graphs is numbered starting from 1, the preceding Neolithic (LBK + STK) is labelled as 0. Even though time scale is categorized linear regression was applied. In comparisons with the distinctive decreasing or increasing time trend the linear regression is calculated and displayed in graphs. The non-parametric Mann-Whitney *U* test was used for the testing differences between means of size in particular periods, applied with respect to the amount of available data.

The bones of non-adult individuals and pathological bones have been excluded. The individual age has been assessed not only on the basis of the epiphyseal fusion, but also based on the character of the bone surface and muscle insertions; especially in the case of the elements with an early fusion of the epiphysis or the elements without the epiphysis (talus). In the case of molars dimensions the effect of age or the degree of eruption and abrasion has been taken into consideration (cf. Payne & Bull, 1988). The metric values obviously influenced by age have been excluded. After this methodical treatment, the variability within one time horizon and one region consists mainly of the following genetically-based components:

(*a*) the sex (sexual dimorphism);

(*b*) the form or breed (particularly domestic/wild form in the given case).

The dimensions that display lower sexual dimorphism and lower variability, and that do not display marked allometric differences are preferred in the analyses that follow. In general, those measurements having the best potential to characterize the body size have been selected for the identification of size changes in time. For example, it was taken into account that the dimensions of bones of hind limbs in the artiodactyls are usually less sexually dimorphous than the size of bones of forelimbs as described above. It was also taken into account that many dental dimensions (cheek teeth) show relatively little sexual dimorphism - probably as a result of the rule described by Carranza & Pérez-Barbería (2007). Logically, in the process of selection, in addition to the value of the information provided by the measurement, the amount of available data has also been taken into account. Therefore, the dimensions of the phalanges and molars have also been used and the greatest level of attention was paid to cattle, as they are the most abundant. One of the reasons for carrying out parallel analysis of several dissimilar dimensions is to avoid the risk of making an interpretation based on a single source, which could potentially be erroneous due to random distortion or due to methodological, allometric, demographic or taphonomic reasons. The details concerning the selection of dimensions and of the procedures and methods are given in single species analyses in the results section. Further details concerning particular assemblages and methods are included in Kyselý (2010a).

RESULTS

Cattle (*Bos taurus*)

A classification of the cattle (*Bos*) as domestic cattle (*Bos taurus*) or aurochs (*Bos primigenius*) by using metric limits can be problematic and uncertain. With regard to the existence of overlap in most dimensions (Grigson, 1969; Lasota-Moskalewska & Kobryń, 1989; Kyselý 2008a), some of the finds remained unclassified (labelled as ‘*Bos* indet.’). Specimens which are clearly outside the overlap were interpreted as domestic or wild according to morphometrics, with the help of measurements and suggestions given in Degerbøl & Fredskild (1970), which is based mostly on Danish material, and Bökönyi (1995), based mostly on material from the Carpathian Basin.

The appropriateness of using these two sources comes from their geographical proximity to the studied area and from the position of the studied area between both regions, with respect to the fact that aurochs body size changed only very little during the Holocene (Lasota-Moskalewska & Kobryń, 1990). The determination was in only one case confirmed by the molecular-genetic method (Kyselý & Hájek, 2012).

Absolute size

A combination of the indices from the work of Driesch & Boessneck (1974) and Matolsci (1970) has been used for the calculation of withers height, of which the indices according to Matolcsi are preferred (Table 2, Figure 3). Only in the case of potential castrates is the index by Calkin preferred, as it was created on the basis of a more representative number of neutered individuals. The method of assessment of body mass based on the withers height was proposed by Vigne (1991; the mass is marked as LWa), however, his calculation states weights roughly 10-15% higher than the figures of the combined data (height vs. mass) for various primitive tauroid breeds, according to the examples in Petrášek (1972) and Vohradský (1999). Therefore, the weight data in the following text are given after LWa correction (the calculated LWa is systematically reduced by 13%).

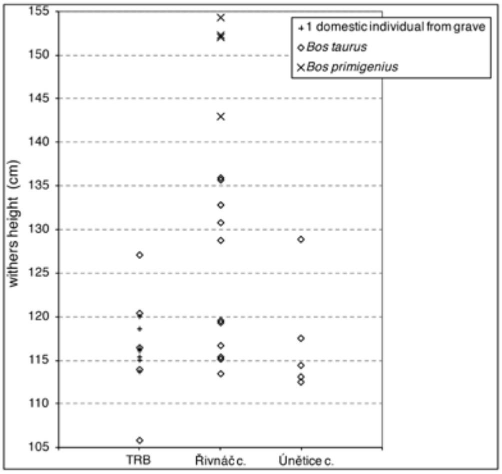

FIGURE 3

Withers heights of cattle (*Bos*) from the two best-represented Eneolithic cultures in the Czech Republic. Based on heights in Table 2 calculated using Matolcsi´s indices. Since a strong predominance of females is observed or expected, indices for females were used in the case of metapodia.

According to finds of long bones from the best-represented periods, i.e. TRB and Řivnáč Culture, withers height (WH) in domestic cows from the Bohemian region was calculated at c. 114-117 cm (n = 17; Table 2). It corresponds with the average body mass c. 350-390 kg. Males could have been c. 5-10 cm higher. Identification of castrates according to isolated bones is mostly very difficult or impossible. However, based on breadth-length index and absolute length, three metapodials from the analysed collection may be castrates (Table 2, 6). The height of these potential castrates was c. 134-138 cm (using the index according to Calkin, 1960), which corresponds to c. 540-590 kg. All these values are considerably lower than the size of aurochs, which during the period of Řivnáč C. attained WH between c. 140 and 160 cm, which corresponds to c. 700-1020 kg (n = 4; Figure 3, Table 2). The values of the WH (if males and females are considered together) suggest that domestic cattle from the TRB period may have been about 5 cm lower (~ 50 kg) than those in the following Řivnáč C. In the Bronze Age WH is somewhat smaller (Roblíčková, 2004), which seems to be true also for the earliest Bronze Age culture, Únětice C. (Figure 3).

The metacarpus and metatarsus lengths are less dependent on sex than the length of other long bones, and according to some calculations are even statistically independent of the sex (Calkin, 1962; Higham, 1969; Wilson *et al*., 1977; Grigson, 1982; Bartosiewicz, 1984, 1985; Thomas, 1988; Berteaux & Guintard, 1995). Therefore, these dimensions are especially suitable for comparison of the body height even in the case where the metapodials are not sexed (Figure 4). From this point of view, however, castrates are problematic since they can have elongated metapodial bones[2]. However, we can assume that the number of castrates in the herd was probably very low (cf. share of males and possible castrates in Table 2, 6), so that they do not influence statistics too much. The comparison of Czech Eneolithic cattle with cattle in neighbouring regions shows that the Czech finds fall into the

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[2] A castration causes the delayed fusion of the epiphyses and consequently the prolongation of the bone lengths (Boessneck, 1956; Calkin, 1960, 1962; Matolcsi, 1970; Grigson, 1982; Thomas, 1988).

		n	arithmetic mean (mm)	median (mm)	min.-max. (mm)
metacarpus - length	Bohemia	9	203.2	194	188.4-224.2
	neighbouring regions	50	196.6	195.9	182-223
metatarsus - length	Bohemia	6	220.1	223.5	200.3-228
	neighbouring regions	41	226	225	180-257

TABLE 3

Statistics of metapodial lengths of Czech Eneolithic cattle (data from this study) compared with those taken from Eneolithic cattle burials/ depositions from neighbouring central European states (data from localities after Kyselý, 2002a) - the same data as in Figure 4. Domestic cattle is here defined using the following criteria: MTC length maximally 230 mm and MTT length maximally 260 mm (with respect to Degerbøl & Fredskild, 1970; Kobryń & Lasota-Moskalewska, 1989; Bökönyi, 1995).

size variation of central European cattle (Figure 4). The mean values of the metapodial lengths in both groups, i.e. Bohemia vs. surrounding areas, do not substantially differ (Table 3).

Changes over time

In the majority of the graphic analyses (Figures 5, 7, 8, 10, 12, 13 & 15) there are presented only the finds determined as domestic cattle (*Bos taurus*) and finds classified as *Bos* indet. Aurochs could be excluded from these comparisons, since a distinctive change in aurochs size is not presumed (cf. Lasota-Moskalewska & Kobryń, 1990). This procedure can assist better visibility of temporal trends in domestic cattle. The dental measurements analysed are the length of the third molar and length of the molar row (Figures 5-7), which in *Bos* are probably only slightly and statistically insignificantly sexually dimorphous, as Grigson (1974, 1982) states and as metric data on aurochs from Degerbøl & Fredskild (1970) suggest. Of the postcranial measurements, the bones of a hind limb have been preferred (tibia and talus; Figures 10, 11, 12) as their breadths are less sexually dimorphous than the breadths of bones of a forelimb (see above). In the literature the distal breadth of the metacarpus is frequently used for comparison. This dimension has therefore also been included (Figures 8, 9), although it displays relatively strong

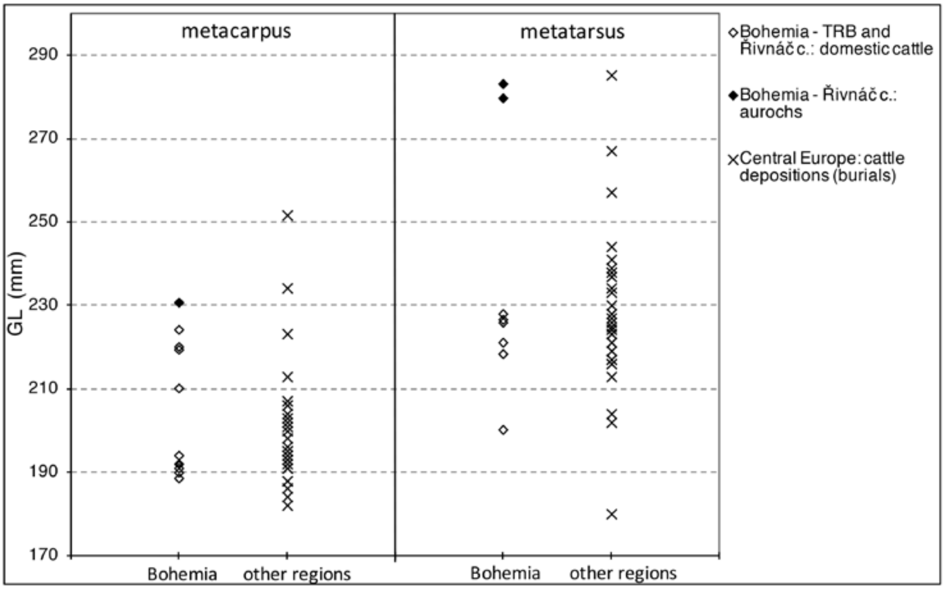

FIGURE 4

Lengths of metapodials (GL) of Czech Eneolithic cattle (data from this study) compared with those taken from Eneolithic cattle burials/ depositions from neighbouring central European countries (data from localities included in Kyselý, 2002a) - the same data as in Table 3.

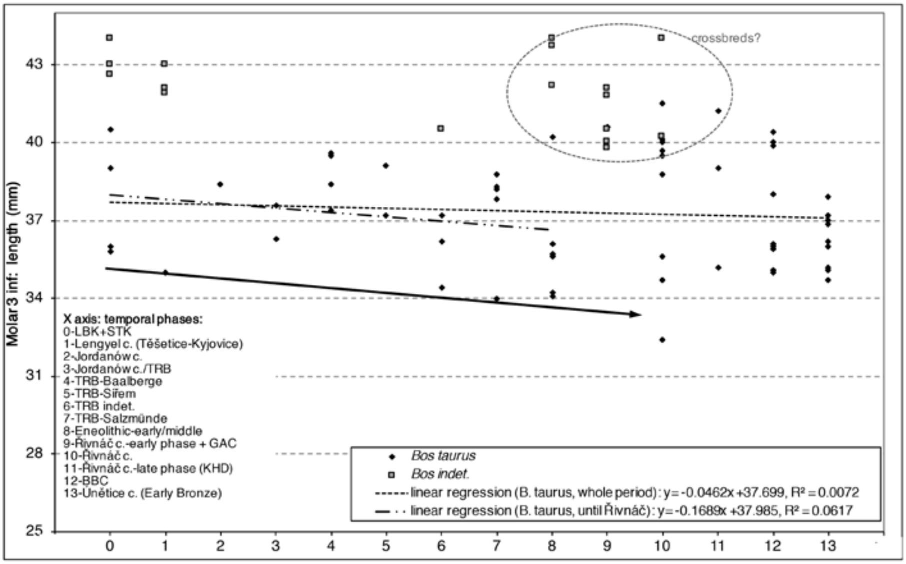

FIGURE 5

Variation over time (X axis) of the *Molar 3 inferior* greatest length (on Y axis, identical to measurement no. 10 in Driesch, 1976) of Czech Eneolithic cattle (*Bos*). *Bos taurus* and *Bos* indet. are included, aurochs is not included. Categories on the X axis are ordered chronologically (pre-Lengyel period labelled as 0). Full lines with arrows indicate roughly min. and max. limits for all or most of the *Bos taurus* cases. Broken lines show linear regressions. Circle indicates the position of potential crossbreds. For sources of data and sites see Table 1and text. For acronyms, terms, methods, definitions and dating of cultures see text and Figure 2.

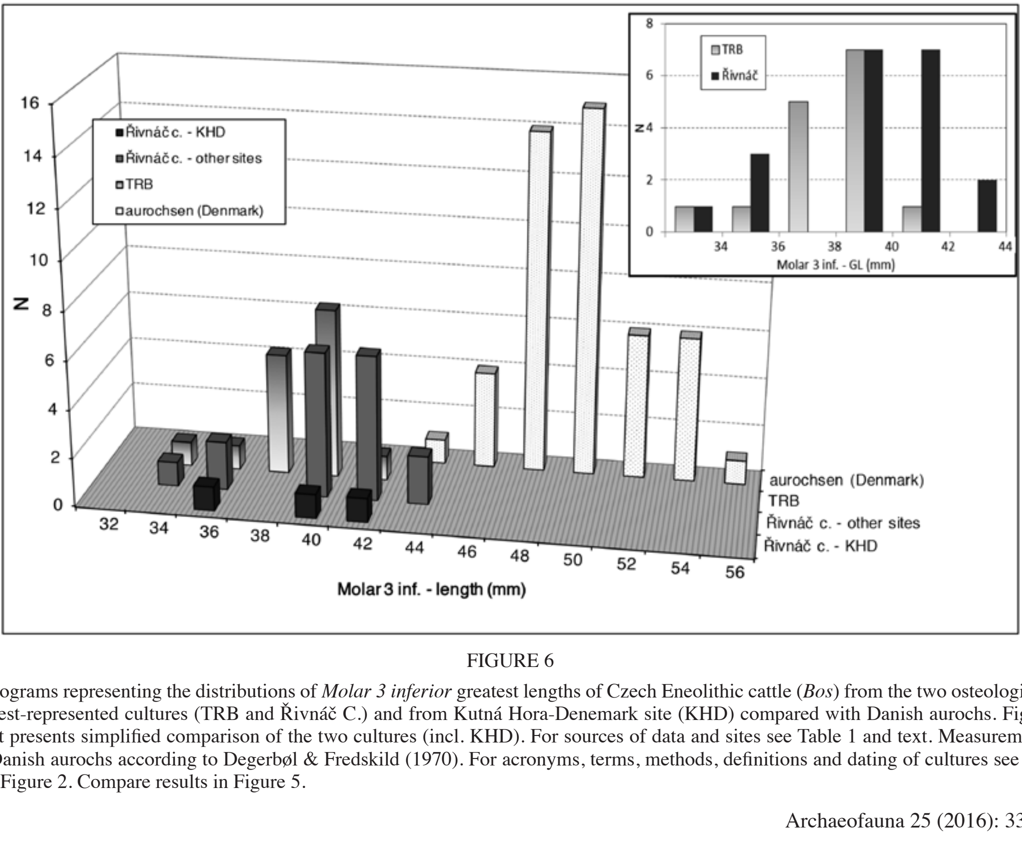

FIGURE 6

Histograms representing the distributions of *Molar 3 inferior* greatest lengths of Czech Eneolithic cattle (*Bos*) from the two osteologically best-represented cultures (TRB and Řivnáč C.) and from Kutná Hora-Denemark site (KHD) compared with Danish aurochs. Figure inset presents simplified comparison of the two cultures (incl. KHD). For sources of data and sites see Table 1 and text. Measurements of Danish aurochs according to Degerbøl & Fredskild (1970). For acronyms, terms, methods, definitions and dating of cultures see text and Figure 2. Compare results in Figure 5.

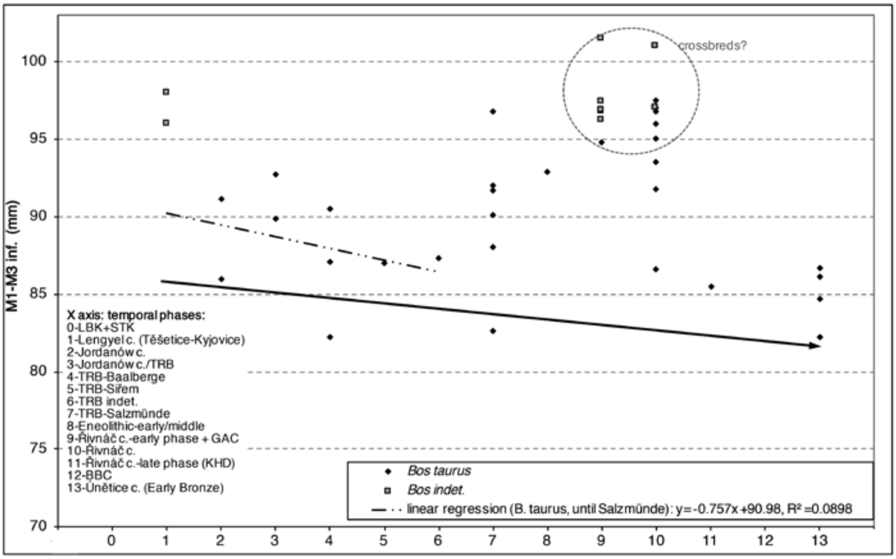

FIGURE 7

Variation over time (X axis) of the *Molar inferior* row alveolar length (on Y axis, identical to measurement no. 8 in Driesch, 1976) of Czech prehistoric cattle (*Bos*). See Figure 5 for further explanatory notes.

sexual dimorphism and a strong overlapping between the domestic and wild forms. The distal tibia (see Bd in Figures 10 & 11) and distal metapodial epiphysis (Bd in Figures 8, 9) fuse at the age of 2-3 years (Silver, 1969; Schmid, 1972), the time when body growth is almost finished or has substantially slowed down. Using fully fused distal ends of these elements eliminates the bones of non-final size. Furthermore, the *phalanges proximales* are compared, which are abundantly represented in the material (Figures 13-15). Their distal breadth is not considerably influenced by the position of the element within the body (according to Bartosiewicz, 1993), thus, at least in the case of distal breadth (Figure 15), all the *phalanges proximales* can be seamlessly evaluated together regardless of whether they originate from fore or hind limb.

Based on the osteometric comparisons, the following facts have been found:

(1) During the studied time interval there is an observed reduction in body size of domestic cattle. It was repeatedly observed in both studied dental (Figures 5, 7) and all studied postcranial (Figures 8, 10, 12, 13, 15) measurements, which is apparent from the inclination of the regression lines. The continuous decreasing trend is visible particularly from the Neolithic up to the turn of TRB and Řivnáč Culture. Subsumption into the category domestic or wild can be partly subjective. Therefore, since the minimum undoubtedly represents domestic animals, it is important that this trend is also displayed by minimal values of partial distributions (see arrows in the graphs).

(2) An interruption of the above described trend was observed, resulting in the shift of distribution towards a bigger body size in the period of the Řivnáč Culture. The difference between the cattle sizes in the Řivnáč C. and previous TRB culture is statistically significant in three of the four evaluated measurements (Table 7). It includes the shift of the mean and sometimes also the shift of the minimum (Figures 12-15). This leads to the accumulation of the values in the transitional (overlapping) zone between the sizes of domestic cattle and aurochs. This shift and the increased frequency of individuals of a 'transitional size' are displayed in the period of Řivnáč C. by all postcranial as well as dental measurements, perhaps with the exception of the metacarpus distal breadth (see circles in Figures 5, 7, 8, 10, 12, 13, 15). The shift between Řivnáč C. and the previous TRB is specially demonstrated by histograms (Figures 6, 9, 11, 14).

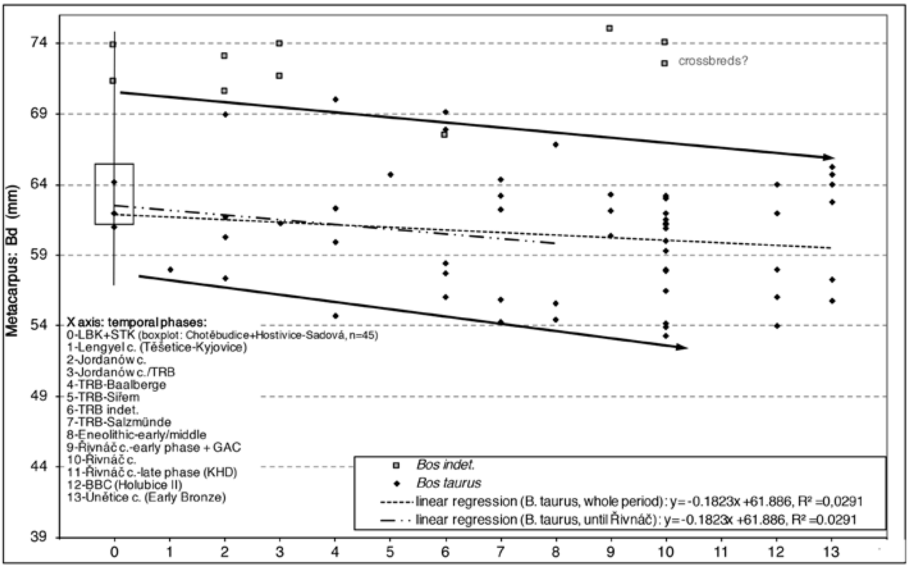

FIGURE 8

Variation over time (X axis) of the *Metacarpus* distal breadth (Bd on Y axis) of Czech prehistoric cattle (*Bos*). Boxplot (based on the histogram by Kovačiková *et al*., 2012) shows min.-max. (line) and 25%-75% quantiles (box) of *Bos taurus* + *Bos* indet. The boxplot is not included into the calculation of regression. See Figure 5 for further explanatory notes.

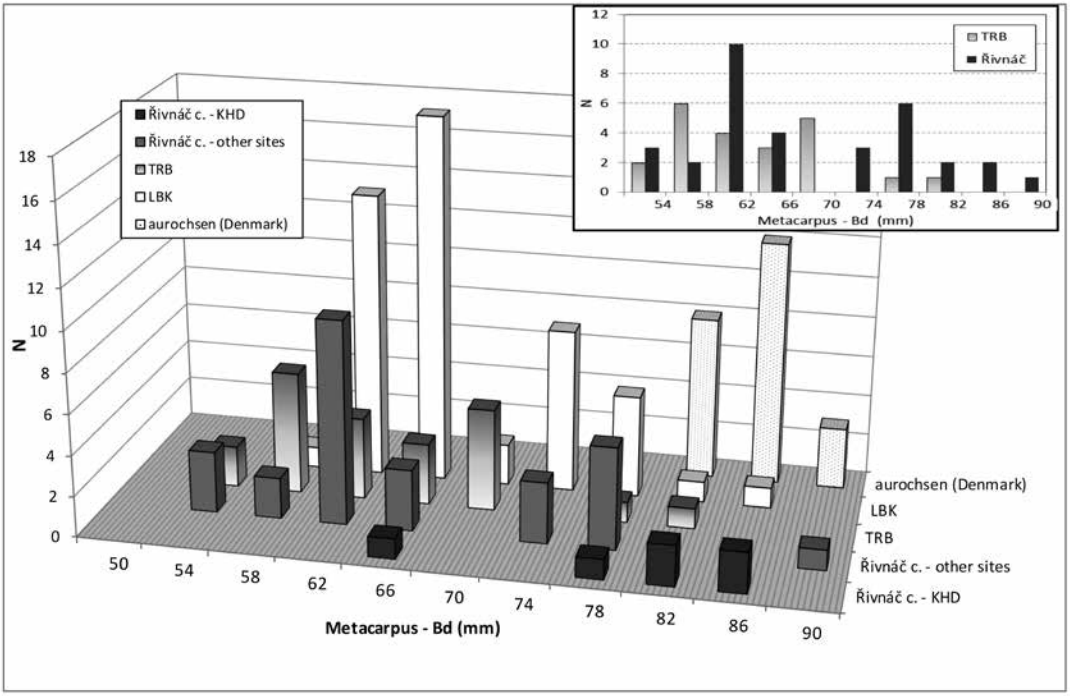

FIGURE 9

Histograms representing the distributions of *Metacarpus* distal breadths of Czech Neolithic and Eneolithic cattle (*Bos*). See Figure 6 for further explanatory notes. Compare results in Figure 8 obtained by using the corresponding data (data from Chotěbudice and Hostivice-Sadová included).

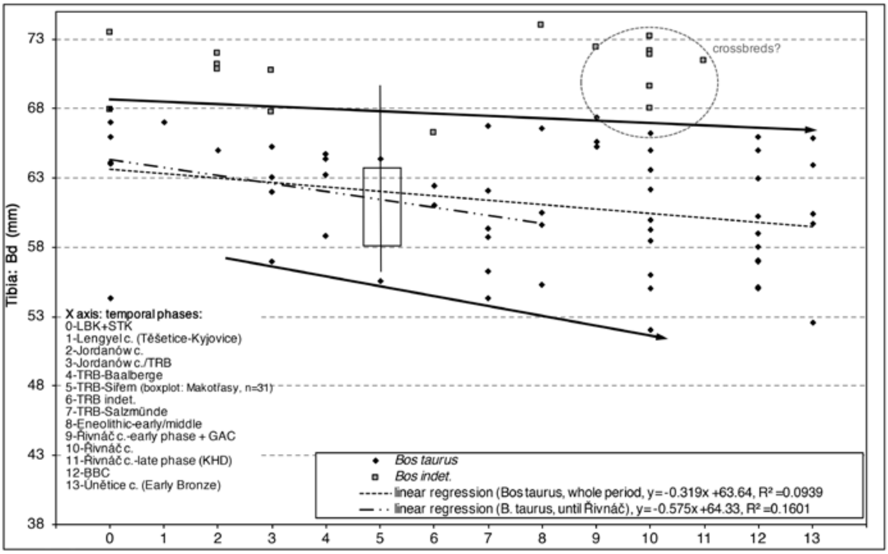

FIGURE 10

Variation over time (X axis) of the *Tibia* distal breadth (Bd on Y axis) of Czech prehistoric cattle (*Bos*). Boxplot (see notes in Figure 8) is based on the histogram by Clason (1985). See Figure 5 for further explanatory notes.

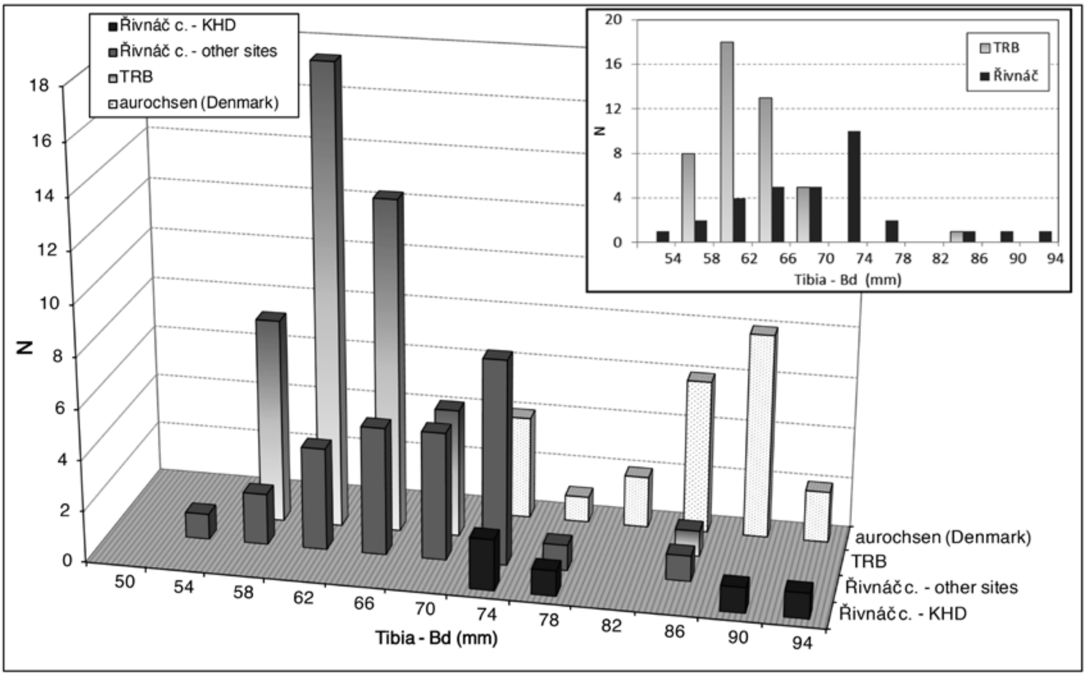

FIGURE 11

Histograms representing the distributions of *Tibia* distal breadths (Bd) of Czech Eneolithic cattle (*Bos*). See Figure 6 for further explanatory notes. Compare results in Figure 10 obtained by using the corresponding data (data from Makotřasy included).

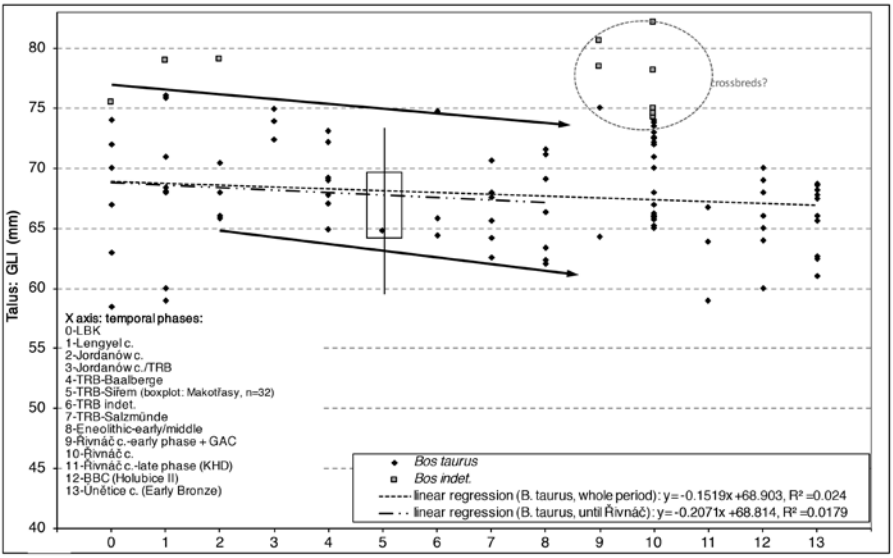

FIGURE 12

Variation over time (X axis) of the *Talus* lateral length (GLl on Y axis) of Czech prehistoric cattle (*Bos*). Boxplot (see notes in Figure 8) based on the histogram by Clason (1985). See Figure 5 for further explanatory notes.

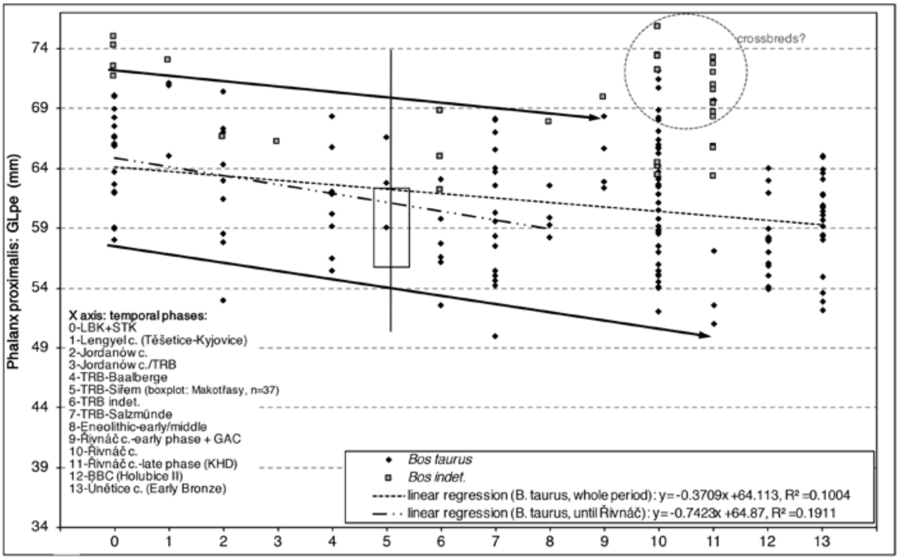

FIGURE 13

Variation over time (X axis) of the *Phalanx proximalis* peripheral length (GLpe on Y axis) of Czech prehistoric cattle (*Bos*). All phalanges included, regardless of position in the body. Boxplot (see notes in Figure 8) based on the histogram by Clason (1985). See Figure 5 for further explanatory notes.

(3) Disproportion between the resulting distributions of dental dimensions and distributions of postcranial dimensions have been observed: almost no teeth attain the size of aurochs, not even in Řivnáč C. (Figure 6), while postcranial dimensions correspond in a number of cases to aurochs (Figures 9, 11 & 14).

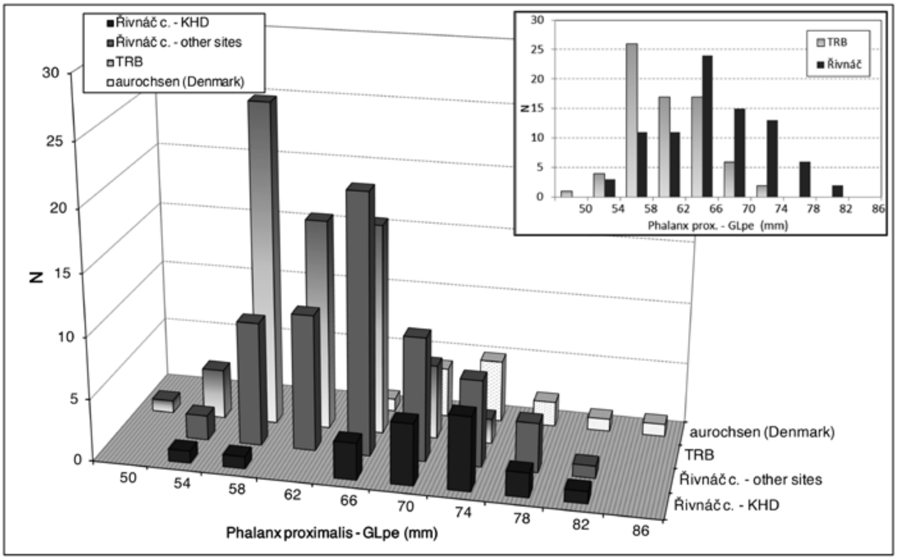

FIGURE 14

Histograms representing the distributions of *Phalanx proximalis* peripheral lengths (Glpe) of Czech Eneolithic cattle (*Bos*). See Figure 6 for further explanatory notes. Compare results in Figure 13 obtained by using the corresponding data (data from Makotřasy included).

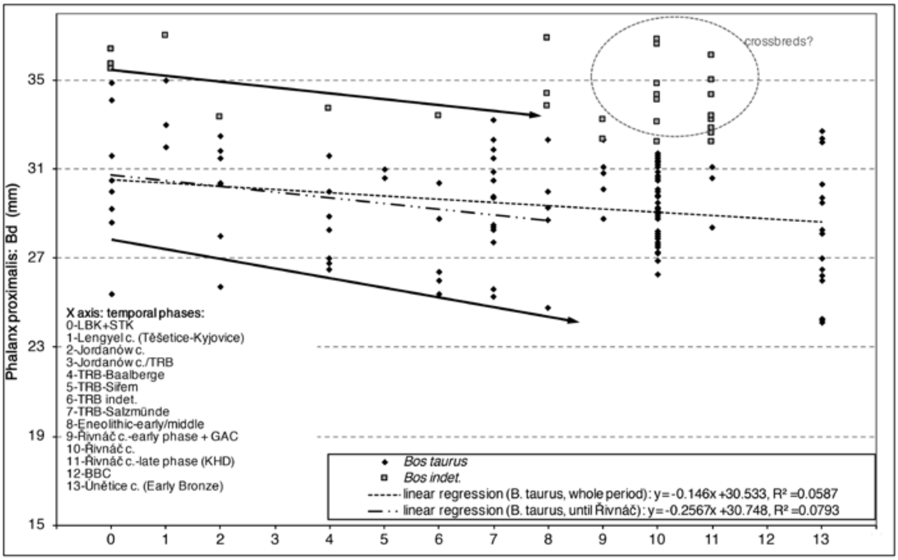

FIGURE 15

Variation over time (X axis) of the *Phalanx proximalis* distal breadth (Bd on Y axis) of Czech prehistoric cattle (*Bos*). All phalanges included, regardless of position in the body. See Figure 5 for further explanatory notes.

Interpretations

Wide metric variabilities found within most of the time horizons (Figures 9, 11, 14) clearly show that the given collection does not represent a single, genetically closed population. This is obvious from comparison with variability in the single homogenous cattle population (e.g. in Higham, 1969; Berteaux & Guintard, 1995). On the basis of metric values, the presence of aurochs as well

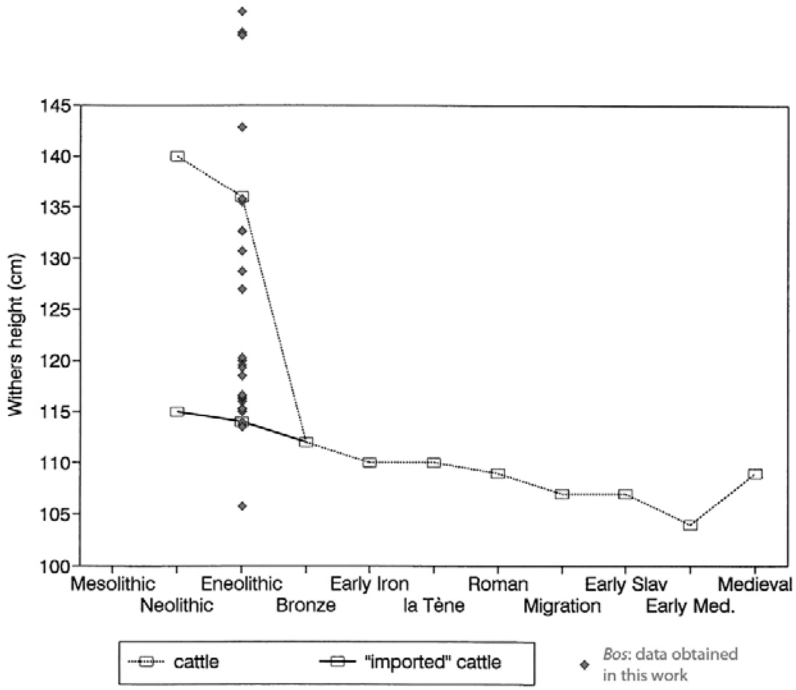

FIGURE 16

Changes in the cattle withers height in Bohemia from the Neolithic to the Middle Ages according to Peške (1994). Data from this study both domestic and wild, presented by grey diamonds are projected onto the original graph constructed by Peške (black squares and lines). Bifid line given for Neolithic-Eneolithic cattle represents the coexistence of domestic and wild forms.

as domestic cattle is also apparent. This proves the coexistence of domestic and wild forms. Also, the occurrence of two or more domestic breeds in the region is not excluded entirely. One could conclude this from the presence of hornless and loose horn cattle beside horned cattle (Ambros, 1988; Kyselý, 2010c), but this observation could also be just the effect of a specific combination of alleles in individuals from a single population. However, in the Neolithic-Eneolithic period a long-term coexistence of genetically non-fused domestic breeds of different body sizes is not expected in such a small region as Bohemia. Several observed outliers, for example particularly small cattle in LBK+LGK according to talus and tibia, can be extremes of real size variability; but unrecognized intrusion from the later period is also not fully excluded. The size of domestic cattle found within the present study does not contradict earlier results from Bohemia (cf. Ambros, 1968; Clason, 1985; Peške, 1994) or results from neighbouring central European regions[3]. The presence of domestic cattle of a very small size, typical for western and south-western European regions was also observed in southern Germany (Glass, 1991; Benecke, 1994). This smaller ('western') breed is presently presumed as far as the northern Pre-Alps (Austria, Mondsee C.; Pucher, 2004, 2006, 2010), but it has not been found further eastwards or in the North (i.e. in Hungary and Poland; Bökönyi & Kubasiewicz, 1961). Also, within Bohemia and Moravia, the influence of a smaller 'western' breed has not been described and is neither expected nor observed.

The general trend of reduction in cattle body size from the Neolithic up to the Middle Ages –with a temporary increase in size in the Roman period in the regions that were not outside the Limes Romanus–

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[3] Poland, Slovakia, Hungary, Austria, Germany; according to data in Matolcsi, 1970; Bökönyi, 1974; Lasota-Moskalewska, 1980, 1989; Glass, 1991; Benecke, 1994; Makowiecki & Makowiecka, 2000; Pucher, 2004, 2006; Bogucki, 2008; Makowiecki, 2009; see also Figure 4.

was observed in all central European countries[4], so the Czech territory is not an exception. Some results suggest that an especially rapid reduction in size occurred during the course of the Bronze Age or between the Eneolithic and Bronze Age[5]. The results from the East Alpine area even suggest a rather sudden change in cattle size, detected before the beginning of the Late Bronze Age (Pucher, 2013). In the central European region this trend gradually resulted in small medieval cattle of a WH in cows of only c. 100-110 cm with individuals smaller than 100 cm not exceptional[6] (cf. Figure 16); and an individual estimated to be 89 cm high was even detected in Bohemia (Peške, 1985b). Some dimensions evaluated in this study suggest a relatively rapid body-size reduction in the pre-Řivnáč period as well: an extrapolation of respective regressions three thousand years later (i.e. in the Middle Ages) would result, on an assumption of the linear trend, in much smaller cattle than were actually observed in reality[7]. The comparisons usually show repeated reduction in size after the Řivnáč anomaly; some dimensions seem to also reveal reduction between BBC and Únětice C. (i.e. between the Eneolithic and Bronze Age; Figures 3, 5).

To explain the body-size increase in domestic cattle in the Řivnáč C. (see point *2*), the below mentioned possible reasons have been taken into consideration:

(*a*) the cross-breeding between domestic and wild forms;

(*b*) independent local domestication of European aurochs;

(*c*) the adoption or increased frequency of castration of bulls, or change to management preferring males;

(*d*) the importation of a bigger breed into the studied region;

(*e*) an increased degree of hunting of aurochs (possibly females classified as *Bos* indet. or misinterpreted as domestic);

(*f*) better care, especially higher quality feed.

In support of and against these interpretations, the following arguments are taken into consideration:

Arguments against model (*c*): The castrates are larger and have prolonged long bones when compared to uncastrated bulls[2], nevertheless, the body-size increase in the Řivnáč C. has also been detected in the dentition measurements and the breadths of limb bones which are not as greatly influenced by castration (see above and Pöllath & Peters, 2005; Bartosiewicz, 2013, 82-83). Additionally, the use of non-dimorphous or slightly dimorphous dimensions, as in the case of this study (see above), minimizes the influence of sex ratio on the distribution. Arguments against (*d*): From central Europe or adjacent areas very large domestic breeds are not reported in the Eneolithic; finds of domestic cattle from regions neighbouring the Czech territory more or less match the breeds with withers height on average 115-125 cm (Matolcsi, 1970; Bökönyi, 1974; Benecke, 1994; Makowiecki & Makowiecka, 2000; Kyselý, 2002a). This is also valid for the Baden Culture in Hungary and eastern Austria (where WH is about 115-120 cm; Matolcsi, 1970; Bökönyi, 1974; Pucher, 2006), which is the assumed source region for the Řivnáč Culture. Moreover, in the case of imports, one would expect mixing with local breeds; but for the cross-breeding to cause such a strong anomaly, the imported breed would have reached considerable body size (similar to the size of aurochs), which is hardly probable.

A similar disproportion to that described in point (*3*) has already been observed for the region in earlier works (Kyselý, 2008a,b, 2010a), where a very low proportion of teeth and cranial fragments falling into the size range of *Bos primigenius* also suggests a very small percentage of pureblood aurochs, which is in contrast to the results from extremity bones. This disproportion may be explained (A) by allometries or (B) by means of taphonomy, in case aurochs heads had been left on kill-site, i.e. outside

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[4] It follows from a number of studies based on the material from Bohemia (Peške, 1994; Roblíčková, 2004), the Netherlands (Clason, 1967), Poland (Lasota-Moskalewska, 1980, 1989; Makowiecki, 2009), Austria (Pucher, 2006, 2010, 2013), Switzerland (Schibler & Schlumbaum, 2007), Hungary (Matolcsi, 1970; Bökönyi, 1974), Germany (Nobis, 1954; Boessneck, 1958; Teichert, 1984) and central Europe in general (Glass, 1991; Teichert, 1993; Benecke, 1994), similar situation is also in Britain (Jewell, 1962)

[5] For various regions see: Lasota-Moskalewska, 1980, 1989; Benecke, 1994; Peške, 1994; Roblíčková, 2004; Makowiecki, 2009; Pucher, 2013.

[6] For various regions see Peške, 1985b, 1994; Kratochvíl, 1988; Lasota-Moskalewska, 1989; Teichert, 1993; Kyselý, 2000, 2003; Makowiecki, 2009.

[7] The extrapolated data for c. AD 1000: only c. 43 mm in the case of the tibia distal breadth and c. 42 mm in the case of the phalanx proximalis length (cf. Figures 10, 13), which would correspond to females smaller than 85 cm.

the settlement, and thus cannot be represented in the graphs. Allometries are typical for an unsettled phenotype, as would be a phenotype originated through cross-breeding or domestication. For example, a crossbred animal usually does not display an accurately mean phenotype, rather it is a mosaic of the features of both parents. So, if the first explanation (A) is true this disproportion can be an argument for hypothesis (*a*). On the other hand the observation does not support hypothesis (*b*), since during domestication cheek teeth are much more stable than bones (~ postcranial dimensions, body size), thus reacting with delay (e.g. Clutton-Brock, 1999).

The incorporation of indigenous wild cattle into introduced domestic stocks (i.e. genetic contributions from the aurochs gene pool) could happen via the cross-breeding of domestic and wild forms or via independent local domestication of European aurochs (hypotheses *a* and *b*). However, the new domestication of aurochs, when not combined with cross-breeding with domestic cattle, is difficult to imagine in a situation where domestic cattle were abundant (the most frequent species in Czech Neolithic and Eneolithic assemblages; Kyselý, 2012; Kovačiková *et al.*, 2012) and when was no reason for the total disappearance of existing domestic cattle. Therefore, independent local domestication is considered inprobable; although these two phenomena can be related to one another and they are not (or are hardly) distinguishable solely on the basis of osteomorphometry. The significant evidence for cross-breeding of domestic and wild forms is the shift of total distribution towards the bigger sizes including the shift of the average and the minimum. A simple contribution in the form of the hunting of aurochs would probably not shift the distribution of domestic cattle and respective statistics (mainly the minimum) in the observed way. The influence of a heterosis effect on the size of crossbreeds of first generations, which may lead to their clearer visibility and emphasis in the graphic comparisons, should also be considered. On the other hand, outbreeding depression is improbable in the case of the combination of the primitive Neolithic breeds and genetically similar aurochs. Based on the discussion given above, the author of the paper inclines to the 'cross-breeding' model (*a*). A relatively strong representation of aurochs in the Czech Eneolithic (Kyselý, 2005, 2008a,b, 2012) makes conditions suitable for that.

Although it is not possible to exclude better feeding and care for domestic cattle in the Řivnáč C., an argument against that hypothesis (*f*) is the evidence which points to the regressive husbandry development only in the Řivnáč C. (for example the increased proportion of hunting and meat-oriented sheep/goat utilisation; Kyselý, 2012).

Sheep/goats (*Ovis/Capra*)

Only some finds could have been more closely determined as sheep (*Ovis aries*) or as goats (*Capra hircus*). Within more closely determined Lengyel and Eneolithic finds in the CR sheep dominate over goats and in the Middle Eneolithic the absence of goats has even been detected (Kyselý, 2012: Graph 38). Therefore, the results based on the material determined only as sheep/goats mainly concern sheep.

Absolute size

Finds suitable for the calculation of withers height of goats are quite rare and for sheep more copious data are available only in the material from the Lengyel period and the Řivnáč Culture. The majority of estimations were calculated on the basis of short bones (calcaneus and talus), although these give less reliable results than long bones. Nevertheless, the advantage is that the talus and calcaneus lengths are only slightly sexually dimorphous (c. 2-5%, according to Davis, 2000). The determined average WH in sheep is 63.1 cm in the Lengyel period and 69.5 cm in the Řivnáč C. (Table 2 and Figure 17). These withers heights were estimated with the help of indices provided by Teichert (1975) and Schramm (1967) (for alternative exponential calculations of WH according to May & Teichert, 2001, see Table 2). This could correspond with the average body mass of about 40-45 kg and 50-55 kg respectively[8]. Sheep from neighbouring central European regions reported in a comparable period by Bökönyi (1974), Benecke

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[8] The rough estimation of body mass is based on the data for various primitive breeds according to Vohradský (1999) and Sambraus (1999).

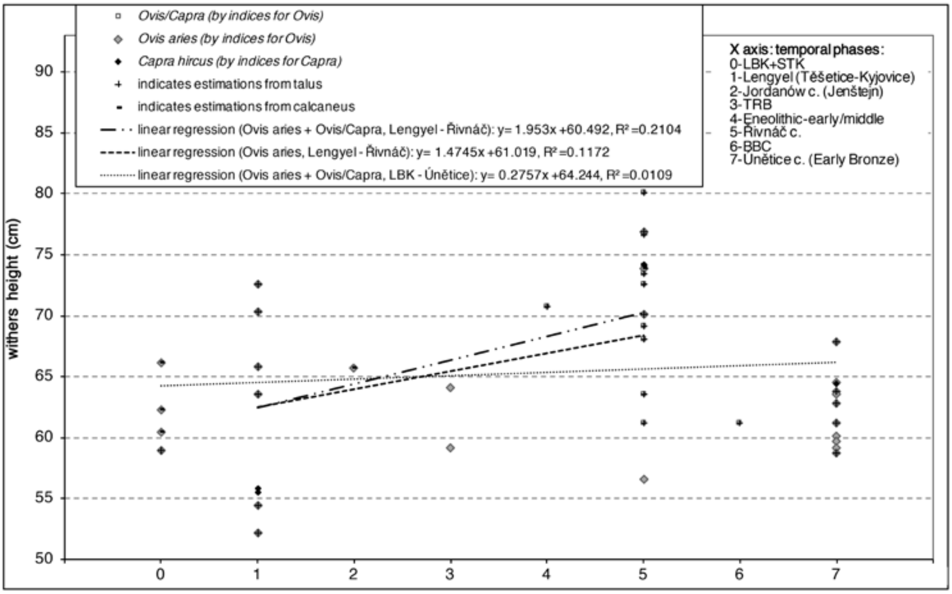

FIGURE 17

Variation over time (X axis) of the withers height (Y axis) of Czech prehistoric sheep and goats (*Ovis* / *Capra*). Based on heights in Table 2 estimated by indices for sheep (after Teichert, 1975) and indices for goats (after Schramm, 1967). For further explanatory notes and methods see text and Figure 5.

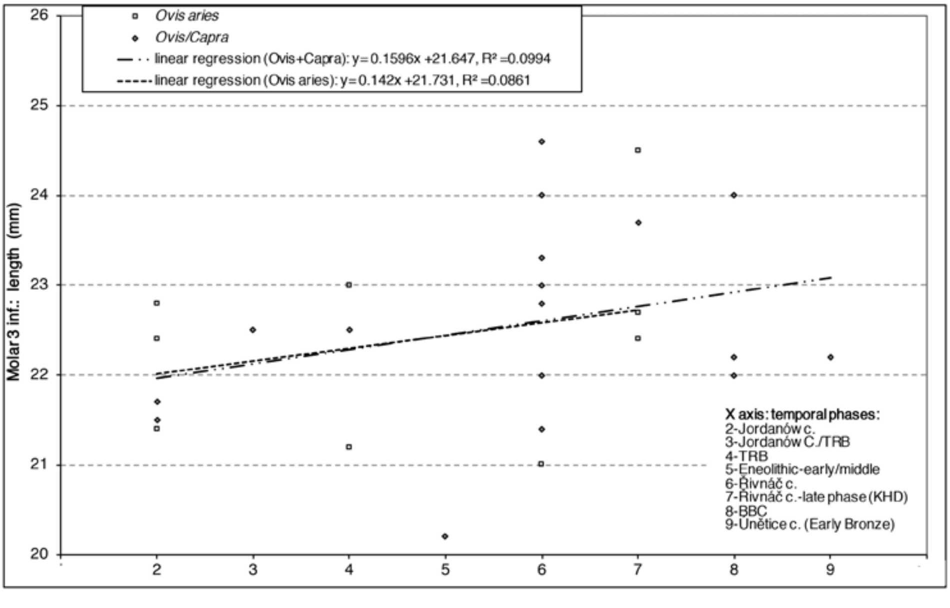

FIGURE 18

Variation over time (X axis) of the *Molar 3 inferior* greatest length (on Y axis, identical to measurement no. 10 in Driesch, 1976) of Czech prehistoric sheep and goats (*Ovis* / *Capra*). For further explanatory notes and methods see text and Figure 5.

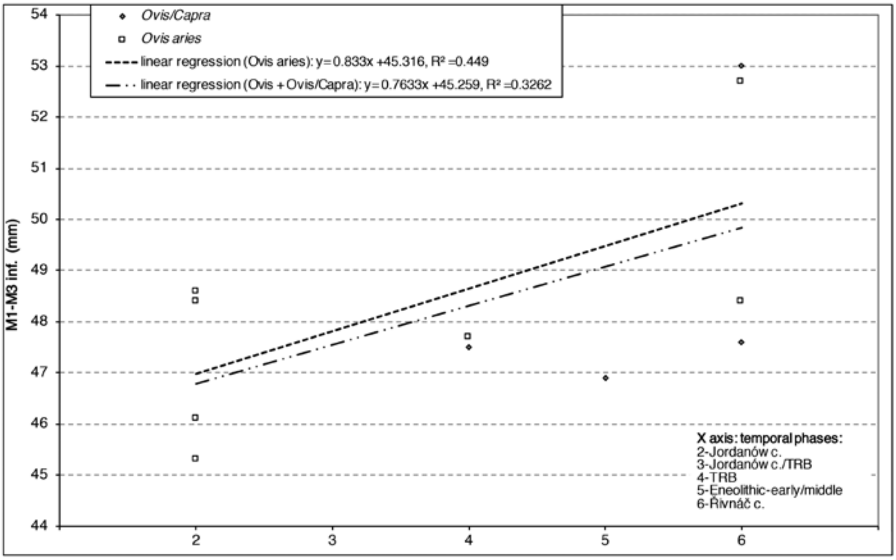

FIGURE 19

Variation over time (X axis) of the *Molar inferior* row alveolar length* (on Y axis identical to measurement no. 10 in Driesch, 1976) of Czech prehistoric sheep and goats (*Ovis* / *Capra*). For further explanatory notes and methods see text and Figure 5.

(1994) and Makowiecki & Makowiecka (2000) had similar heights.

Changes over time

The body size and many skeletal dimensions are dependent on sex. However, it can be presumed that the dental dimensions used for the comparisons (Figures 18, 19) are not particularly sexually dimorphous (as follows from c. 5-6% inter-sex difference in P2-M3 in wild goats; Fandos & Vigal, 1993). In addition to the dental dimensions, the moderately dimorphous distal humerus (dimorphism c. 7% inter-sex difference; Davis, 2000) and the weakly dimorphous calcaneus and talus (see above, in Figure 17 talus and calcaneus are distinctly indicated) have also been used. An almost identical shape for the regression of sheep and the regression of small domestic ruminants, considered as a whole, was found (see regression lines in Figures 18-20). Therefore, the results based on whole (sheep-goats) material are acceptable for sheep. Analyses of mutually diverse dental (Figures, 18, 19) and postcranial (Figures 17, 20) dimensions suggest an increase in body size which occurred in the period between the Lengyel C. and the Middle Eneolithic. Some comparisons correspond to a change during the course of the Jordanów and Řivnáč Cultures or even a leap between TRB and the Řivnáč C. (Figures 17-19). The differences between the sizes in the earlier and later periods are, according to some tests, statistically significant (Table 7).

Interpretations

To explain the body-size increase, the following potential causes have been taken into account:

(*a*) the adoption or increased frequency of castration of rams, or change to management preferring males;

(*b*) the importation of a bigger breed into the studied region;

(*c*) better care, especially higher quality feed.

The increase in body size of sheep in the Eneolithic was not observed only in the studied region, but also in the surrounding areas of the Czech Republic (e.g. Benecke, 1994; Döhle, 1994). The influx of bigger sheep has been already described by Bökönyi, who placed this event, based on Hungarian finds, somewhere at the end of the Eneolithic or on the cusp between the Eneolithic and Bronze Age (Bökönyi, 1974, 1987). This phe-

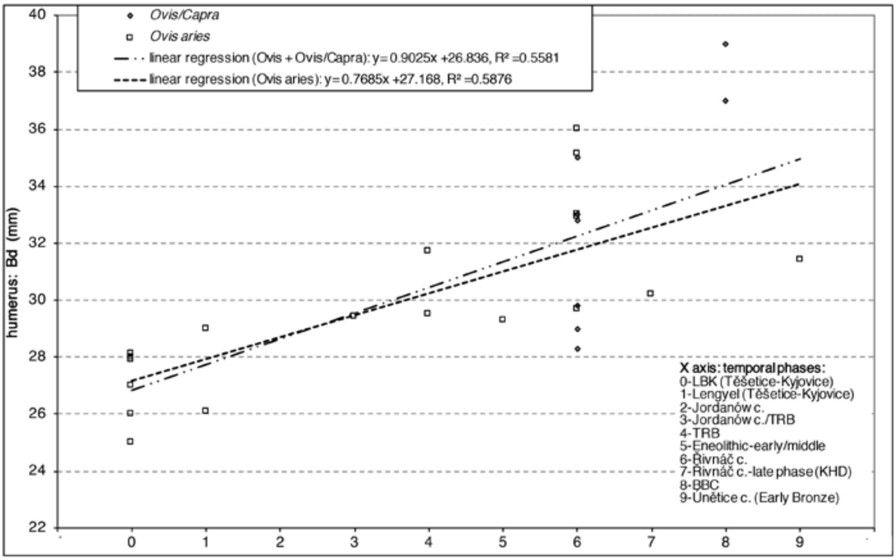

FIGURE 20

Variation over time (X axis) of the *Humerus* distal breadth (Bd on Y axis) of Czech prehistoric sheep and goats (*Ovis* / *Capra*). For further explanatory notes and methods see text and Figure 5.

nomenon seems to be extended to a large part of Europe, although some comparisons suggest that the body enlargement happened earlier (comparable to the Czech Early Eneolithic; Döhle, 1994) while others suggest a later date (Bökönyi, 1974, 1987; Benecke, 1994).[9] This fact is often explained by the importation of a new bigger breed (see discussion section). The appearance of this new breed in central Europe is dated to the second half of the fourth millennium BC (perhaps with the Baden Culture) which roughly corresponds to the Middle Eneolithic in the Czech concept of archaeological periodization. With regard to the limited amount of available data from the CR it is difficult to identify details of size development, nevertheless, most of the results also fit the idea of the importation of a larger breed during the period mentioned above, that is, either during the Middle Eneolithic represented by the Baden-Řivnáč cultural complex (c. 3350-2800 BC), or on the cusp between the TRB and Řivnáč C. (Figures 17-19), although the evaluation of the distal humerus (Figure 20) does allow an earlier body enlargement. As the increase is also observed in the sexually slightly dimorphous dimensions, it is highly improbable that the sheep size increase was the result of a change management influencing the proportion of the sex, or castration, cf. hypothesis (*b*). Hypothesis (*c*) is analogical to the situation in cattle. In the following Bronze Age no further increase in size was observed within the Czech territory; the sheep were on the contrary rather smaller than in the Řivnáč Culture. The WH in the Bronze Age is usually between 60 and 70 cm (x = 64, n = 43), specifically in the first Bronze Age culture (Únětice C.) it is mostly 60-64 cm (according to Roblíčková, 2004, b; see also Table 2 and Figure 17).

Pigs (*Sus domesticus*)

In the classification of the pig (*Sus*), distinguishing between domestic pigs (*Sus domesticus*) and wild boar (*Sus scrofa*) by using metric limits can be problematic and uncertain. With regard to the existence of an overlap in most dimensions, part of the finds remained unclassified (labelled as ‘*Sus* indet.’). Specimens which are clearly outside the overlap were interpreted as domestic or

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[9] Bökönyi put BBC and CWC to the Early Bronze Age. There could therefore be a degree of artificial bias due to the existence of the various regional chronology categorizations.

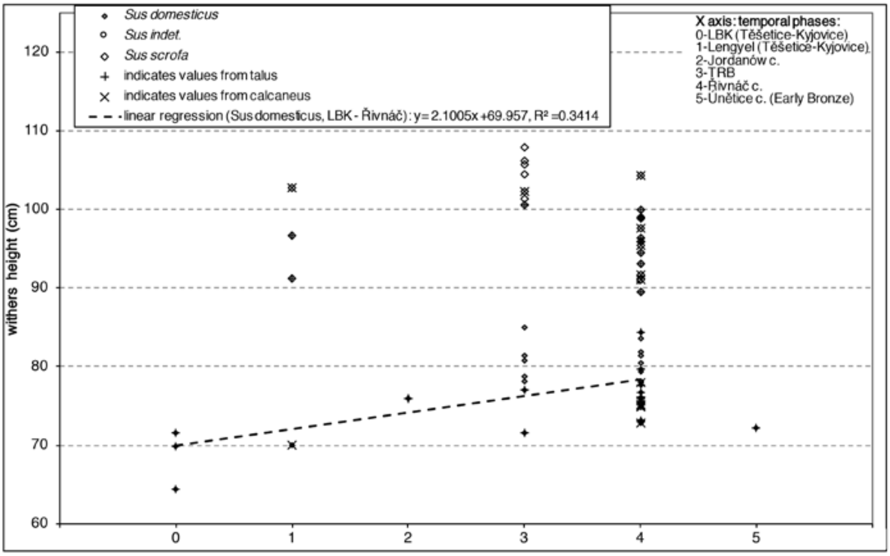

FIGURE 21

Variation over time (X axis) of the withers height (Y axis) of Czech prehistoric pigs (*Sus*). Based on heights in Table 2 calculated using Teichert´s indices. For further explanatory notes and methods see text and Figure 5.

wild according to metric and morphology with the help of measurements and suggestions given in Lasota-Moskalewska *et al*. (1987), Bökönyi (1995), Mayer *et al*. (1998) and Albarella *et al*. (2009).

Absolute size

Teichert's indices (1969) were preferentially used to calculate WH, while calculations of WH based on May *et al*. (1996) were used as an alternative (Tables 2, 4; Figure 21). Due to a lack of complete stylopodium and zeugopodium bones WH was calculated from short bones (talus and calcaneus) and metapodials. A larger amount of data for withers height estimates is available only from the Řivnáč Culture. When calculated using Teichert´s indices, an average WH of 76.2 cm was estimated for Řivnáč C. pigs using the talus and calcaneus bones, while an average value of 81 cm was estimated using the metapodials (for detailed statistics see Table 4). Corresponding to these height figures is an average body weight of approximately 60-80 kg - estimated on the basis of combined data for height × weight in today's wild boar (according to Herre, 1986). Compared to later phases (TRB, Řivnáč), the body size of domestic pigs could have been considerably less in the earlier (LBK + LGK) period (cf. Tables 4, 5). Lengyel and Eneolithic pigs identified as wild boar are substantially larger than pigs determined as domestic.

Changes over time

Comparisons were made using dimensions for which a particularly low sexual dimorphism was determined or is assumed, and which are recommended and commonly used (according to Payne & Bull, 1988; Albarella & Payne, 2005; Albarella *et al*., 2009). Specifically analysed are the breadth of the distal tibia (Figure 27), the length of the talus and calcaneus (included in Figure 21, labelled separately) and selected dental dimensions (Figures 22-26). In the case of the dimensions of molars used in the comparisons, the influence of individual age can be almost entirely ruled out. Although the average size and the size range were both greater for males than for females, the differences between the sexes were not found to be statistically significant in all ten measurements of individual molars evaluated by Mayer *et al*. (1998). Dimorphism in the breadth of molars is only 0-4% according to Payne &

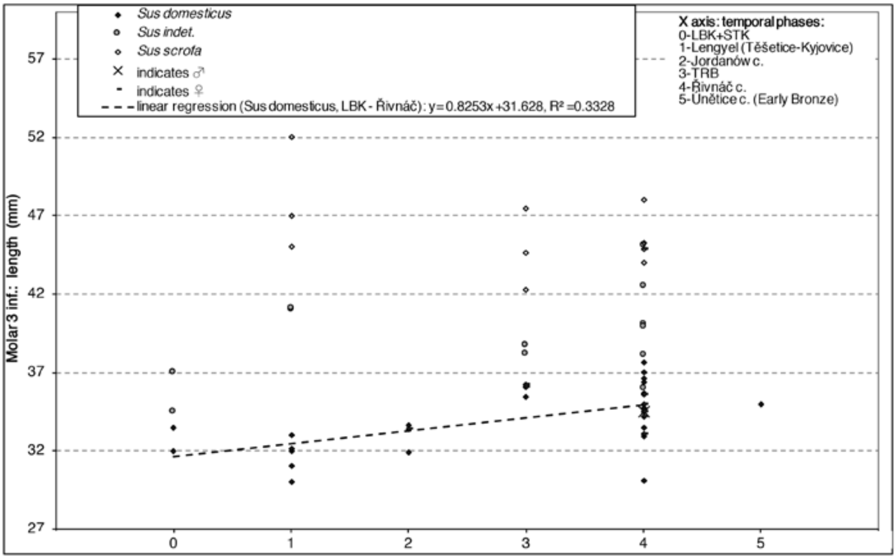

FIGURE 22

Variation over time (X axis) of the *Molar 3 inferior* greatest length (on Y axis identical to measurement no. 10 in Driesch, 1976) of Czech prehistoric pigs (*Sus*). For further explanatory notes and methods see text and Figure 5.

Bull (1988), the degree of dimorphism in the length of rows of molars is probably also low (cf. Herre, 1986). Also included is the frequently used M_3 length, despite the fact that it is highly variable and exhibits more pronounced dimorphism (cf. Kratochvíl, 1981; Herre, 1986; Payne & Bull, 1988) (Figure 22, 23).

Comparisons identified the following changes in time:

(1) All of the analysed dimensions, such as dental (Figure 22-26), postcranial (Figures 21, 27), lengths (Figure 21-23) and breadths (Figures 24-27), indicate a body-

	Sus domesticus						
	n	calculated after Teichert (1969)			calculated after May *et al*. (1996)		
		arithmetic mean (mm)	median (mm)	min.-max. (mm)	arithmetic mean (mm)	median (mm)	min.-max. (mm)
LBK + Lengyel	4	69	70	64.4-71.6	62.9	62.8	61.9-64.1
TRB	8	78.9	78.7	71.6-85	68.4	68.6	64.1-71.8
Řivnáč C.	20	77.6	77.2	72.9-84.3	66.7	65.7	63.6-71.0
	Sus scrofa						
	n	calculated after Teichert (1969)			calculated after May *et al*. (1996)		
		arithmetic mean (mm)	median (mm)	min.-max. (mm)	arithmetic mean (mm)	median (mm)	min.-max. (mm)
LBK + Lengyel	3	96.9	96.7	91.3-102.7	72.9	70.7	69.4-78.7
TRB	7	104.1	104.5	100.6-107.8	79.9	81	71.7-82.5
Řivnáč C.	13	95.9	95.9	89.5-104.3	72.4	71.3	69-79.4

TABLE 4

Statistics of WH of Czech Neolithic and Eneolithic pigs based on data from Table 2. See text for acronyms.

dimension	Eneolithic		LBK+LGK		Middle Ages
	arithmetic mean (mm)	n	arithmetic mean (mm)	n	arithmetic mean (mm)
Molar 3 inf. - L	35	18	31.9	6	30.3
Molar 3 inf. - B	16.1	18	15.1	6	14.8
M1-M3 inf.	70.2	14	67	1	63.5
Tibia - Bd	30.1	21	26.8	6	28-29
Talus - GLl	42.8	10	38.3	3	40.2
Calcaneus - GL	80.6	6	75	1	78.4

TABLE 5

Comparison of selected dimensions of pigs determined as domestic (*Sus domesticus*) between the Eneolithic (from Proto-Eneolithic to Late Eneolithic; this study), the Neolithic-Lengyel period (LBK, LGK; this study) and the Middle Ages (Mikulčice site; Kratochvíl, 1981). See text for acronyms.

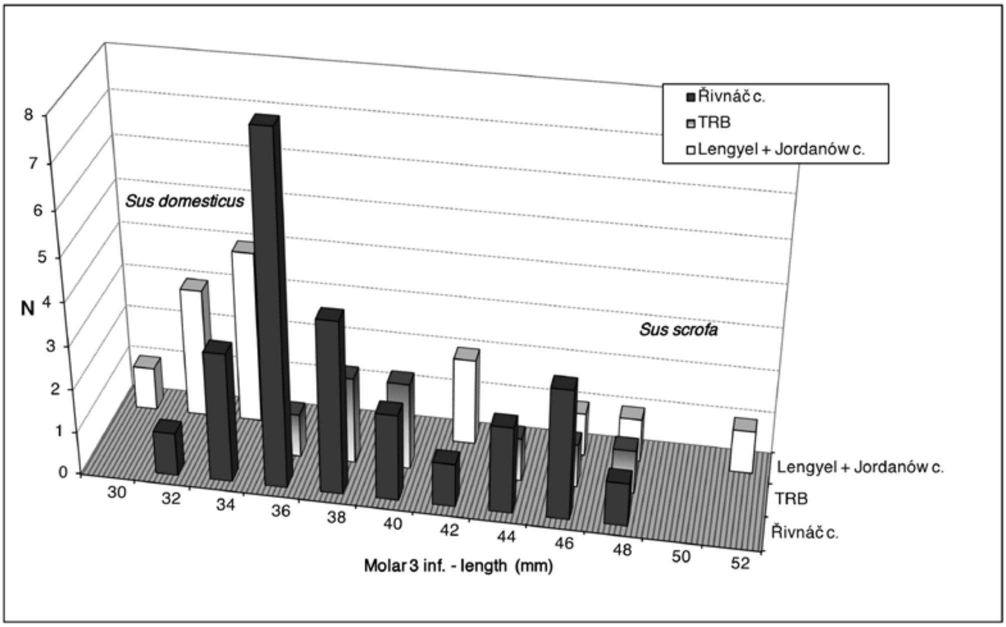

FIGURE 23

Histograms representing the distributions of the *Molar 3 inferior* greatest lengths of Czech prehistoric pigs (*Sus*) in the three cultural phases (LGK+Jordanów, TRB and Řivnáč C.). For further explanatory notes and methods see text and Figure 6. Compare results in Figure 22 obtained by using the corresponding data.

size increase in domestic pigs during the course of the Neolithic and Eneolithic (see the slope of regression lines). Some dimensions narrow the change down to the Proto-Eneolithic and TRB periods, since the most graphically visible jump occurs specifically between these two cultures. Median values grow significantly between the early and late phases of the studied period (Table 7). Absence of data from Baalberge doesn't allow us to reconstruct the development of the size more precisely, but relatively low values from Makotřasy, dated to the middle of TRB (Table 2), suggest the possibility that domestic pigs were not affected by a growth in body size until the Salzmünde phase of TRB. Some dental dimensions indicate a repeated body-size reduction in the Řivnáč Culture. These trends are apparent in cases where only 'reliably' identified domestic pigs are evaluated, as well as when finds of *Sus domesticus* are put together with finds of *Sus* indet.

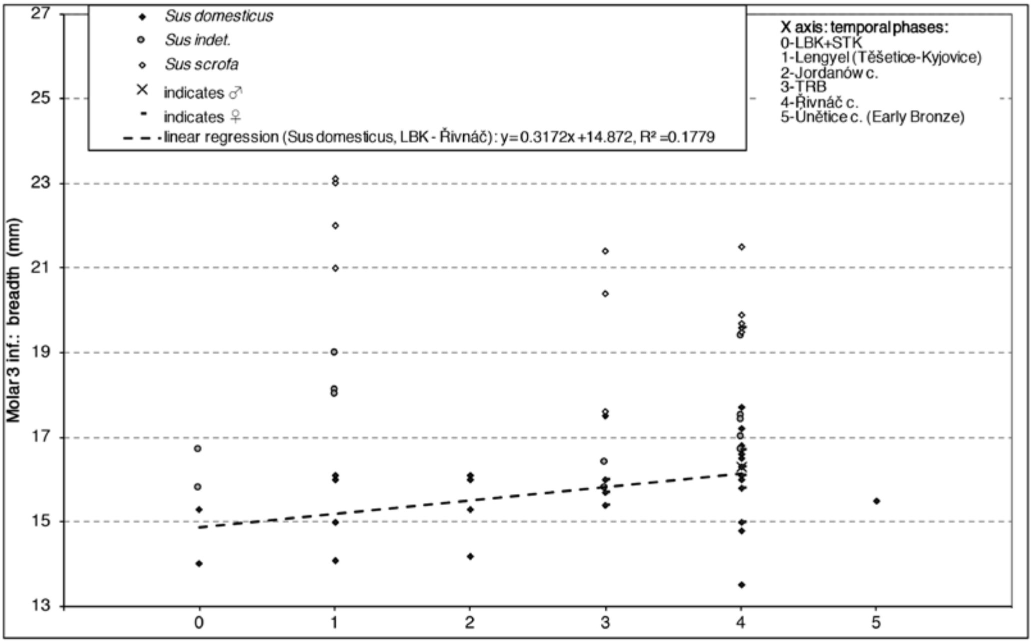

FIGURE 24

Variation over time (X axis) of the *Molar 3 inferior* greatest breadth (on Y axis, identical to measurement M3WA according to Albarella *et al*., 2009) of Czech prehistoric pigs (*Sus*). For further explanatory notes and methods see text and Figure 5

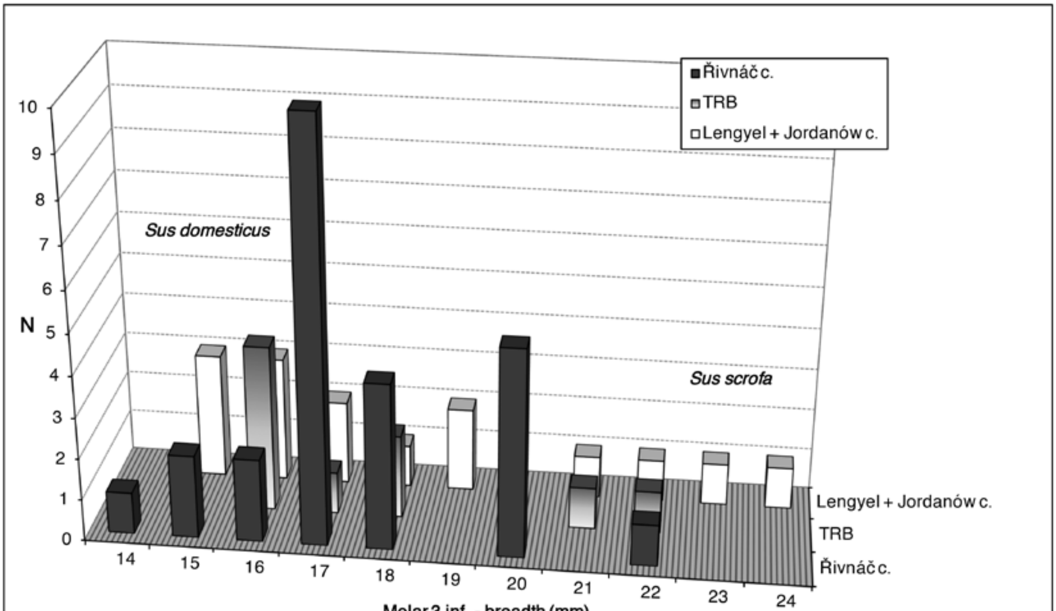

FIGURE 25

Histograms representing the distributions of the *Molar 3 inferior* greatest breadths of Czech prehistoric pigs (*Sus*). See Figure 23 for further explanatory notes. Compare results in Figure 24 obtained by using the corresponding data.

(2) Domestic pigs in the TRB and Řivnáč Cultures are on average larger than domestic pigs from the Early Middle Ages in the studied area. The difference is greater in dental dimensions than in postcranial dimensions. This is seen in a comparison with the size of domestic pigs from the early medieval Great Moravian site of Mikulčice[10] (Table 5). Nevertheless, domestic pigs from the earlier period (LBK + LGK) were smaller than TRB and Řivnáč C. pigs and could be identical in size or even smaller than the pigs from early medieval Mikulčice (cf. Table 5; Figure 21, 27).

(3) Even if a small amount of applicative primary data is available, the frequency of domestication traits, particularly the absence of premolar 1 (Figure 29) and the shortening of M_3 (Figure 28), seems to decrease in the Middle Eneolithic in comparison with previous periods.

Interpretations

The wide metric variabilities found within most of the time horizons clearly show that the given collection is not made up of a single, genetically closed, population[11]; smaller individuals apparently represent domestic pigs (*Sus domesticus*) and larger individuals wild boar (*Sus scrofa*). Thus, the evidence suggests the coexistence of domestic and wild forms, an interpretation that is also supported by the bimodal nature of distributions (Figures 23, 25). The markedly smaller size of domestic pigs compared to the size of wild boars is a common phenomenon in the earliest stages of agricultural history. In central Europe, including the Czech Republic, noticeably small pigs (sometimes referred to as 'turbary pigs' or *Sus scrofa palustris*[12]) are typical for the Early Neolithic (Rütimayer, 1861; Bökönyi, 1974; Lasota-Moskalewska *et al*., 1987; Benecke, 1994; L. Peške *pers. com*.).

The increase in the physical dimensions of pigs observed in the studied period is in contrast to the general domestication trend. This general trend is not as strong as that observed during prehistory and early history in domestic cattle, but a tendency toward a reduction in body size has been observed for at least the pre-Roman period (Teichert, 1970, 1993; Lasota-Moskalewska *et al*., 1987).

Attention has been paid in particular to the following potential causes for the body-size increase:

(*a*) cross-breeding between domestic and wild forms;

(*b*) independent local domestication of European wild boar;

(*c*) the importation of a larger breed to the studied region;

(*d*) the hunting of wild boar;

(*e*) a change in the sex ratio or castration;

(*f*) better care, especially higher quality feed.

In similarity with the situation for cattle and sheep/goats, the differences between the time phases described in point (*1*) are clearly not the result of inter-site, or inter-culture differences in the management having potential influences on the sex ratio (*e*). This follows for several reasons: The dimensions used usually exhibit a low degree of sexual dimorphism and their consequent distributions are therefore weakly dependent on the sex ratio. The low influence of sex on the resulting trends is also evident from the position of the sexually determined finds in the overall distribution, since many of the relatively big domestic pigs are females, even in the later phases (Figures 22, 24, 26). Moreover, registered differences in the sex ratio between the individual phases of the studied period are not great (Table 6), which again does not suggest a strong influence of the sex ratio.

Earlier comparisons suggest some regional differences. For example, somewhat larger pigs have been recorded in the period 3500-1500 BC in Hungary and eastern Europe and smaller pigs in southern and western Europe (Lasota-Moskalewska *et al*., 1987). Benecke (1994) records especially large pigs in the Lengyel and Baden Cultures in the Danube region and in Slovakia, which is (according to Benecke) probably environmentally conditioned. Nevertheless, a local (i.e. Czech) or

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[10] The data from Mikulčice (south Moravia, CR) published by Kratochvíl (1981) represent one of the largest collections of osteometric data from a single site in the whole of Europe, and they are thus particularly representative.

[11] Evaluated according to the degree of variability within a single sample (population) given in Payne & Bull (1988), Albarella *et al*. (2009) and Herre (1986).

[12] For an explanation and discussion of the terms 'turbary pig' and *Sus srofa palustris*, compare, for example, Bökönyi (1974) and Rowley-Conwy *et al*. (2012).

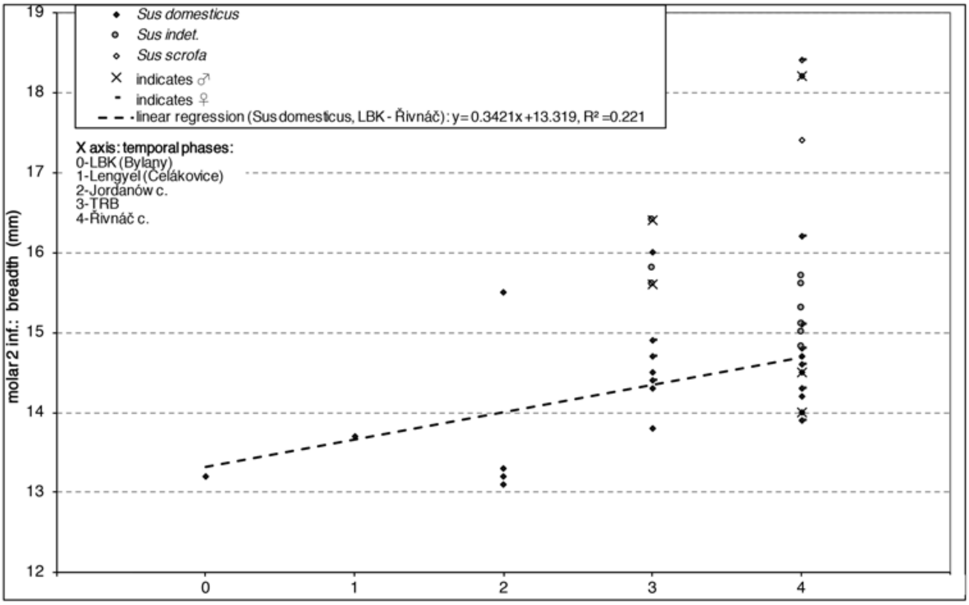

FIGURE 26

Variation over time (X axis) of the *Molar 2 inferior* greatest breadth (on Y axis) of Czech prehistoric pigs (*Sus*). For further explanatory notes and methods see text and Figure 5.

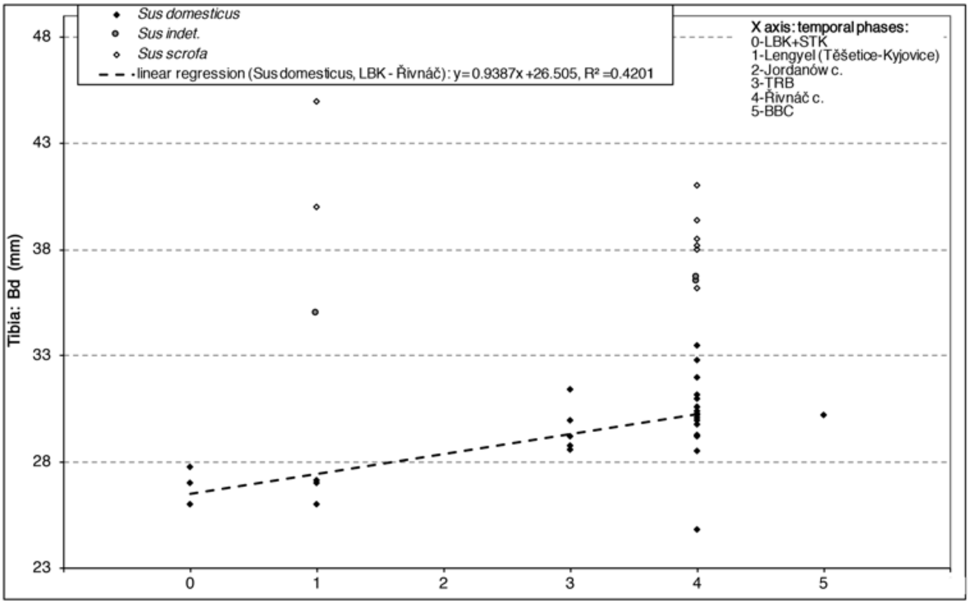

FIGURE 27

Variation over time (X axis) of the *Tibia* distal breadth (Bd on Y axis) of Czech prehistoric pigs (*Sus*). For further explanatory notes and methods see text and Figure 5.

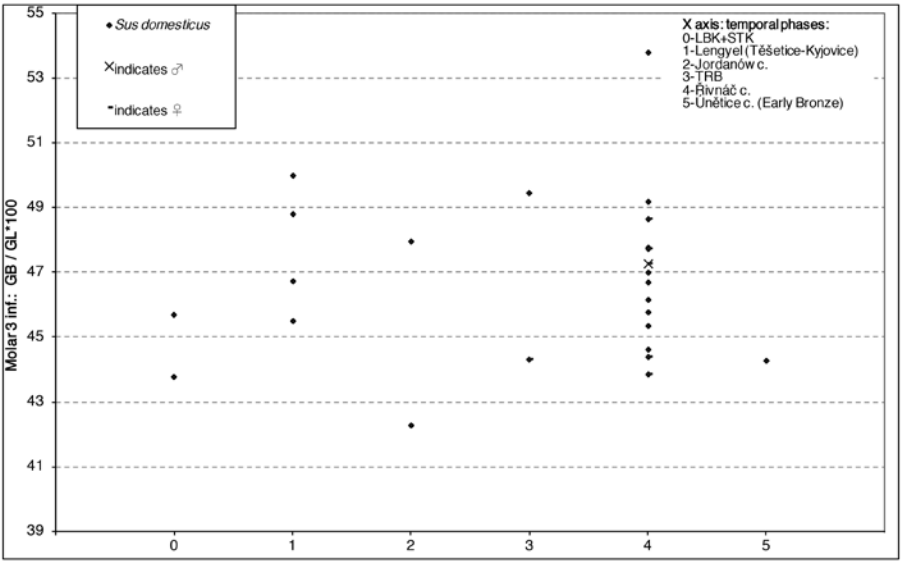

FIGURE 28

Variation over time (X axis) of the *Molar 3 inferior* greatest breadth/length index (GB/GL*100 on Y axis) of Czech prehistoric pigs (*Sus*). For further explanatory notes and methods see text and Figure 5.

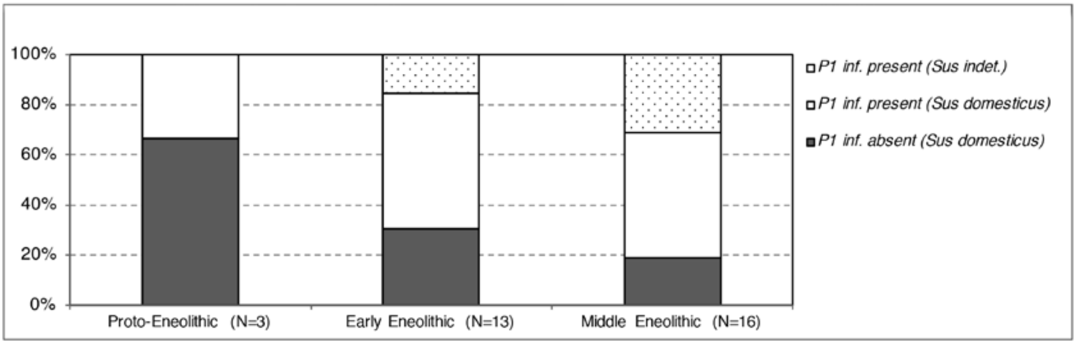

FIGURE 29

Frequency of presence/absence of *Premolar 1* in various temporal phases within Czech Eneolithic pigs (*Sus*). Note: According to Herre (1986) the share of mandibles without P_1 is only 22% among wild boars (N=124). Within the Czech Eneolithic no wild boars without P_1 were observed (this study, n = 8: P_1 and P^1 together)

possibly northern origin is assumed for the key Jordanów and TRB Cultures, which lack distinct and mass ceramic imports from the Danube region and evidence for a broad immigration to the CR (Neustupný *et al*., 2013). Under these circumstances, an osteometrically detectable (i.e. mass) import of a relatively difficult to transport species, such as the pig, from the Danube region or even more remote areas of Eastern Europe is not assumed. Moreover, if the body size of ‘Danube pig’ was environmentally conditioned, their large size would not persist in the new living conditions of central Bohemia.

As with cattle, the shift in the overall distribution of size (average, minimum values) is difficult to explain merely as the result of the hunting of wild boar (or possibly larger feral pigs) involved in interpretation (*d*). However, this pattern corresponds well to a population formed by local domestication or to a population created by cross-breeding as interpretations (*a*) and (*b*) suggest. Shortness of M3 and missing of P1 are traits of advanced domestication that are clearly observed in earlier phases of the studied period. The reduction in the frequency of these signs over time (Figure 28, 29) corresponds to the notion of an influence from the wild boar gene pool, as well as an increase in body size. However, the existence of these signs in Řivnáč C. may be in concordance with the persistence of genetic information from previous domestic breeds. The rapid appearance of such signs would have been unlikely in the case of reoccurring, new domestication.

The repeated body-size reduction in domestic pigs in the period of the Řivnáč Culture indicated by certain comparisons could, with the validity of model (*a*) or (*b*), represent a restart of the general body-size reduction domestication trend. The fact that pigs with a height at the withers of 62-82 cm (x = 72 cm, n = 21; Roblíčková, 2004), thus slightly smaller than in the Eneolithic, were reported for the ensuing Bronze Age in the Czech territory also supports this trend.

DISCUSSION

In all animals evaluated, an increase in body size was observed. This contradicts a common trend known from the early (an also later) stages of domestication as described and discussed by many authors[13]. The phenomenon therefore warrants further discussion.

Cattle

Osteometric comparisons have revealed a trend involving the relatively swift reduction in the size of domestic cattle (*Bos taurus*). This is not surprising, since body-size reduction is a common phenomenon in the process of cattle domestication. This trend matched the results obtained in surrounding regions, even though the regionally specific form of WH development can differ somewhat. A distinct anomaly was detected in Bohemia involving a repeated body-size increase in the Middle Eneolithic (Řivnáč Culture, c. 3200-2800 BC). Discussion in the results section led to the conclusion that the most probable interpretation is that the anomaly is the result of cross-breeding between domestic and wild cattle.

The idea, that central European domestic cattle stocks were influenced by the aurochs gene pool either through local domestication or through the cross-breeding of domestic and wild forms, is not new. The possibility of cross-breeding was suggested and discussed by Bökönyi (1962, 1969, 1974) for the Herpály, Tisza and Lengyel Cultures in Hungary and adjacent areas, by Lasota-Moskalewska (1980) for Poland, by Müller (1964) and by Döhle (1990) for the Linear Band Ceramic in central Germany and by Kyselý (2008a) for the Kutná Hora-Denemark settlement (Řivnáč Culture) in Bohemia. A number of genetic studies analysing cattle mtDNA suggest that the cross-breeding of domestic and wild forms could have occurred, but the contribution of European aurochs to the gene pool of domestic breeds was very small (Beja-Pereira *et al*., 2006; Edwards *et al*., 2007; Achilli *et al*., 2009; Bonfiglio *et al*., 2012; Schibler *et al*., 2014). Nevertheless, even independent local domestication of aurochs in Italy is suggested (Bonfiglio *et al*., 2010). However, if breeding did occur between wild males and domestic females (a more probable combination), the contribution of aurochs would not be detectable using mtDNA since mtDNA is not inheritable from males. Therefore, a substantially greater contribution of aurochs to the gene pool of domestic cattle than that suggested by the conclusions of the archaeogenetic studies is not ruled out. The results of our osteometric analyses propose that the Middle Eneolithic in Bohemia could be one of the periods

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[13] The causation of body-size reduction in domesticates is a difficult question, which requires in-depth analysis and consideration. Here I would like to mention 'the conscious selection' of smaller animals, especially of smaller males, for the purpose of easing human-cattle relationship, the shrinking of territory and altered selection pressure, the emphasis on numbers of animals as opposed to quality, limitation of fodder available in the winter' (Boessneck & Driesch, 1978), impossibility to feed at night due to protection against predators (Clutton-Brock, 1999), early weaning, early mating of heifers, paedomorphism and others (see Zeder *et al*., 2006), climatic evolution and ecological degradation (Vigne, 1999), or genetic fragmentation and isolation accompanied by the founder effect and inbreeding (Vigne, 1999). Recently supportive evidence for insufficient winter nutrition being the causation is proposed (Hejcman *et al*., 2014).

taxon	period	male	probably male	indet., castrates?	female	probably female
Bos taurus	Proto-Eneolithic	-	-	-	1	4
	TRB	-	3	-	5	9
	Řivnáč C.	-	1	3	8	6
***Bos taurus* total**		**0**	**4**	**3**	**13**	**15**
Bos indet.	TRB + Řivnáč C.	-	1	-	1	5
Bos primigenius	Řivnáč C.	-	4	-	2	1
Capra hircus (mostly horncores)	Proto-Eneolithic + TRB	2	2	-	3	-
Ovis aries (mostly horncores)	FBC+Řivnáč C.	8	1	-	2	-
Ovis/Capra (mostly pelves)	Proto-Eneolithic + TRB + Řivnáč C.	3	4	-	10	1
***Ovis/Capra* total**		**13**	**7**	**0**	**15**	**1**
Sus domesticus	Proto-Eneolithic	1	-	-	4	-
	TRB	4	-	-	12	1
	Řivnáč C.	13	-	-	21	1
***Sus domesticus* total**		**18**	**0**	**0**	**37**	**2**
Sus indet.	Proto-Eneolithic + TRB	9	-	-	3	-
	Řivnáč C.	9	1	-	1	-
Sus scrofa	Proto-Eneolithic + TRB	5	-	-	-	-
	Řivnáč C.	25	3	-	8	-

TABLE 6

The comprehensive quantification of sex-determinable finds of cattle (*Bos*), sheep/goats (*Ovis/Capra*) and pigs (*Sus*) according to material from Eneolithic settlements in Bohemia (ritual and other anomalous findings excluded). Sex determination obtained by using pelvic and metacarpal bones in the case of cattle, using pelvises and horn cores in the case of sheep/goats, using canine teeth or their alveoli in the case of pigs. Quantified by NISP. From Kyselý (2010a; 2012), updated. For acronyms see text.

and locations where such cross-breeding occurred. If this hypothesis is correct, the degree of the impact on the metric composition of the population eliminates the possibility of an isolated mating event; to the contrary, this must have involved mass cross-breeding activity. Since such hybridization is only manifested in mtDNA to a small extent, the combination of domestic females and aurochs males must have occurred most frequently during the presumed mating. In such a case, intentional and systematic human-controlled cross-breeding can be assumed. Another, more complex, scenario is that feral individuals escaped from captivity were genetically influenced by aurochs and subsequently re-introduced into breeding. A particularly distinct indication of cross-breeding was found at the periphery of the area occupied by the people of the Řivnáč Culture, specifically at the Kutná Hora-Denemark site (Kyselý, 2008a).

Such an anomaly has not been broadly observed in neighbouring central European regions for the corresponding time (cf. Matolcsi, 1970; Bökönyi, 1974; Benecke, 1994). However, it appears that somewhat larger cattle were also detected in the contemporary Cham Culture in southern Germany, in the Jevišovice and Baden Cultures in Austria (cf. results in Pucher, 2004, 2006, 2010) and perhaps even in the Baden Culture in Slovakia (cf. Benecke, 1994: Table 25).

Sheep and goats

An increase in physical size was repeatedly observed amongst sheep, *Ovis aries*, during the course of the Czech Neolithic and Eneolithic in more osteometric comparisons. It is not clear whether the increase was in the form of gradual trend or a sudden change in size, although some comparisons suggest a sudden increase. An increase in the body size of sheep seems to be in contrast to the general trend observed in earlier stages of caprine domestication (Clutton-Brock, 1999; Vigne, 1999), and in the domestication of cattle and pigs. Nevertheless, if we accept the sudden increase during the period of the TRB and Baden-Řivnáč Cultures, then a similar phenomenon was observed in sheep and in cattle, as well as in pigs. However, the same causation for both was not found. We cannot explain the increase in sheep size by cross-breeding with an indigenous wild ancestor, or the fact that it had been hunted, as no such indigenous ancestor existed in the region. On the other hand, it is hardly possible to explain the increase in cattle or pig body size due to the importation of a large breed (see above).

The body enlargement in sheep can be best explained as the result of the importation of a new breed (see results section), whose origin could have been from the south-east (where the Czech Middle Eneolithic Baden-Řivnáč cultural complex also originated; Neustupný *et al*., 2013). It has been suggested that the new, larger breed could have been a woolly breed (Bökönyi, 1974; Teichert, 1993; Benecke, 1994; Schibler *et al*., 1997; Schibler, 2004). According to this 'new breed hypothesis' the assumed introduction and spread of a new breed would have occurred over a large part of Europe relatively quickly. This was signalled, for example, by body-size increase in sheep in a comparable period in central Europe and in the Balkans, specifically in the Bernburg and Baden horizon of central Europe and at the beginning of the Bronze Age in Macedonia (Benecke, 1994). The theory of the import of a woolly breed in this period is also supported by the nature of the kill-off patterns from the Czech Eneolithic, where supporting evidence for the possible use of sheep wool is the strongest in the Řivnáč Culture, i.e. 3200-2800 BC (Kyselý, 2012). The mass emergence of spindle whorls occurred at the same time. In the studied region, the growth of spindle whorls was observed in the Boleráz horizon at the Cimburk site (east Bohemia, c. 3400-3300 BC; Zápotocký, 2000, Neustupný *et al*., 2013), and their common occurrence was also determined in the Baden, Cham and Řivnáč

taxon	measurement analysed	phases compared	statistics	significance
Bos taurus	Phalanx prox. GLpe	LBK+LGK X TRB	*U*= 153, p=0.0006, n1=21, n2=31	XX
Bos taurus	Phalanx prox. Bd	LBK+LGK X TRB	*U*= 80, p=0.022, n1=11, n2=28	X
Bos taurus	Phalanx prox. GLpe	LBK+LGK X BBC+Únětice	*U*= 91.5, p=0.000003, n1=21, n2=35	XX
Bos taurus	Phalanx prox. Bd	LBK+LGK X BBC+Únětice	*U*= 73, p=0.0015, n1=16, n2=18	XX
Bos (all *Bos* finds)*	Phalanx prox. GLpe	TRB X Řivnáč	*U*= 1668, p=0.0000006, n1=73, n2=85	XX
Bos (all *Bos* finds)*	Molar 3 inf. GL	TRB X Řivnáč	*U*= 90, p=0.045, n1=15, n2=20	X
Bos (all *Bos* finds)*	Metacarpus Bd	TRB X Řivnáč	*U*= 267, p=0.099, n1=22, n2=3	
Bos (all *Bos* finds)*	Tibia Bd	TRB X Řivnáč	*U*= 331, p=0.00006, n1=32, n2=45	XX
Ovis + Ovis/Capra	humerus Bd	LBK+LGK X TRB+Řivnáč+BBC	*U*= 1.5, p=0.0012, n1=8, n2=17	XX
Ovis + Ovis/Capra	humerus Bd	LBK+LGK X Řivnáč+BBC	*U*= 1.5, p=0.00022, n1=8, n2=14	XX
Ovis + Ovis/Capra	humerus Bd	LBK+LGK+TRB X Řivnáč+BBC	*U*= 10.5, p=0.0003, n1=11, n2=14	XX
Ovis aries	humerus Bd	LBK+LGK X TRB+Řivnáč	*U*= 0, p=0.00063, n1=8, n2=9	XX
Ovis + Ovis/Capra	withers height	LBK+LGK X Řivnáč	*U*= 25, p=0.014, n1=10, n2=13	X
Ovis + Ovis/Capra	withers height	LBK+LGK+TRB X Řivnáč	*U*= 40, p=0.014, n1=13, n2=14	X
Ovis + Ovis/Capra	M3 inf. GL	Jordanów+TRB X Řivná+ BBC	*U*= 40, p=0.107, n1=9, n2=15	
Sus domesticus	withers height	LBK+LGK X TRB+Řivnáč	*U*= 0.5, p=0.0016, n1=4, n2=30	XX
Sus domesticus	Tibia Bd	LBK+LGK X TRB+Řivnáč	*U*= 6, p=0.00098, n1=6, n2=21	XX
Sus domesticus	M3 inf. GL	LBK+LGK+Proto-En. X TRB+Řivnáč	*U*= 17.5, p=0.00055, n1=10, n2=18	XX
Sus domesticus	M3 inf. GB	LBK+LGK+Proto-En. X TRB+Řivnáč	*U*= 43.5, p=0.027, n1=10, n2=18	X
Sus domesticus	M2 inf. GB	LBK+LGK+Proto-En. X TRB+Řivnáč	*U*= 20, p=0.011, n1=6, n2=22	X

TABLE 7

Selected results of the statistical tests evaluating the difference between the medians of metric distributions in two time phases. The Mann-Whitney test (*U*) was used in all the cases. X = statistically significant at the 95% confidence level, XX = statistically significant at the 99% confidence level. See Table 1, Figure 2 and text for more information about the cultures and material. In cases when only histograms were available in the source data the middle values of each metric category span had to be used in the calculation of the *U* statistic. For acronyms see text.

Cultures (Burger, 1988; Zápotocký & Zápotocká, 2008; Neustupný *et al*., 2013). Within the Switzerland territory, spindle whorls first appeared during the period of the Corded Ware Culture (c. 2800 BC, Schibler, 2004). A change in the composition of weaving artefacts was also observed at the contemporary Bronocice site (southern Poland, TRB-Baden; Milisauskas & Kruk, 2011). Moreover, the increased importance of sheep is also indicated by the almost complete disappearance of goats from Czech material in this period, i.e. 3200-2800 BC (according to Kyselý, 2012). The given indications correspond time-wise to the current opinion that, worldwide, 'no actual woven woollen textiles are firmly dated before about 3000 BC, but they were very widespread by 2800 BC' (Anthony, 2007) and to the earliest European direct finds of spinnable wool from the Clairvaux-les-Lacs site (eastern France, 3000-2900 BC; Hundt, 1986), the Novosvobodnaya site (Russia, Kurgan 2, 2849-2693, BC,p =96%; Shishlina *et al*., 2003; Anthony, 2007; (Shishlina *et al*., 2008) and others from the middle of the third millennium BC in Switzerland and Germany (Sherratt, 1983). When the situation in Mesopotamia (where wool production may have originated) was studied through kill-off patterns, Pollack (1999) showed that the shift there to a wool-sheep butchering pattern occurred no earlier than the Late Uruk period, after 3350 BC.

Pigs

The introduction of domestic pigs (*Sus domesticus*) into central Europe at the beginning of the Neolithic (as part of the 'Neolithic package'), originally suggested on the basis of the small body size, was later confirmed by a genetic study (Larson *et al.,* 2007). But the study indicated that the mtDNA of Near East pigs (Y1 haplotype) soon disappeared from the historical record, and that only mtDNA from indigenous European wild boar was detected in the bones of domestic pigs from later periods (at least since 3900 BC) and in modern European breeds. Therefore, the cited publication suggests an entirely different scenario than in the case of cattle. Recently, Larson *et al*. (2011) stated that it is not yet known whether 'the replacement of the pig was the result of continual hybridization by the only locally available source of wild boar, thus minimizing and then eliminating the genomic input of Near Eastern wild boar, or a more active selection against those pigs who displayed Near Eastern affinities'. They also stated that 'it is unknown whether the process, concluding that modern European pigs are derived from European wild boar, was independent or was kick-started by the introduction of Near Eastern domestic pigs into Europe, however the second possibility is more probable'. Although the date of the described replacement is not precisely identified in the archaeogenetic study, the authors originally speculated that the main change could have occurred during the first five centuries following the importation of the Neolithic package (Larson *et al*., 2007, 2011). However, a new study has proven the existence of the Y1 haplotype in the Middle Chalcolithic (Gumelniţa C., c. 4500-3950 BC), based on archaeological material from Romania, and it was suggested that Y1 was replaced during the Bronze Age (2000-1200 BC) (Evin *et al.,* 2014).

The genetic replacement described above is consistent with the increase in the body size of pigs in the Czech territory as described in this study. The presented osteometric analysis potentially narrow the period of this event down to the Proto- to Early Eneolithic (i.e. 4300-3300 BC), during the course of which the change in size was detected most clearly (Figures 21-27). The change approximately 1400 to 2400 years after the importation of the Neolithic to the studied region is somewhat later than the genetic replacement proposed by the authors of earlier archaeogenetic studies (Larson *et al*., 2007, 2011). If the interpretation of the change in the body size of pigs in the Czech territory as the result of cross-breeding with wild boar, or the independent domestication of local wild boar, is correct it occurred under conditions in which pigs had already been raised for a long time. This is clear from the presence of domestic pigs in the region in the earliest phases of the Neolithic, whose domestic status is evident from the small sizes recorded in LBK and STK (Figures 21-27). In addition, previous determinations from many Czech sites suggest the common presence of domestic pigs in these cultures (Peške, 1994, 1997; Peške *et al*., 1998; Kovačiková, 2009). A later dating of the event would thus not testify to the entirely independent domestication of wild boar, but, at the least, to a style inspired by methods originating in the Near East. The generally low share of pigs in the LBK and STK periods in central Europe (Bökönyi, 1974; Benecke, 1994; Döhle, 1994; Kovačiková *et al*., 2012) could represent the primary situation, prior to local domestication or cross-breeding, followed by a rising abundance due to local domestication or cross-breeding leading to a relatively large percentage of domestic pigs in the Eneolithic (as recorded in Kyselý, 2012). The increase in abundance of European domestic pigs is also stated by Larson *et al.* (2007). In the actual conditions of the Eneolithic it seems less probable that the body size of *de novo* domesticated animals reduced as quickly as graphic comparisons suggest. This, together with the existence of domestication traits even in the Řivnáč Culture (Figure 28, 29), correspond better to the possibility of cross-breeding instead of entirely new domestication. However, local domestication and cross-breeding could be combined, which is easy to imagine in the case of easily reproducible and easily manageable animals, such as pigs. Since the feralization of primitive pig breeds is simple, it is also possible to consider the presence of feral pigs even in the Eneolithic, a situation that would be a good basis for the bidirectional flow of genetic information (domestic < > wild).

The small number of analysed mtDNA samples originating from the bones of pigs found at four archaeological sites in the Czech territory points to the presence of haplotypes identical to central European wild boar (Larson *et al.*, 2007; Pavelka, 2007)[14], of which only three finds from the Kutná Hora-Denemark site (Řivnáč C.) and three more from the Dolní Beřkovice site (STK?) were morphometrically 'reliably' identified as domestic. If the dating of the Dolní Beřkovice finds is really STK, the archaeogenetic study suggests the incorporation of wild boar genes to domestic stock in the Czech territory quite early; otherwise the archaeogenetic study suggests it at least in the Middle Eneolithic (Řivnáč C.).

The local domestication of European pigs had already been presumed earlier. For example, Bökönyi (1974) presents a number of cases of large domestic pigs, which he interprets as being due to the local domestication or as the result of cross-breeding. According to this author, these activities could have occurred more frequently during the Neolithic, 'reaching a peak in the period between the end of the Neolithic and the end of the Bronze Age' (according to the Hungarian chronology[9]). Domestic pigs also increased in body size in Austria around 4000 BC (Pucher, 2006, 2010). Benecke's comparisons (1994: Abb. 64) do not rule out an increase in body size in the Early Bronze Age. The increase in body size was also described in regions of Europe other than central Europe (Larson *et al.*, 2007), so the phenomenon could be widespread. As in the case of domestic cattle, a combination of the following opposing trends could occur: (1) an increase in body size as the result of the inclusion of a wild ancestor in the domestic breed gene pools and (2) a general domestication trend involving body-size reduction.

Concluding remarks

The author has tried to methodically exclude or reduce the influence of age, sex and pathologies on the results by the selection of measurements. The effect of allometry, taphonomy, other deforming factors and the effect of randomness is minimized by the combined appraisal of more skeletal dimensions of a mutually different nature. Therefore, the observed temporal size changes and tendencies are not highly influenced by sex ratio, castration, slaughtering strategies, allometries, taphonomy or randomness.

The possible influence of external factors, not based on genetics (higher quality feed, lactation period, stabling) is difficult, if not impossible, to filter out. Nevertheless, it seems improbable that differences between studied cultures or between studied settlements, in the way animals were fed or conditions in which they were raised, were so distinct within the Neolithic-Eneolithic that they could cause systematic bias and statistical difference in body size. As for diet, Higham (1969), for example, considers it 'intrinsically unlikely that only certain animals were raised on a high plane of nutrition in prehistoric settlements'. It seems more reasonable to assume an opportunistic approach to raising and feeding animals that would result in the statistical levelling of possible individual deviations. Moreover, the heritability of physical and osseous dimensions is relatively high. For

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[14] Sites: Homolka (Řivnáč or Únětice C.; haplotypes ANC--Aside and ANC-Cside according to Larson *et al.*, 2007), Kutná Hora-Denemark (Řivnáč C.; haplotype GL222 according to Pavelka, 2007), Dolní Beřkovice (dating after J. Řídký, 2009 and *pers. com.* STK?; haplotype GL222 according to Pavelka, 2007) and Velké Přílepy-Kamýk (dating after Klementová & Hložek, 2005 and D. Daněček *pers. com.* cf. Late Bronze; haplotype GL222 according to Pavelka, 2007).

these reasons, this (non-genetic) factor is not emphasised in interpretations. As was already argued, environmentally conditioned selection does not seem to be very probable due to the stable climatic conditions of the Middle Holocene in central Europe. Furthermore, sophisticated artificial selection leading to a rapid increase in body size is not assumed due to the level of breeding in the Neolithic and Eneolithic.

In addition to the factors discussed above, it is also possible to contemplate a culturally-conditioned selective influence on the composition of settlement waste and, hence, osteological assemblages. Also unknown for the given period is the level of the social and economic diversification of the occupied area, which could possibly have created the need for selective import/export. Nevertheless, the author of this study assumes that these two factors have a much lower, if any, impact on the osteometric composition than, for example, on the species or age composition of the sample. Therefore, they should not impact the conclusions and interpretations presented here.

The author is aware that despite the relatively large total volume of metric data, some of the presented conclusions are based only on a small amount of available data. Some of the conclusions must therefore be regarded as preliminary. The author is likewise aware of many factors whose influence cannot be distinguished by an osteological study, including the heretofore less considered heterosis effect, the founder effect, the possibility of feralization as early as the Neolithic and Eneolithic, or the handling of animals in a manner that defies economically conditioned pragmatic rules. Collecting additional data, especially from as yet less represented cultures and future studies across Europe could help resolve questions such as: Do the body size changes in farm animals determined in various regions have the same cause? Could it be a result of the inclusion of a wild ancestor in the domestic stock gene pools or a result of independent local domestication? Did it occur in various regions at the same time, or at various times?

CONCLUSIONS

This study presents the available metric data documenting a variety of skeletal dimensions, body size and variability in size of Neolithic, Eneolithic and Bronze Age domestic cattle (*Bos taurus*), sheep/goats (*Ovis*/*Capra*) and pigs (*Sus domesticus*) originating in archaeological sites in the territory of the Czech Republic. In particular, the detection of changes in body size and trends in size development of these animals over time were the focus of the study. As well as presenting the data and its comparisons, detailed discussions and some theoretical ideas are included in the paper. The main results and the most probable interpretations are listed below.

A gradual body-size reduction of domestic cattle was observed from the Neolithic to the Early Bronze Age in the Czech territory, which is the same as or similar to the trend in other European regions. During the Early Eneolithic Funnelbeaker Culture and Middle Eneolithic Řivnáč Culture the withers height of domestic cows was c. 114-117 cm on average, whilst bulls could be 5-10 cm higher.

There was an anomalous increase in domestic cattle body size in Řivnáč C. (c. 3200-2800 BC) in Bohemia. After considering various arguments, this anomaly was interpreted as most probably being the result of the cross-breeding of domestic females and aurochs males. Other interpretations, like a higher frequency of hunting of aurochs or local domestication of aurochs, are considered less likely.

The bodysize increase in sheep corresponds with the hypothesis that larger, probably woolly, sheep were imported into Central Europe. According to the Czech osteometric data, this change could have occurred between or within the TRB and Baden-Řivnáč C. (i.e. in the second half of the 4th millennium BC). In the Lengyel period, sheep were only 62.5 cm high in the withers on average, later in the Middle Eneolithic sheep reached c. 69.5 cm on average.

The withers height of domestic pigs in the Middle Eneolithic was 73-84.5 cm. In earlier periods (Linear Pottery, Lengyel) pigs were markedly smaller. The increase in pig body size occurred during or between the Proto- and Early Eneolithic (c. 4300-3350 BC). This increase is interpreted as being the result of genomic input of indigenous wild boar to the domestic stock gene pool, through cross-breeding between domestic and wild forms or local wild boar domestication. If true, this finding identifies the place and time (or one of the places and times) of the replacement of domestic pigs of Near Eastern ancestry by European wild boar - a genetic event demonstrated by earlier archaeogenetic studies.

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