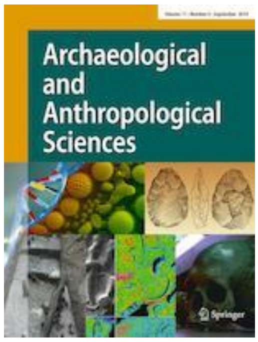
Behind the steps of ancient sheep mobility in Iberia: new insights from a geometric morphometric approach



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Abstract

In Western Europe, the transition from the middle Iron Age to the early Roman period implied changes in livestock practices, with the emergence of a specialized and selective animal husbandry. These changes have been related in Italy and south of France with changes in livestock management involving their mobility between ecologically complementary areas. The study of this question in the Iberian Peninsula has only been partially investigated through palaeoenvironmental analyses, and the information about the origin and significance of this phenomenon is very scarce. To shed new light on this topic we used an archaeozoological approach, with the application of geometric morphometrics. They were used to study size and shape variability in sheep astragali from 9 sites dating from the middle Iron Age to the early Roman period (5th c. BC–3rd c. AD) and located on the Pyrenees and on the north-eastern Iberian coast as a case study. The results we obtained, combined with Number of Identified Specimens (NISP) and kill-off patterns, showed local specificities in terms of breeding methods and sheep morphologies between the two areas during the middle Iron Age. On the contrary, sheep with similar size and the implementation and development of similar sheep husbandry practices in the Pyrenees and the north-eastern Iberian coast were documented during the early Roman period. These results suggest the existence of livestock links between these two areas during the Roman period, that could be involved a possible movement of sheep between the lowlands and the Pyrenees for the first time.

Keywords

Ovis aries; Astragalus; Morphological changes; Iron Age; Roman period; Iberian Peninsula

Introduction

With the formation and development of the Roman Empire, important changes took place in animal husbandry. There was a shift from a more diversified range of livestock intended for the own consumption of each settlement, to a more specialized and selective range of livestock, the purpose of which was to supply animal products to consumer populations (Noddle 1984; Grant 1989; Columeau 1993; Leguilloux 1994; Lepetz 1996; King 1999; Mackinnon 2004; Oueslati 2006; Albarella et al. 2008; Gudea 2008; Deschler-Erb 2017; Trixl et al. 2017; Pigière 2017).

These changes in animal husbandry have been related in Italy and the south of France to changes in the management of livestock that might have led to the movement of flocks between ecologically complementary areas. Large enclosures have been documented in the "La Crau" area (Arles, south of France), which were used for animal mobility practices (Brun 1996; Leguilloux 2003; Leveau 2016). Several epigraphic testimonies and legal documents, such as the Theodosian Code or the agrarian law of the 111 BC, have been recovered in Italy. They show both the practice of an animal mobility between different areas and the existence of a regulation of this activity (Brun 1996; Corbier 2007; Mackinnon 2004). References to this activity by Latin authors are also frequent (Pline: Hist. Nat. XXI. 57; Varron: Re. Rust. I.6.5; II. 1.16–17; II.10.3; III. 1.8; Horace: Carm. II. 15.14).

Several archaeozoological studies have also shown the existence of a more specialized and intensive animal husbandry right after the Roman conquest in the Iberian Peninsula (Fernández 2003; Colominas 2013, 2017b; Colominas et al. 2017), which also would have involved changes in the management of livestock. Evidence of the practice of animal mobility, however, are almost non-existent and this topic has never been studied from an archaeozoological approach. These evidences mainly come from Landscape Archaeology studies that show an increase of the exploitation of the Pyrenees as seasonal pastures starting in the Roman period. Different palaeoenvironmental analyses have documented an increase of human pressure on landscapes from the Roman period onwards in several areas of the Pyrenees (Galop 2005; Leveau 2009; Segard 2009; Palet et al. 2011). Regional palynological records and local and regional charcoal analyses suggest that a process of forest degradation affecting the Pyrenees took place during that period (Ejarque 2013; Pèlachs et al. 2007). At the same time, field surveys have documented the existence of enclosures and shepherd huts at 2000 m of altitude (Rendu 2003; Leveau 2009; Segard 2009; Leveau and Palet 2010; Gassiot et al. 2012; Palet et al. 2014), not documented before.

Therefore, it could be in this period when livestock mobility would have also started in the Iberian Peninsula. This mobility would not only be produced to use the existing natural resources from nearby areas (activity probably practiced from the origins of the presence of domestic animals), but also by an increasingly accentuated pressure on vegetal resources. This pressure would make animal mobility between ecologically complementary areas necessary and essential for their survival.

Based on these considerations, this study aims to explore for the first time the existence of animal mobility as livestock system during the Roman period in Iberia. To achieve this, we analysed morphological differences between sheep astragali through the application of two-dimensional (2D) geometric morphometrics. We used the Pyrenees and the north-eastern Iberian coast as a case study. This approach allowed us to document the local, regional or inter regional character of livestock practiced from the middle Iron Age to the early Roman period (5th c. BC–3rd c. AD) on the Pyrenees and the north-eastern Iberian coast and, therefore, to evaluate animal husbandry interactions between these two areas.

Material

Sheep astragali come from 9 sites located on the Pyrenees (Cerdanya mountains) and the north-eastern Iberian coast (Empordà valley) (Fig. 1, Table 1). These two environments have been historically connected, as the Empordà valley has been an ancient line of communication and one of the oldest tracks of penetration to the eastern Pyrenees from the coast (Miralles, and Tutusaus 2005). Until now, livestock farming was a major contributor to the economy of these two areas and sheep was the most frequent animal in their transhumant movements (Miralles and Tutusaus 2005).

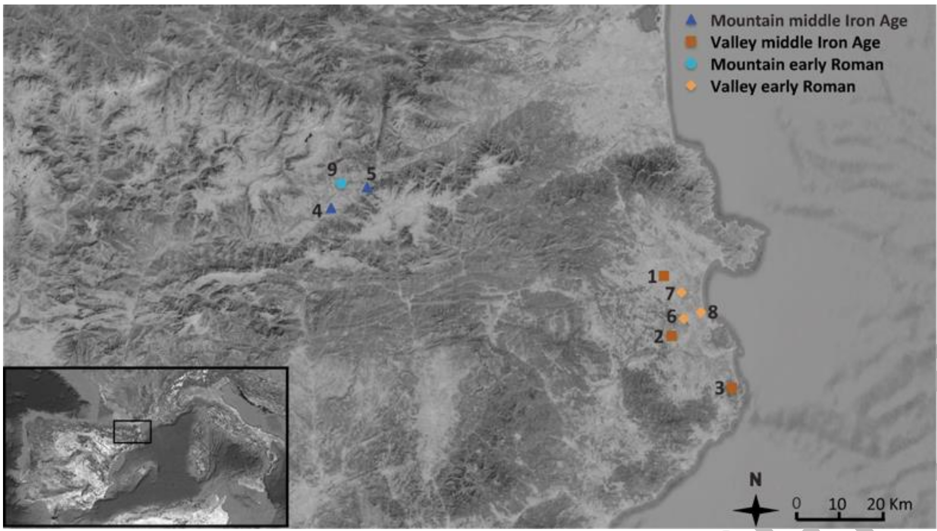

Figure 1. Location of the sites investigated in this paper. See Table 1 for complementary information

Archaeological information							Archaeozoological information			
Site name	N° map	Site code	Samples' chronology	Site type	Area	Altitude	NISP	N astragali	% sheep/goat	References
Mas Castellar de Pontós	1	mcp	5th–2nd c. BC	Village	Empordà plain	154	5219	11	43,2	Colominas 2013
Sant Sebastià de la Guarda	2	ssg	5th–3rd c. BC	Village	Empordà plain	156	3172	6	43,8	Colominas 2012
Sant Julià de Ramis	3	sjr	5th–1st c. BC	Village	Empordà plain	128	1260	4	29,9	Colominas 2011
Castellot de Bolvir	4	bec	4th–1st c. BC	Village	Cerdanya mountains	1140	427	5	31,8	Colominas 2017a
Lló	5	llo	6th–1st c. BC	Village	Cerdanya mountains	1630	531	4	64,03	Vigne 1980
Mas Gusó	6	mg	1st c. BC–3rd c. AD	Military site	Empordà plain	20	1423	8	36,8	Gallego et al. 2017
Tolegassos	7	tlg	1st c. BC–3rd c. AD	Villa	Empordà plain	13	1124	7	38,8	Gallego et al. 2017
Empúries	8	emp	1st c. BC–3rd c. AD	City	Empordà plain	17	1633	6	26,3	Colominas 2017b
Llívia	9	llv	End 1st c. BC–3rd c. AD	City	Cerdanya mountains	1224	475	6	39	Colominas 2017a

Table 1. Archaeological and archaeozoological information of the sites investigated in this paper, including the Number of Identified Specimens (NISP), the number of astragali (N) and the percentage of bones belonging to caprine (sheep and goat). See Fig. 1 for complementary information.

Mas Castellar de Pontós was occupied from the middle of the seventh century BC until the beginning of the second century BC. The site is characterized by an overlap of three settlements with a large number of storage pits, whose main function was the management of the production and distribution of cereal surpluses of the surrounding area (Pons 2002).

Sant Sebastià de la Guarda was a village occupied from the 6th to the 1st c. BC. The 1400 m2 excavated area have allowed to document some houses organized around several streets, plus a large number of storage pits for cereals (Burch et al. 2010).

Sant Julià de Ramis was a political and economic urban village, which controlled the surrounding territory before the foundation of the Roman city of Gerunda. The oldest phase of occupation was in the 6th c. BC and remained inhabited until the 1st c. BC (Burch et al. 2011).

Llo was an open-air site composed by three domestic areas surrounded by a wall in which several huts were documented (Campmajó 1983). It was occupied from the Middle Neolithic to the medieval period (Campmajó 1983; Rendu et al. 1996).

Castellot de Bolvir was a village with a clear purpose of controlling the territory in which production, residence and storage activities were carried out (Morera et al. 2011). Up to now, 15 domestic units have been identified (Morera 2017). It was in use from the 4th c. BC until the 1st c. BC. About 10 km to the South, the site of Baltarga is localized. It is currently under excavation and enough astragali have not been recovered to be part of this study, but together with Castellot de Bolvir, they are the two most important Pyrenean Iron Age sites known until now (Morera 2017). In the last quarter of the 1st c. BC, these two Pyrenean villages were abandoned and the city of Iulia Libica (Llívia) was built. It is the only Roman city known so far in the eastern Pyrenees and the forum continued activated until the middle of the 3rd c. AD (Guàrdia et al. 2017).

Mas Gusó was a military and administrative site established for the territorial control of the Empordà valley linked to the creation of a new road network and a tax collection system (Casas et al. 2016). It was occupied from the 2nd c. BC until the 3rd c. AD.

Tolegassos was a villa occupied from the 1st c. BC to the 3rd c. AD (Casas and Soler, 2003).

Empúries was a trading post founded in the 6th c. BC by Greeks. In the early 1st c. BC, a new Roman city was laid out which eventually assimilated the Greek city and its commercial role (Aquilué et al. 1999; Tremoleda 2008), being the most important Roman city of the area. It was occupied until medieval times.

Faunal remains were widely studied from all these sites and a corpus of 57 astragali was possible to recover (Fig. 1, Table 1). The preservation of faunal remains in mountain environments is generally very poor (Antolín et al. 2018; Bréhard and Campmajó 2005) and explains the lower sample in the mountain than in the coast. However, the mountain sites presented here are the only well dated mountain sites with large faunal assemblages of the area.

This study focuses on the astragalus. We selected this bone because it is a compact and dense element, which tends to survive well. The astragalus rapidly reaches adult size and, once fully ossified, it exhibits limited size change (Albarella and Payne 2005; Payne and Bull 1988; Rowley-Conwy et al. 2012). It also appears to be unaffected by nutrition and sex (Boessneck 1969; Davis 2000; Ruscillo 2003; Popkin et al. 2012; Haruda 2017; Davis 2017) and it is relatively easy to differentiate between sheep and goats (Albarella 1997; Albarella and Davis 1996; Davis 2017). At the same time, it has been demonstrated that bovid astragali dimensions positively correlated with body size (Davis 2000; Barr 2014). On the other hand, several studies have shown the relationship between astragalar morphometrics and the habitat preference of bovid species (DeGusta and Vrba 2003; Plummer et al. 2008; Barr 2014, Haruda 2017). Therefore, the astragalus can be an ideal element to analyse regional phenotypes of sheep living in different environments. Astragali were identified to Ovis aries according to the qualitative characteristics laid out in Boessneck (1969); Prummel and Frisch (1986), and Zeder and Lapham (2010). Only fully formed bones from adult individuals without any pathology and damage were selected for this study. A total of 57 astragali were analysed (Table 1).

Methods

We applied a 2D landmark and sliding semi-landmark Geometric Morphometric approach to study sheep archaeological astragali. Geometric morphometrics (GMM) is a quantitative approach that allows for the comparison of bone geometry by providing detailed size and shape data. GMM is becoming more common in archaeozoology and it had been applied in astragali caprines to study differences in sheep and goat morphology from Late and Final Bronze Age central Asian contexts (Haruda 2017) and more recently to investigate the process of domestication in the Near East (Pöllath et al. 2018; Pöllath et al. 2019).

In this study, data were collected from 2D digital photographs of the lateral and plantar surface of each bone. Pictures were taken using a Reflex Camera (Nikon D90) coupled with a micro length (AF-S Micro Nikkor 60 mm). The configuration of landmarks and sliding semi-landmarks is shown in Fig. 2 and explained in Online Resource 1. We selected 6 landmarks for the plantar view and 4 landmarks for the lateral view, according to the features and position of this bone in the body but also according to the feasibility and repeatability of application of the GMM methodology. Semi-landmarks were recorded as equidistant points along the curves that were delimited by the landmarks. The lead author took all photographs and measurements.

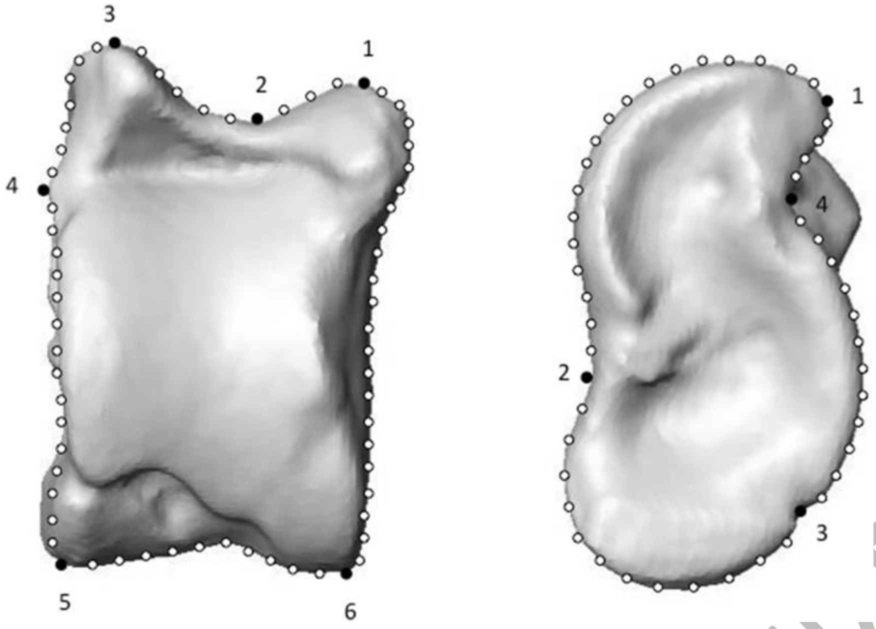

Figure 2. Location of the 2D landmarks (in black) and sliding semi-landmarks (in white) along the plantar (left) and lateral (right) views of Ovis aries astragalus

Landmarks and semi-landmarks were digitized preferentially on left bones when available (pictures of right bones were mirror reflected before data acquisition). The specimens were superimposed using a Generalized Procustes Analysis (GPA) (Rohlf and Slice 1990; Goodall 1995). Morphometric analyses were carried out using the R package Morpho (Schlager 2017). The Procrustes distance was the criterion used for optimizing the positions of semi-landmarks. Procuste coordinates and centroid size were analysed using multivariate and univariate statistics respectively.

Differences in the logarithm of centroid size between groups were illustrated with boxplots, and their significance tested with the pairwise Wilcox tests and analyses of variance (ANOVA). Shape differences among populations were tested using multivariate analysis of variance (MANOVA) based on dimensionality reduced matrix (Evin et al. 2013). Interaction between geography and chronological periods were explored using two-way analyses of variances.

The relationship between the sizes of the lateral and plantar views of the astragali was quantified by a correlation. p values of the tests were adjusted for multiple comparisons (Benjamini and Hochberg 1995).

Results

Sheep astragali variation shows significant differences between geography and chronology. When all specimens are analysed together, specimens from the middle Iron Age are smaller than from the early Roman period (lateral side, $p = 0.0005$; plantar side, $p = 4e\text{-}6$) without shape differences (all $p > 0.05$). Specimens from the valley are larger than the ones from the mountains (lateral side, p = 0.0037; plantar side, p = 3e-4) and with differences in shape for the plantar view of the astragali (F (5,51) = 4.1434, p = 0.003) but not the lateral view (p = 0.44).

While the size variation through time and space was homogeneous for the plantar view (p = 0.18), the lateral size variation did not appear homogeneous between periods and geographies as revealed by the two-way analysis of variance for which the interaction term was significant (F = 7.948, p = 0.007). It means that the size variation between the mountain and the valley differ through time.

If we go into detail, mountain Iron Age sheep had the smallest astragali (Fig. 3, Table 2), showing statistically size differences with early Roman sheep but also with valley Iron Age sheep (a consistent pattern for both views of the bone analysed). At the same time, valley Iron Age sheep also presented a statistically smaller size than valley early Roman sheep. Therefore, a size increase from the middle Iron Age to the early Roman period was observed but also differences between sheep bred in the Cerdanya mountain and in the Empordà valley during the Iron Age were also documented. Both views of the bone showed statistically significant differences between the middle Iron Age samples from the mountain and the valley (Table 2).

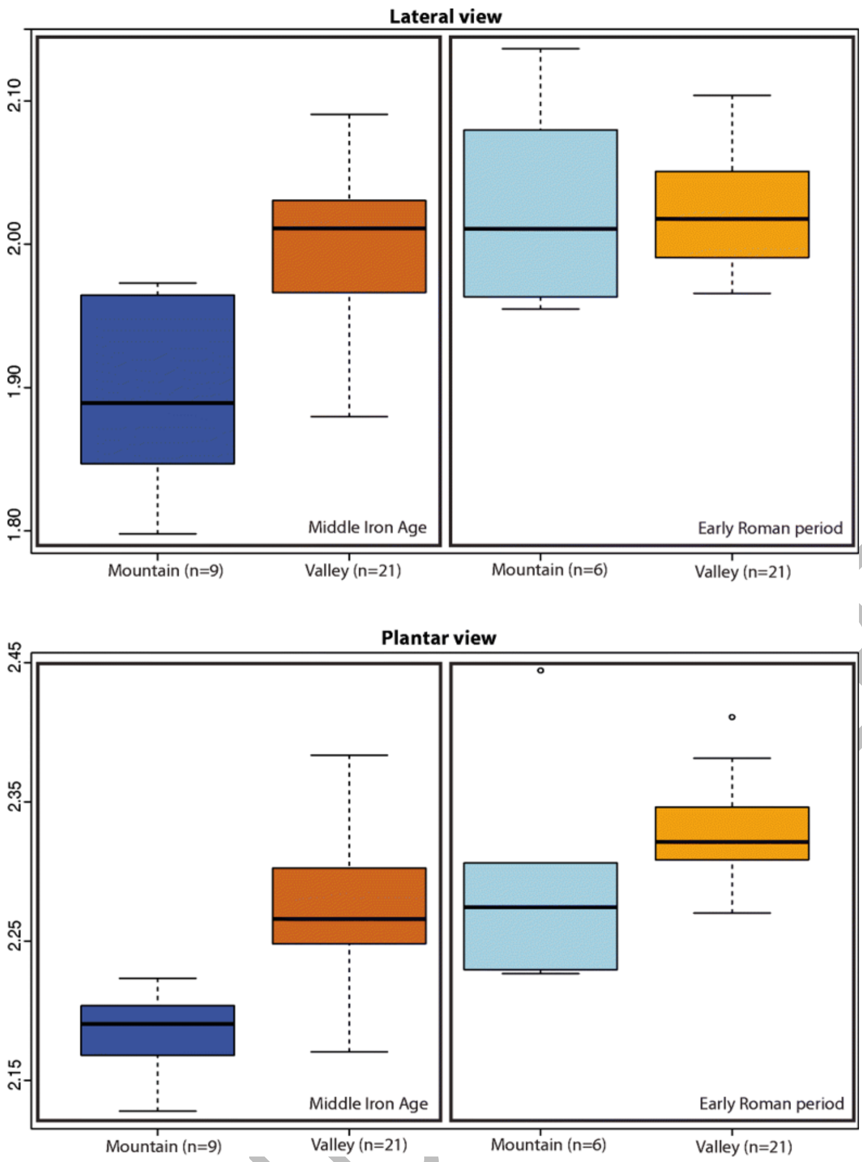

Figure 3. Boxplot of the log (centroid) size of the lateral and plantar view of sheep astragalus, comparing size variation between geography and chronology

Pairwise Wilcox test	Lateral view			Plantar view		
	Mountain Iron Age	**Valley Iron Age**	**Mountain early Roman**	**Mountain Iron Age**	**Valley Iron Age**	**Mountain early Roman**
Valley Iron Age	0.0019**			0.00049**		
Mountain early Roman	0.024	0.5714		0.00060**	0.84247	
Valley early Roman	0.000005**	0.1108	0.7119	0.00000084**	0.00049**	0.05035

Table 2. The pairwise Wilcox test comparison between geography and chronology. Probabilities p values displayed in the lower left triangle with the significant (below the 0.05 threshold) ones with **

Centroid size comparison of mountain and valley early Roman sheep varies depending on the lateral and plantar views of the bone. Boxplot lateral results showed that mountain early Roman samples were in the same range as valley early Roman samples, with no statistically significant differences between them (Fig. 3). Pairwise Wilcox test results for the plantar side also do not show statistically significant differences (Table 2). However, the plantar centroid size for the mountain early Roman sheep is smaller than the valley early Roman sheep (Fig. 3).

Another data to highlight observed in the two views analysed, despite the relatively small sample size and non-significant comparison, is the great variability observed in the range of the size values within the valley Iron Age sheep in comparison to the valley early Roman sheep (Fig. 3).

The results did not varied if the data were breakdown by sites (Fig. 4, Table 3), showing that the morphological differences between geography and chronology were homogeneous.

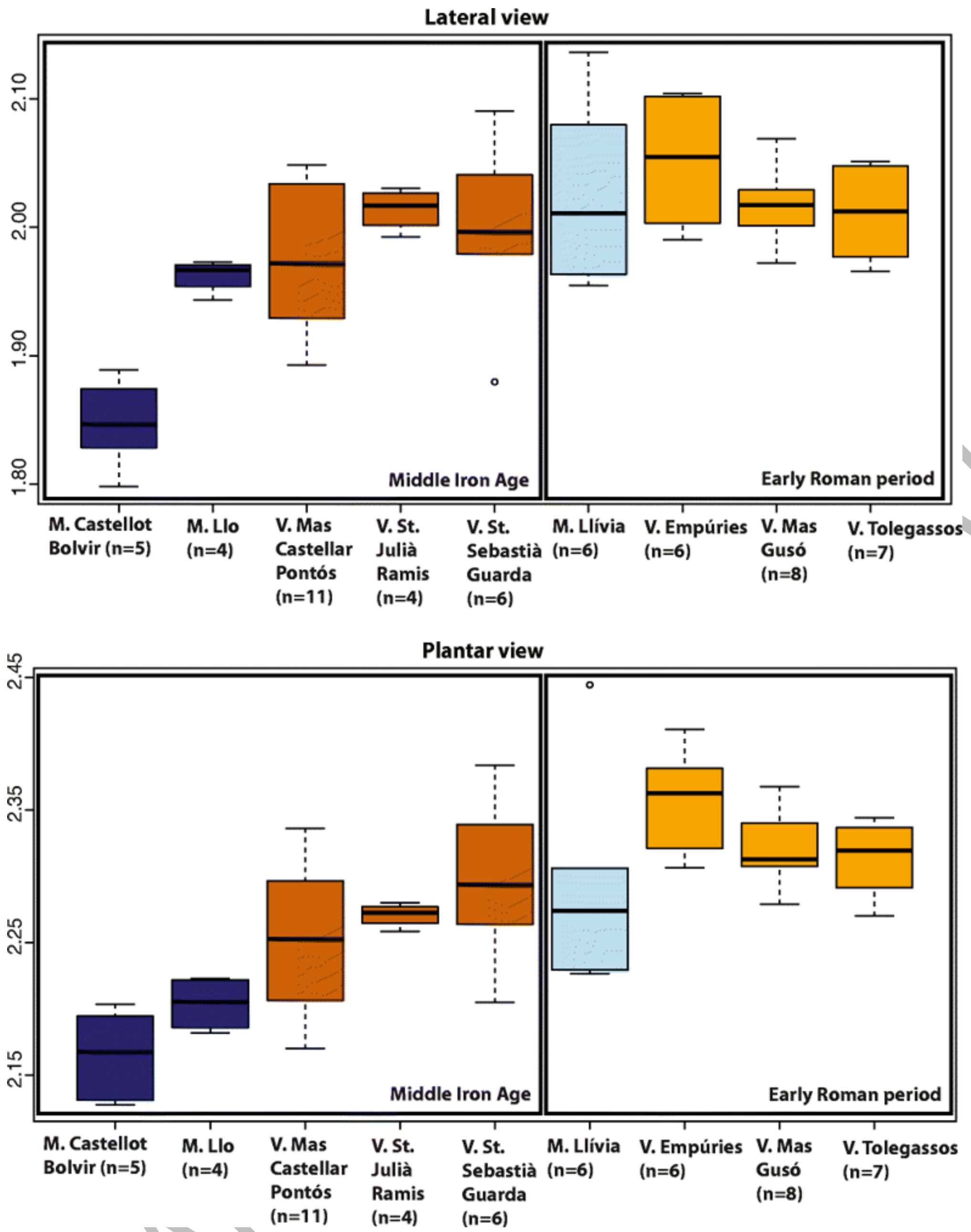

Figure 4. Boxplot of the log (centroid) size of the lateral and plantar view of sheep astragalus, comparing size variation between sites (M = mountain; V = valley)

Pairwise Wilcox test								
Lateral view	MIA-BEC	MIA-LLO	MR-LL	VIA-MCP	VAI-SJR	VAI-SSG	VR-EMP	VR-MG
MIA-LLO	**0.057****							
MR-LL	0.031	0.514						
VIA-MCP	*0.01600*	*0.881*	0.542					

VAI-SJR	*0.057***	*0.086***	1000	**0.881**				
VAI-SSG	*0.043***	*0.294*	0.950	**0.881**	**0.935**			
VR-EMP	0.031	0.053**	*0.618*	0.086**	0.604	0.309		
VR-MG	0.028**	0.053**	*1000*	0.616	1000	0.859	**0.535**	
VR-TLG	0.030	0.117	*1000*	0.447	1000	0.935	**0.309**	**0.935**
Plantar view	MIA-BEC	MIA-LLO	MR-LL	VIA-MCP	VAI-SJR	VAI-SSG	VR-EMP	VR-MG
MIA-LLO	**0.245**							
MR-LL	0.022	0.026						
VIA-MCP	*0.034*	*0.207*	0.630					
VAI-SJR	*0.038*	*0.061***	1000	**0.608**				
VAI-SSG	*0.022*	*0.076***	0.763	**0.215**	**0.801**			
VR-EMP	0.022	0.026	*0.123*	0.026	0.026	0.241		
VR-MG	0.022	0.022	*0.169*	0.026	0.026	0.665	**0.133**	
VR-TLG	0.022	0.026	*0.241*	0.046	0.126	0.707	**0.126**	**0.801**

Table 3. The pairwise Wilcox test comparison between sites. Probabilities p values displayed in the lower left triangle with the significant (below the 0.05 threshold) ones with **. Italicized data are results between geographies; Boldface data are results within geographies (MAI = mountain Iron Age; MR = mountain Roman; VAI = valley Iron Age; VR = valley Roman). See Table 1 for complementary information

If we focused on the middle Iron Age data, differences between most of the sites from the valley and the two sites from the mountains were observed. The results documented within the two mountain middle Iron Age sites should also be highlighted, as they showed differences in sheep size in the lateral view but not in the plantar view (Fig. 4, Table 3). Comparisons between the valley sites dated to the middle Iron Age also showed some variations within sampled sites, although no statistically significant differences were documented through pairwise Wilcoxon's test (Table 3).

If we focused on the early Roman data, no differences between the sites from the valley and the mountain site of Llívia were observed. At the same time, no differences were documented within the valley sites.

The sizes of the lateral and plantar views of the astragali were correlated (correlation = 0.73 (95% confidence interval, 0.58–0.83; p = 1.4e-10, Fig. 5) with a clear size increase over time. Size increase between the middle Iron Age and the Roman period was especially visible in the mountain (Fig. 5). Through based on limited sample size, the values of the middle Iron Age sheep astragalus from the valley appeared more variable in comparison with the small dispersion of the early Roman valley's sheep values (Fig. 5 and Online Resource 2). Another aspect to be observed was the association of the values from the Roman mountain site of Llívia with the values from the early Roman valley sites (Fig. 5 and Online Resource 2).

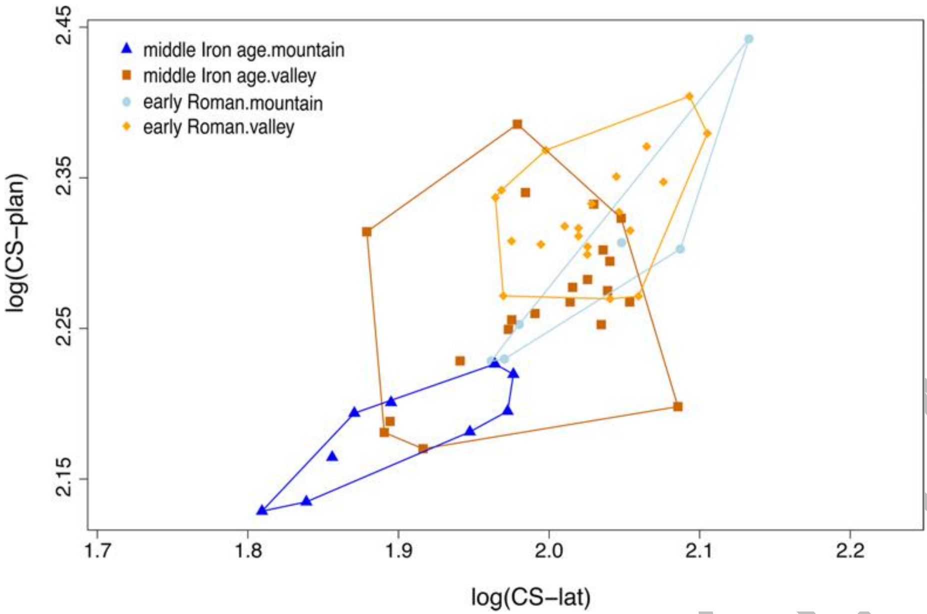

Figure 5. Scatterplot representation of the log (centroid) size of the lateral and plantar astragalus view comparing size variation between geography and chronology

Discussion

Geometric morphometric data showed consistent results for both views of the bone analysed. Only some discrepancies have been documented between views in relation to shape modifications. In that sense, we must take into account that different pressures apply on these two facets of the bone in accordance with the joint (Barr 2014). At the same time, the results presented here are based on a relatively small number of specimens (no other sites are present in the area), which may have precluded the detection of subtle shape differences between the various populations.

Geometric morphometric results showed important size changes between the Pyrenees and the north-eastern Iberian coast during the transition from the middle Iron Age to the early Roman period, which were not accompanied by astralagus shape modifications.

Several potential factors, such as climate or environment, diet, sexual dimorphism or human intervention, may have contributed to the diversity in sheep size distribution.

Climate or environmental factors, such as Bergmann's rule, can be eliminated. Bergmann's rule predicts a relationship between body size and climate, where one should expect larger body size linked to colder climatic conditions (Bergmann 1847; Rensch 1938). We clearly documented the contrary. At the same time, no strong climatic differences exist between the two areas and no climate changes have been observed between the middle Iron Age and the early Roman period in them (Rendu 2003; Ejarque 2013; Ejarque et al. 2016; Montaner et al. 2014).

The quality of diet could also have affected sheep size, but the environment of each geography show the existence of better pastures in the mountain area than in the valley along all the period under study here (Rendu 2003; Ejarque 2013; Ejarque et al. 2016; Montaner et al. 2014; Gallego et al. 2017). Therefore, this factor seems very unlikely to be the only explanation of sheep size changes. At the same time, we must remind that astragalus is a bone that appears to be unaffected by nutrition (Popkin et al. 2012; Haruda 2017; Davis 2017).

Sexual dimorphism could partially explain the results, but, as has been explained before, astragalus does not show a strong sexual dimorphism (Boessneck 1969; Davis 2000; Ruscillo 2003; Popkin et al. 2012; Haruda 2017; Davis 2017).

Therefore, of the factors known to principally impact on the size of an organism, human intervention likely explains our data, because the size changes occurred contemporaneously between the different geographies but also throughout all the studied time period.

Human intervention induces changes through two possible evolutionary mechanisms: conscious intervention through selective breeding based on target characters or unconscious intervention through isolation within a controlled human environment (Zohary et al. 1998).

Diachronic morphological differences

A clear size increase of sheep bred in the mountain area as well as in the valley has been documented between the middle Iron Age and the early Roman period. This sheep size increase linked with the Roman conquest was also documented in other areas of the Iberian Peninsula (Fernández 2003; Colominas 2013, 2017b; Valenzuela et al. 2017) and the Roman Empire, such as England (Albarella 2007; Albarella et al. 2008; Dobney 2001; Grant 1989; Maltby 1981; Noddle 1984), Switzerland (Breuer et al. 2001), France (Lepetz 1996), Romania (Gudea 2008) or Italy (MacKinnon 2004).

There were, however, differences in the timing and extent of this change, and there is a diversity of opinions on the cause or causes of this size increase. Some scholars argued that it should be linked with local improvement of existing stock, taking into account that this increase in size was not a sudden change (Lepetz 1996; Mackinnon 2004; Noddle 1984). For others, this was caused by the introduction of new stock rather than merely by improved conditions (Albarella et al. 2008; Gudea 2008).

The sample studied here was small and therefore, the data should be interpreted with caution, but they are consistent with the data obtained in other areas of the Iberian Peninsula, where a gradual sheep size increase from the early Roman period onwards was documented and no significant shape changes were observed (Colominas 2013, 2017b). Consequently, we propose that there was an improvement of the local stock that gradually replaced flocks of small sheep in the lowlands and in the mountains, showing that Roman husbandry methods seemed to have had influence on the management of sheep in the Empordà valley but also in the Cerdanya mountains.

Synchronic morphological differences

Morphological diversity between middle Iron Age sheep

The mountain and valley middle Iron Age sheep discussed in this study differ from each other in their astragal size (for both sides). The individuals from the valley sites have the largest astragali, whereas the individuals from the mountain sites have the smallest. We propose that these differences might reflect different sheep populations between the mountain and the valley communities rather than environmental characteristics (e.g. climate, vegetation). Nevertheless, the limited number of mountain sites with enough animal remains makes it difficult to conclude whether small sheep, especially at Castellot de Bolvir, were an exception or occurred commonly.

Similar evidences, however, were documented in Switzerland with Bronze Age cattle. In the study performed by Bopp-Ito et al. (2018a) Alpine cattle were smaller than the Central Plateau cattle. Those differences likely reflect different economic interrelationships between Alpine and other geographically related communities, which might have led to the emergence of size diversity in Swiss Bronze Age cattle (Bopp-Ito et al. 2018a).

Some differences have also been observed in this study within the two mountain middle Iron Age sites but also within the valley sites. These data suggest that livestock particularities existed not only on a geographical scale but also on a local scale and probably resulted from different animal husbandry strategies between settlements and/or from the existence of distinct domestic stock. In that sense, topography could only partially explain size diversity documented during that period.

Local phenotypic variability has also been observed in Bronze Age sheep within the north Italian region (Trentacoste et al. 2018) and in Bronze Age pigs within the Switzerland Plateau (Bopp-Ito et al. 2018b) suggesting a lack of genetic interaction among these populations (Bopp-Ito et al. 2018b).

Species representation and kill-off-patterns documented in the middle Iron Age sites studied here support this interpretation. Cattle’s remains predominated (46%), followed by those of caprine (32%) and pigs (14%) at Castellot de Bolvir (Colominas 2017a). Sheep kill-off-patterns show a clear predominance of slaughters between 6 and 12 months, indicating the exploitation of these animals to obtain meat (see Colominas 2017a for more information). The studies performed at Llo documented a predominance of caprine remains (64%), followed by cattle (27%) and pig remains (5%) (Vigne 1980). Sheep kill-off-patterns show a predominance of slaughters at juvenile ages (Vigne 1980).

The data from the valley sites also show some differences between sites. Animal husbandry practices at Mas Castellar de Pontós focused on sheep and goats (43%). Pigs were the second most abundant specie (22%), followed by cattle (20%) (Colominas 2013). The analysis of sheep mortality profiles shows that their husbandry was more oriented towards wool production and breeding rather than meat (see Colominas 2013 for more details). Animal husbandry at Sant Sebastià de la Guarda focused on sheep and goats (44%). Cattle were the second most abundant specie (33%), followed by pigs (19%) (Colominas 2012). Sheep were exploited for their wool but also to obtain meat (see Colominas 2012 for details). Animal husbandry at Sant Julià de Ramis was mainly focused on sheep/goats (30%), followed by cattle (26%) and pigs (24%) (Colominas 2011). Sheep kill-off patterns show that these animals were exploited more for their wool than for their meat, with a predominance of the slaughters at adult and old ages (see Colominas 2011 for details).

Therefore, a diversified livestock strategy between mountain and valley settlements but also within valley settlements is documented during that period, in which animal husbandry practices were adapted to the necessities of each settlement.

Morphological diversity between early Roman sheep

A similar size increase and morphological similarities (no size and shape differences were observed) between the early Roman mountain site of Llívia and the early Roman valley sites have been documented. Although these data must be interpreted with caution, as the early Roman sample from the mountain come from the single Roman mountain site of the area with faunal remains, we consider that topography was not a factor that influenced size diversity in that period. We propose that the sheep size increase documented at Llívia, similar to that documented in the other early Roman sites from the valley, is showing a similar sheep improvement pattern and/or similar stock for both areas.

Species representation and kill-off-patterns of the early Roman sites studied here support this interpretation. We document a predominance of caprine remains (39%), followed by pigs (26%) and cattle (21%) at Llívia (Colominas 2017a), a different pattern from the previous period and from the data of Castellot de Bolvir. At the same time, sheep kill-off-patterns show a predominance of slaughters at older ages to obtain wool (see Colominas 2017a for details), changing the age of slaughters documented in the Cerdanya mountain area during the previous period. Similar sheep kill-off-patterns, with a clear predominance of the slaughter at older ages, have also been documented during the early Roman period in the valley sites, as a result of a more intensive and specialized animal husbandry, in which sheep was exploited to obtain wool and pigs were the main source to obtain meat products (Colominas 2013, 2017a, b).

Therefore, the similarities in the osteometric but also in the osteological data documented between the two areas seem to indicate the integration of the Pyrenees, and specifically of Llívia, to the livestock model documented on the north-eastern coast for the first time. Is in that period when a similar animal husbandry with the same orientation in the exploitation of domestic animals in the eastern Pyrenees and in the north-east Iberian lowlands is observed for the first time (Antolín et al. 2018; Knockaert et al. 2018; Colominas 2017a).

These results fit in with data from the studies of other archaeological remains recovered at Llívia, such as imported marbles or ceramics, and from the study of the surrounding territory, which also show a close economic relationship between Llívia and the southern communities during the Roman period (Leveau and Palet 2010; Olesti 2014; Olesti et al. 2014; Guàrdia et al. 2017). It is also in that period when the Pyrenees would be intensively exploited with activities related to mining, metallurgy or pitch that could only be economically feasible in market-oriented economies with a well-developed distribution network (Orengo et al. 2013). In that sense, we propose that this sheep size increase should be related with the presence of an improved sheep that could produce better quality wool, being more suitable for an economy strongly oriented towards the market, in which the eastern Pyrenees would be part for the first time.

The data presented here have also documented a potential relative increase of size homogeneity of the early Roman valley's sheep. Early Roman sheep bred in the valley share common morphometric characteristics compared to Iron Age sheep bred in the same location. A general reduction of sheep withers' height variability from the Republican to the Imperial period was also documented in Italy in the comparison of sheep from South, Central and North Italian areas (Mackinnon 2004). Similar evidences were also documented at France with Roman cattle (Duval et al. 2013) and pigs (Duval et al. 2018). The data have been interpreted as indicative of the beginning of a period of stability in terms of cattle growth (Duval et al. 2013) and due to the development of an economic consistency across Gaul under the Roman influence (Duval et al. 2018). We though that this decrease in size variability could also be linked precisely with the intensive and specialized animal husbandry that characterize Roman livestock practices around the Empire, with a conscious intervention through selective breeding, in contrast of the unconscious intervention that would characterize middle Iron Age animal husbandry.

Conclusions

Our study has demonstrated that astragalus is a bone that can be used to study changes in ovine morphology and that the landmarks and sliding semi-landmarks measured here can be used to study phenotypic astralagus variations. In that sense, we consider that this paper can be used as a baseline to explore other areas and/or chronologies, with the aim of investigating ovine morphology.

The application of this approach combined with the other available archaeozoological data has allowed us to document the local character of the livestock practiced in the Pyrenees and the north-eastern Iberia during the middle Iron Age, with the breeding of sheep with distinct size and the implementation and development of different sheep husbandry practices in the two areas. Therefore, local breeding strategies have been documented during that period.

On the contrary, the data presented here for the early Roman period seem to suggest that the livestock practiced in the Roman mountain city of Llívia was similar to this practiced in the lowlands, with the breeding of sheep with similar size and the implementation and development of similar sheep husbandry practices. These evidences could be denoting for the first time the existence of livestock links between these two areas, as has been documented with the study of other archaeological materials.

Therefore, the changes in the exploitation of domestic animals documented in Iberia with the Roman conquest would be accompanied by changes in animal management that could be involved a possible movement of sheep between the lowlands and the Pyrenees for the first time. The increase of agriculture on the coastal plains could have implied a more accentuated pressure on the existent pasture areas, making necessary regional movements of sheep. In that sense, the early Roman period could be the prelude of the intensive exploitation of eastern Pyrenean highlands as pastures, specially documented during the medieval period onwards, due to large sheep transhumance from the Mediterranean coast to the eastern Pyrenees to exploit summer pastures, practiced until nowadays.

The livestock links documented here between the Pyrenees and the coast, could involve sheep movements but also trade and sharing technologies among other aspects, as a result of the development of a common economic model between these two areas. The socio-cultural aspects that could shape these links also deserve further considerations.

We consider that the exploratory explanation presented here is the most suitable to our dataset. However, three lines of further investigation are required to conclusively test the various hypotheses developed here. First, more samples especially from the mountain area are required to properly contrast the early Roman data presented here. Second, integration with an isotopic or DNA analyses would be suitable for a fuller understanding the possible movement of animals between these two areas. Finally, the comparison of this case study area with other mountain-valley areas would be useful to better understand this phenomenon.

Notes

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