



Did Romanization impact Gallic pig morphology? New insights from molar geometric morphometrics



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ABSTRACT

In Western Europe, at the turn of our era, the emergence of the Roman economic and agropastoral model is considered as the trigger for morphological changes experienced by livestock. This assumption is now undermined, reviving questions of the origin and mechanism of these changes as well as the influence of Gaul's agricultural particularities in the process. To investigate this question we used a geometric morphometric approach to study the phenotypic relationships of almost 600 dental remains of pigs (*Sus scrofa domesticus*) from 11 Gallic and Italian sites, and pinpoint evidence of Roman or indigenous signature on the livestock. The comparison of these different samples allowed us to demonstrate that the link between the Roman and Gallic pigs is weak, and, more importantly, that each of the two territories seem to follow its own livestock management model. Furthermore, each region or settlement within Gaul adopted their own particular pastoral or supplying strategies; apart from two urban sites of central Gaul which showed clear phenotypic relationships with southern populations. These results suggest that the pigs' morphology depended mainly on agricultural and economic characteristics of the different territories, within Gaul and Italy, except perhaps on some urban sites with different supply strategies. It seems, therefore, that the changing economic environment impacted both provinces independently, or at least differently, since it cannot be excluded that there may have been some commercial relationships between them.

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1. Introduction

In recent years, the changes in growth and form of domestic herds from the Roman Empire have been extensively investigated by zooarchaeologists (cf. for example Albarella et al., 2008; MacKinnon, 2010; Colominas et al., 2013). In Gaul, these morphological changes are attested long before the Roman Conquest, as early as the end of the Iron Age (between the 4th and the 1st century BC). During this period, the livestock's morphology appeared to differ from one region to another (administrative

regions or valleys – see Duval et al., 2012) and, at least for the Northern Gaul (Duval et al., 2013), phenotypic changes happened as early as La Tène C (about 260–150 BC). Later (between the 2nd and the end of the 1st c. BC, depending on the region), according to studies mainly performed on cattle and horse, the emergence of the Roman economic and agropastoral practices will lead to the acceleration of morphological changes and the emergence of a new diversity of forms and growth patterns (cf. for example Johnstone, 2004; MacKinnon, 2010; Duval et al., 2012). Unfortunately these studies were unable to provide answers about the precise causes and mechanisms of this phenotypic differences and changes, and overlooked one of key component of Gaul's domestic livestock: the pig.

The morphological change in Gallic pigs over time is still poorly documented due to the lack of large conducive samples (although this could be overcome by the use of the LSI method – see for example Duval et al., forthcoming). One of the reasons is that pigs

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were widely consumed in Gaul but often at a very young age; therefore most of their bones' remains are unfused, hampering reliable osteometric analysis. A second one is the high fragmentation of pigs' remains due to butchering practices and post-depositional taphonomy, preventing accurate morphometric investigation. Complete dental remains, however, prove to be the ultimate phenotypic marker to investigate changes in pig populations over large samples, both spatially and temporally.

Thanks to the recent development of geometric morphometric approaches applied to the dental remains of suids (Cucchi et al., 2009, 2011; Evin et al., 2013), we can now investigate the important questions regarding the impact of Romanization on pig morphology in Gaul from the 4th c. BC to the 3rd c. AD. Was pig husbandry in Gaul influenced by the introduction of animals from Roman centers or rather by the zootechnic improvement of local herds? What was the extent of contact between Gaul and Italy, and in particular, the degree of Rome's influence over the Gallic zootechnic improvements? And finally, how diverse was the dental morphology of Gallic pigs?

2. Material and methods

2.1. The archaeological sites

The analysis of pig dental morphotypes in Gaul is based on the form (size and shape) of 599 second lower molars (M_2) using geometric morphometrics (Table 1). The molar tooth was chosen principally because it has been identified as an efficient phenotypic marker to track population histories (Ervynck et al., 2007; Rowley-Conwy, Dobney, 2007; Albarella et al., 2009; Cucchi et al., 2011; Evin et al., 2015), and is well represented within archaeological assemblages. In the samples studied, the first lower molar of pigs (slaughtered primarily around 1–2 years) is often greatly worn,

with the third lower molar still either not completely formed or erupted. The material studied come from 11 sites (9 from Gallic territory and 2 from Italy) in order to compare dental phenotypes of pigs from Gaul and the Italian peninsula (Fig. 1). In order to assess a large area of Gaul, and allow the distinction of regional morphotypes within this territory, the sites chosen came from three distinct geographic areas: (1) *Gallia Belgica*, (2) between *Gallia Lugdunensis* and *Aquitania*, and (3) *Narbonensis* (Fig. 1). This sampling strategy cover a large latitudinal gradient (from an oceanic to a Mediterranean climate) which superimposed over important disparities in administrative status and cultural and agropastoral idiosyncrasies; all of which could have contributed to the diversity in pig morphology. In order to cover both the Gallic and Roman periods, we selected well dated sites with large sample sizes from each area. Where possible, we selected sites with a long chronological time span in order to track size and shape changes over the different periods. The time span covered by the sites of *Gallia Belgica* (under Roman influence from the end of the 1st c. BC) extends from the 3rd c. BC to the 2nd c. AD, from the 2nd c. BC to the 2nd c. AD for *Gallia Lugdunensis* and *Aquitania* (conquered from the end of the 1st century AD too), and from the 5th c. BC to the 3rd c. AD for *Gallia Narbonensis* (occupied since the 2nd century BC); the two Italian sites date from the 3rd to 1st c. BC (Musarna) and 2nd c. AD (Rome).

In the northern region (A), the samples studied come from three sites (situated less than 10 km apart): the rural settlement of Glisy (3rd c. BC), the Gallic, then later a Roman sanctuary, of Ribemont-sur-Ancre (1st c. BC and 2nd c. AD) and the city of Amiens/*Samarobriva* (1st c. AD). In the centre of Gaul (B) we choose three other sites (situated more than 100 km apart): the Gallic village of Levroux (200 BC to 14 AD) where pig husbandry seemed to be preponderant (Horard-Herbin, 1997; Frémondeau, 2012), the Roman agglomeration of *Argentomagus* (1st c. AD) and the city of Tours/

Table 1

Archaeological samples studied with their site name, their membership to the different Roman provinces divided into four geographic areas (A, B, C and D), their chronological span, the sample size per individual chronological context and the latitudinal position of each site. Each chronological context is considered as a population sample whose label is displayed in *Population ID* and will be used in the text, tables and figures. *Chronological factor* provides the grouping factor used to test the temporal effect.

| Site names | Roman provinces | Chronology | n teeth | Chronological factor | Population ID | Latitude | Reference |
|---|---|---|---------|----------------------|---------------|----------|---|
| Glisy – Les Terres de Ville Ribemont-sur-Ancre | A: <i>Gallia Belgica</i> | 3rd c. BC | 49 | 3BC | GLI 3BC | 49.88 | Auxiette (unpublished) |
| | | 1st c. BC | 54 | 1BC | RIB 1BC | 49.96 | Méniel (unpublished) |
| | | third quarter of the 2nd c. AD | 36 | 2AD | RIB 2AD | | Fercoq du Leslay and Lepetz (2008) |
| Amiens/ <i>Samarobriva</i> – Palais des Sports | | 1st c. AD | 50 | 1AD | AMI 1AD | 49.89 | Lepetz (2010) |
| Levroux – Les Arènes | B: <i>Gallia Lugdunensis</i> and <i>Aquitania</i> | phase 1 (200–150 BC) | 33 | 2BC | LEV 1 | 46.98 | Horard-Herbin (1997) |
| | | phase 2 (150–100 BC) | 13 | 2BC | LEV 2 | | |
| | | phase 3 (150–100 BC) | 54 | 2BC | LEV 3 | | |
| | | phase 4 (100–80 BC) | 19 | 1BC | LEV 4 | | |
| | | phase 5 (20 BC to 14 AD) | 13 | 1BC | LEV 5 | | |
| Saint-Marcel/ <i>Argentomagus</i> | | end of the 1st c. BC to the end of the 1st c. AD | 44 | 1AD | ARG 1AD | 46.6 | Rodet-Belarbi (1989) |
| Tours/ <i>Caesardunum</i> | | 1st c. AD | 27 | 1AD | TOURS 1AD | 47.39 | Poupon (unpublished) |
| | | 2nd c. AD | 20 | 2AD | TOURS 2AD | | |
| Lattes/ <i>Lattara</i> | C: <i>Gallia Narbonensis</i> | 5th c. BC | 4 | 5BC | LAT 5BC | 43.57 | Colomer and Gardeisen (1992); Gardeisen (1999, 2003, 2008, 2009); Renaud (2012) |
| | | 4th c. BC | 22 | 4BC | LAT 4BC | | |
| | | 3rd c. BC | 8 | 3BC | LAT 3BC | | |
| | | 2nd c. BC | 13 | 2BC | LAT 2BC | | |
| | | 1st c. BC | 9 | 1BC | LAT 1BC | | |
| Nîmes/ <i>Nemausus</i> Aix-en-Provence/ <i>Aquae</i> <i>Sextiae</i> – ZAC Sextius Mirabeau | | 1st c. AD | 14 | 1AD | LAT 1AD | | Forest (unpublished) Leguilloux (1997) |
| | | from the 1st to the 3rd c. AD | 20 | 2AD | NIM 2AD | 43.84 | |
| Musarna Rome – <i>Vigna Barberini</i> | D: Italy peninsula | from the 3rd to the 1st c. BC | 24 | 2BC | MUS 2BC | 42.42 | Tagliacozzo (unpublished) Lepetz (unpublished) |
| | | 2nd c. AD | 37 | 2AD | ROM 2AD | 41.89 | |

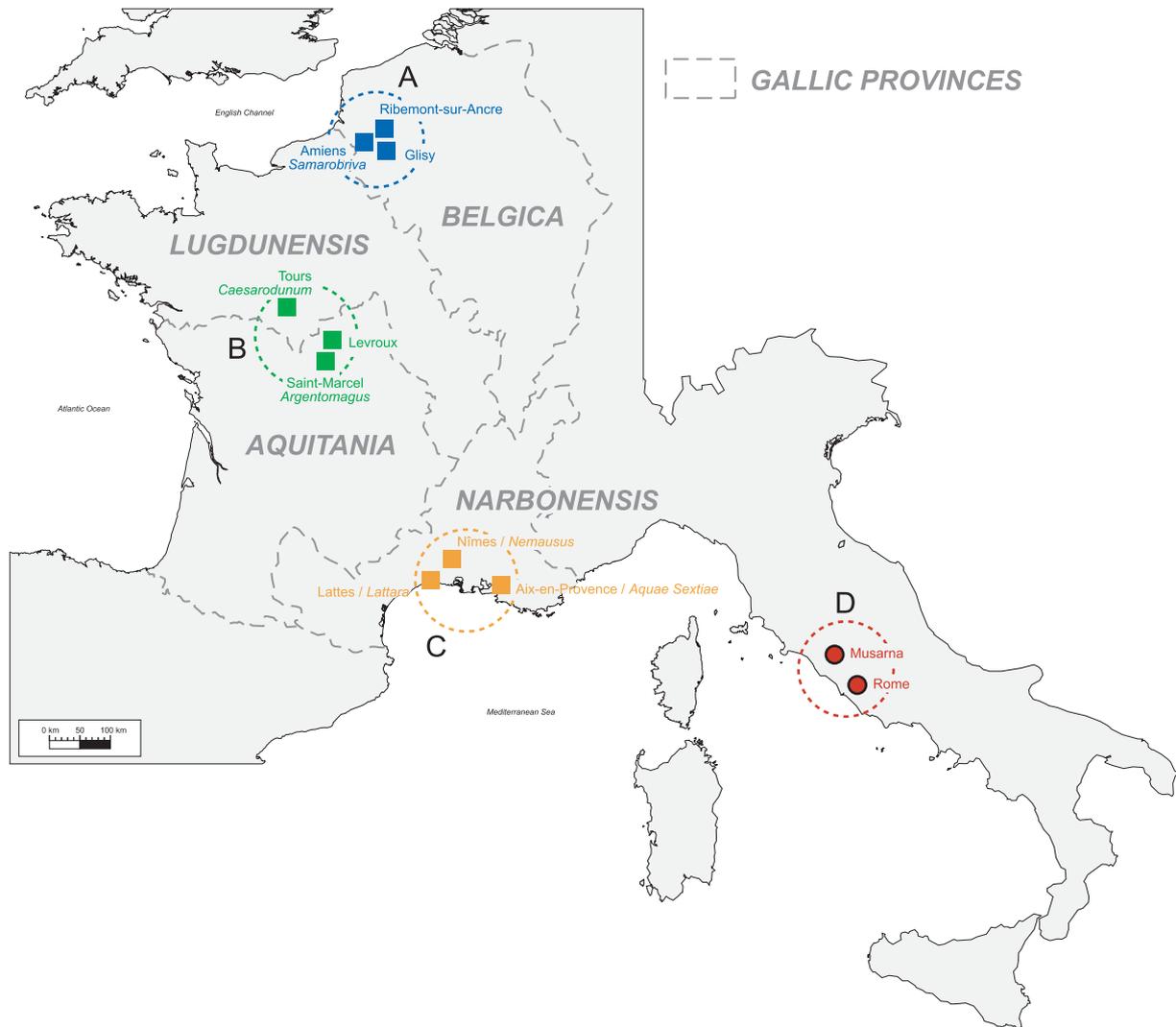


Fig. 1. Location of the archaeological sites studied in Italy and the various Gallic provinces.

Caesarodunum (1st and 2nd c. AD). In Southern Gaul (C), again these sites were located more than 100 km apart, included the proto-historic and antique settlement of Lattes/Lattara (5th c. BC to the 1st c. AD), an important Mediterranean commercial port; the city of Nîmes/Nemausus (1st to 3rd c. AD), chief-town of its territory, and a pork butcher's dumping pit in Aix-en-Provence/Aquae Sextiae (2nd c. AD). Finally, material from Italy (D) comes from the early occupations of the Roman agglomeration of Musarna (3rd to the 1st c. BC) and the imperial palace erected on the *Vigna Barberini* in Rome (2nd c. AD).

2.2. Methods

2.2.1. Geometric morphometrics

In order to quantify the phenotypic relationships between pig populations, the size and shape analysis of the occlusal surface of second lower molars was performed with geometric morphometrics approaches, after the method developed by Cucchi et al. (2011). We have amended it for this study by changing the two landmarks located on the outline of the crown into semi-landmarks, due to lack of repeatability. We have kept the seven landmarks within the occlusal surface (Fig. 2). We extracted 68 equidistant semi-landmarks from the outline of the external 2D projection of the crown with a starting position located at the maximum curvature of

the outline between the metaconid and the entoconid (Fig. 2). Pictures of the occlusal face of teeth were taken with a Nikon D7000 coupled with a 105 mm Micro objective. Landmarks and semi-landmarks were acquired with TpsDig2 v.2.16 (Rohlf, 2010a).

The centroid size and the shape coordinates were obtained after a generalized Procrustes superimposition was performed on the landmark and semi-landmark configurations (Rohlf and Slice, 1990; Goodall, 1995). This procedure is a least square oriented approach that removed information of position, size and orientation from the configurations' coordinates by translating them to a common origin, scaling them to the same centroid size, and rotating them to minimize the distances between each landmark. The semi-landmarks were forced to slide along the tangent of the outline curve to minimize the bending energy to the mean (Bookstein, 1997).

TpsRelw v.1.49 (Rohlf, 2010b) was used to perform the Procrustes superimposition and the sliding of the semi-landmarks, and to compute the centroid size and the Procrustes coordinates: the size and shape variables for the statistical analyses. The Log of the centroid size (LogCS) was used for the statistical analyses.

2.2.2. Statistics

Overall differences of centroid size variation between population samples were tested using an Analysis of Variance (ANOVA)

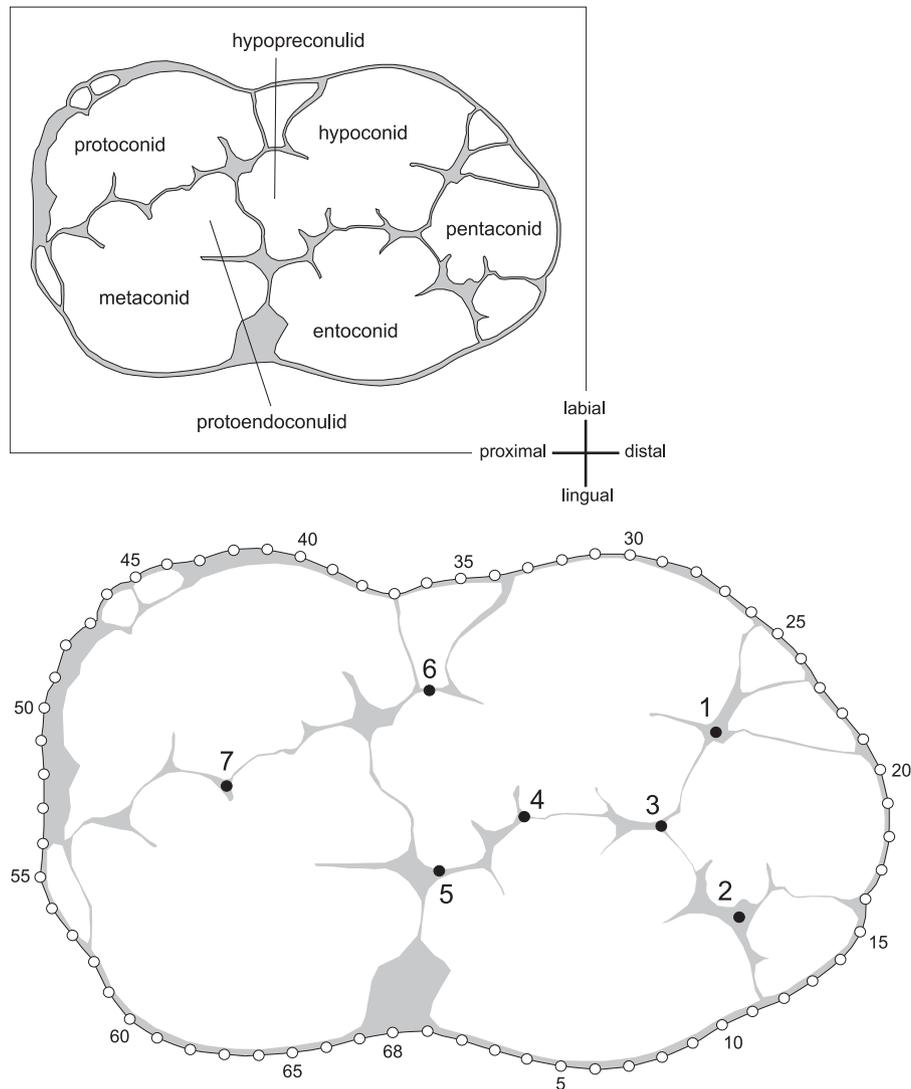


Fig. 2. Occlusal view of the M_2 with the main cusps nomenclature above and the localization of the landmarks (black points) and semi-landmarks (white points) below.

and the pairwise comparison with the associated Tukey's HSD test, for which sample sizes are not required to be equal. The graphical display of molar size variation among population samples was performed using box-plots.

The molar shape differences amongst the population samples were tested using a one-way Multivariate Analysis of Variance (MANOVA) (Pillai's test). Due to the relatively small number of specimens, and compared to the large number of variables generated by shape analyses, we used the dimensionality reduction method with Principal Components analysis proposed by [M. Baylac and M. Friess \(2005\)](#). To display the differences among the various population samples both spatially and temporally, we used a Canonical Variate Analysis (CVA): a multigroup form of discriminant analysis, and a phenogram using the unrooted neighbor joining algorithm (NJ) computed from Mahalanobis distances between the population's mean shape. For the sake of better readability of patterns of molar shape differentiation, the CVA only displays graphically the population mean shapes with their interval of confidence. The association of the different discriminant axes allows a deeper perception of the structure of variation and increased flexibility, welcome in the context of an analysis where factors of variation are intertwined and follow different directions. This representation system is consistent with the idea that it is necessary to multiply

the angles, and not to lead too rigid an approach. Dental shape changes along the discriminant axes of the CVA were visualized by computation of the deformations along the discriminant axes by multivariate regression ([Monteiro, 1999](#)).

To test whether geography and chronology influenced the patterns of the molar centroid size and shape variation, and interacted with the population differences we used two-way ANOVA and MANOVA respectively. The geographic factor is defined by the four areas (A, B, C and D) and the chronological factor is displayed in [Table 1](#).

Finally, considering the large distribution of our samples and knowing the influence of abiotic parameters (precipitation, temperatures, etc.) over the dental morphology of mammals ([Caumul, Polly, 2005; McGuire, 2010; Cucchi et al., 2014](#)), we wanted to assess how much the environmental differences among the sites contributed to the molar size and shape variation of the pigs and influenced their differentiation. We used the coordinates of the latitudinal position of each archaeological site as a useful proxy of the environmental differences among the sites since latitudinal positions reflect both the climatic and ecological parameters of a region. We tested the dependence of size and shape variation with the latitudinal position using univariate (LogCS) and multivariate (Procrustes coordinates) regressions respectively, associated with a

permutation test of 10,000 rounds. The latitudinal values per each sites (Table 1) where obtained from the World Geodetic System 1984.

Statistical analyses were performed using R v.2.13.1 (R Development Core Team 2011), with the ade 4 (Dray and Dufour, 2007), ape (Paradis et al., 2004) and Rmorph libraries (Baylac, 2012), as well as MorphoJ software version 1.05c (Klingenberg, 2011).

3. Results

3.1. Geographical, environmental and chronological variation of the centroid size of pig molars

Overall, ANOVA found highly significant differences in M_2' centroid size among the pig samples ($F = 4.873$, $df = 17$, $P < 0.0001$), however, these differences are not significantly influenced by the environmental distances over the large geographical distribution of the archaeological samples (Table 2).

Two way ANOVA found a highly significant geographic effect over the molar centroid size variation ($F = 15.0656$, $df = 3$, $P < 0.0001$) but a low chronological one ($F = 2.8452$, $df = 8$, $P = 0.0042$), and a slight interaction between the geographic and the chronological effects ($F = 3.7324$, $df = 5$, $P = 0.0025$). Despite the significant differences of centroid size (among population samples, geography and chronology), the distribution of the variation illustrated by the box-plot (Fig. 3) reveals a lack of strong geographical or chronological trend with a very constant M_2' centroid size of the population samples of our dataset. This trend was confirmed by the pairwise comparison (Table 3) which only found significant differences for the smallest specimens from *Belgica* (GLI 3BC and RIB 1BC), LAT 2BC and Italy (MUS 2BC and ROM 2AD) and for the largest ones from LAT 1AD and especially TOURS 2AD.

However, even if most of these differences are not significant, we can see that the molar centroid size for the Gallic period (3rd to 1st c. BC) is smaller than during the Roman period (1st to 3rd c. AD), for population samples from *Belgica* and *Lugdunensis/Aquitania* (Fig. 3), with an increase between La Tène and the Roman period. This observation conforms with results obtained from teeth and limb bones measurements, in Gaul and other regions, for the pig and all other domestic species (Lepetz, 1996a, 1996b; MacKinnon, 2001, 2010; Albarella et al., 2008; Colominas et al., 2013; Duval et al., forthcoming). In contrast, the situation for southern sites is less clear. All the population samples from Gaul have a mean molar centroid size greater than the Italian pigs, although no significant differences have been observed (see Table 3). Hence, molar size variation already shows regional idiosyncrasies with different dynamics of morphological changes across regions. Although the three studied areas do not differ by the molar centroid size of their pigs, we observed some differences in their variation through time. There is also a strong local identity, insofar as in selected areas, size increase appears clearly for sites for where both Gallic and Roman populations were studied (Ribemont-sur-Ancre/Tours/Lattes). Thanks to the long chronological record of the molar centroid size in Lattes, we can also observe a trend towards size reduction from the 5th c. BC to the 1st c. BC followed by an increase towards the 1st c. AD. This same size reduction, indicative of a size reduction in the pig itself, is also observable between the middle La Tène site of Glisy

and the final La Tène site of Ribemont-sur-Ancre (*Gallia Belgica*). This is consistent with data from other domestic species in France (Méniel, 1984) who reached their global minimum at the end of the Iron Age. For these specimens, whose morphological variations are small, the centroid size of the second lower molars seems to describe briefly a coherent evolutionary scheme, observed in post-cranial skeleton morphometrics (Duval, unpublished PhD).

For Italian pigs, the trend is not driven towards a size increase but a decline. Even though not the case in Gaul, this trend is not exceptional since the same observation has already been made for Catalan pig teeth and bone size between the Iron Age and the Roman period (Colominas and Saña, 2009). But most importantly, Italian centroid size values are inferior to other samples across all periods. It is interesting to see that Italian animals, which are presumably those who influenced the morphological evolution of the Gallic pigs, are, even when compared to samples from the La Tène period, the smallest. It appears, therefore, that molar centroid size does not provide any insight into the influence of Italian over Gallic stock.

3.2. Molar shape diversity of Gallic pigs and their relationship with Italian populations

Molar shape differences among the Gallic and Italian population samples of our study were highly significant ($Pillai = 1.6898$, $F = 1.6594$, $P < 0.0001$), and their phenotypic relationships present significant geographic ($Pillai = 0.52823$, $F = 4.0358$, $P < 0.0001$) and chronological ($Pillai = 0.64115$, $F = 1.6621$, $P < 0.0001$) structuration which interact ($Pillai = 0.36760$, $F = 1.5047$, $P = 0.0003$). The geographic pattern of the shape variation is not significantly influenced by the environmental differences between the sites (see Table 2).

The phenotypic relationships between the populations mean shapes, depicted by the NJ phenogram (Fig. 4), evidenced a strong local and regional differentiation, downplaying the time factor. The population samples from the different phases of Levroux display tight phenotypic relationships, just like the two samples of Ribemont-sur-Ancre, and those of Tours. On a larger scale, it appears that all the sites of *Belgica* are grouped, like the Italian ones. As with the centroid sizes, molar shapes from the southern Gaul samples are much more diverse, supporting further the specificity of this geographic area. Despite the strong geographic influence over the M_2' shape variation, other factors seem to have driven the molar shape pattern of our dataset. Indeed, the phenogram displays the dichotomy between the relationships among the Gallic sites of the north and the center (Levroux), and the relationships among the sites of Southern Gaul, Italy and Roman sites of center Gaul (*Gallia Lugdunensis* and *Aquitania*). Strikingly, the urban sites of Tours and *Argentomagus*, in the center of Gaul, dating from the 1st and 2nd c. AD, are neither related with northern samples of *Belgica* nor with the most geographically close population samples of Levroux, but are strongly branched within the *Narbonensis'* samples. Such phenotypic relationships suggest either a strong genetic influence of southern stock in the make up of the herds of these two urban sites, or supply strategies reliant mainly on southern rather than local stocks.

The association of the first two discriminant axes of the CVA (Fig. 5A) supports most of the observations raised from the phenogram, and also provides greater insight into the phenotypic

Table 2

Linear and multivariate regression models testing for influence of latitudinal factors on M_2' size and shape.

| | Total sum of squares | Predicted sum of squares | Residual sum of squares | Percentage predicted | Permutation P |
|--------------------------------|----------------------|--------------------------|-------------------------|----------------------|-----------------|
| Size (Log CS) | 0.00017924 | 0.00000011 | 0.00017913 | 0.06 | 0.938 |
| Shape (Procrustes coordinates) | 0.00087742 | 0.00013758 | 0.0007399 | 15.68 | 0.091 |

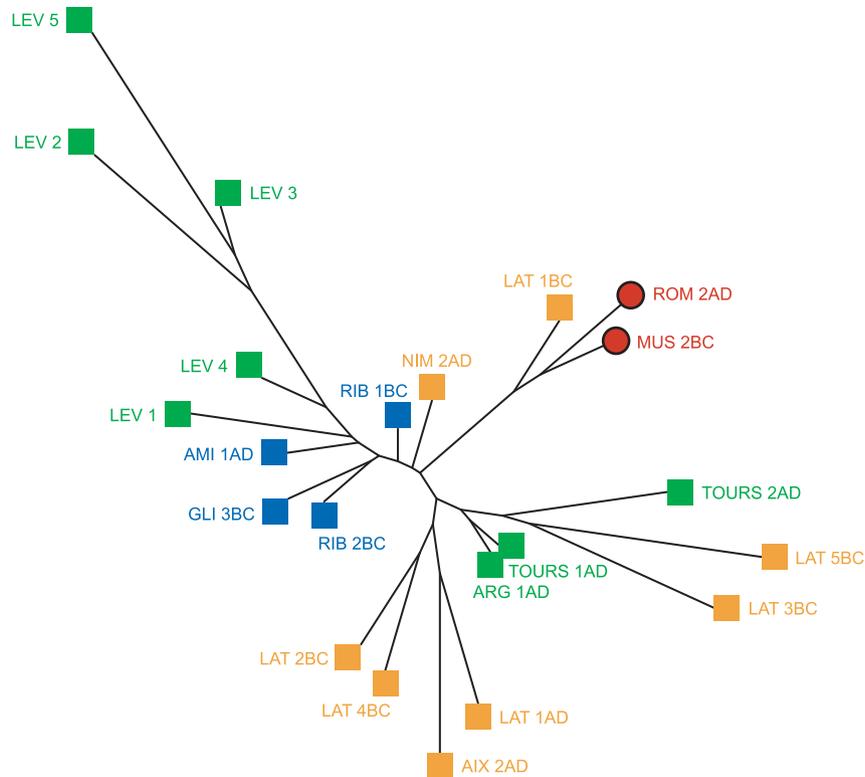


Fig. 4. Unrooted neighbor joining phenogram computed on D-Mahalanobis between group mean shapes. Colours correspond to the four roman provinces displayed in Fig. 1.

the pigs of central Gaul kept their particularities. The third, interestingly, links the Italian settlements with the port site of Lattes (from at least the 4th c. B.C.). Their proximity supports the idea of a certain geographical coherence, and raises the question of a relationship that potentially existed between the largest city of the Roman Empire and the commercial ports of the Mediterranean coast, long before the Roman Conquest.

4. Discussion

4.1. Rome's influence on Gallic pig morphology

According to geometric morphometrics of pig dental phenotype, the relations between Rome and Gaul is weak, contrary to what was thought previously. There are three important trends echoing this observation: firstly, the molar centroid size of Italian pigs is smaller than that of Gallic pigs during both the Iron Age and Roman period; secondly, this size reduces over time while it increases in Gaul and finally, there are clear shape differences between Italian and Gallic pigs which become increasingly evident.

These facts testify to the breeding of animals with distinct physical characteristics, and to the implementation and development of different husbandry practices in the two territories (Gaul and Italy). It seems that far from realizing complete uniformity across the Roman Empire (born from an Italian epicenter), we are presented with two contrasting agropastoral entities with complex internal logics.

There is, however, additional evidence which both supports and refutes this theory. The molars centroid size and shape shows a link between the Italian herds and those from southern Gaul, particularly those from Lattes. This link appears not to be related to environmental proximities between the two provinces. In contrast, it attests more to the possible cultural and agropastoral proximity of the two territories, as well as sustained relationships (probably at

a commercial level) between Gallic ports around the Mediterranean coast and Italy. This phenotypic proximity between Italian and Gallic pigs from Lattes evidenced well before the Conquest, and excludes *de facto* the idea of the development of Roman influence over Gallic livestock during the takeover of Rome on conquered territories. In addition, this connection does not exist at all for northern sites which experienced a completely independent evolution.

The clear phenotypic distinction between animals of the Italian peninsula (at least in Rome) and most of Gallic ones, calls into question the previously assumed link between the Gallic and Roman herds. Consequently, Italian husbandry methods seem to have had no influence on the development of a new form of Gallic animal that evolved entirely according to their own mechanisms, which is supported by post-cranial measurements (Duval, unpublished PhD) showing that Italian pigs are significantly smaller and undergo a delayed size increase compared to the Gallic ones. We can assume, therefore, that the morphological change of Gallic pigs results from the establishment of a new model, devised entirely by Gallic breeders, applied solely to Gallic livestock (at least for the most northern regions) and completely independent from the Italian model; a phenomenon also suggested for cattle husbandry (Duval et al., 2012, 2013).

However, we cannot totally exclude some relations between Gaul and Italy in terms of livestock trade and management, since other trading posts, or zones of influence, outside of Rome and the Latium, could have had much closer links with Gaul. Indeed texts from Latin agronomists stipulate that the Po Valley and the south of the Italian peninsula were much more suited to husbandry than the vicinity of Rome (Polybe, 1970, 2.15; Strabon, 1967, 5.1.12; or Jaillette, 2012). Moreover, the shape proximity between Italian pigs, those from *Narbonensis*, and the Roman ones from the centre of Gaul, could reflect the existence of a large scale and consistent supply area, encompassing southern Gaul

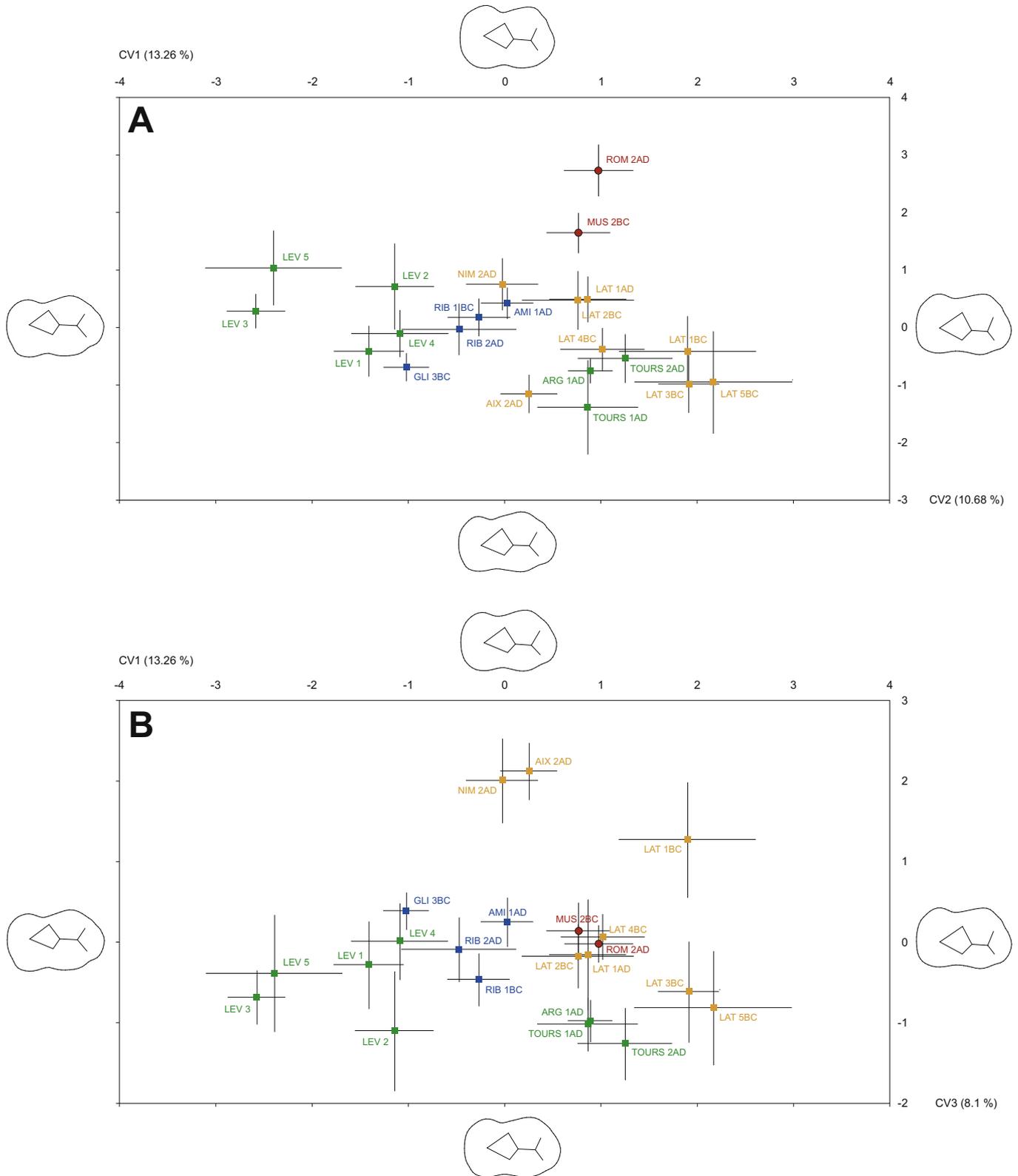


Fig. 5. Bivariate representation of the molar shape space of the Gallic and Italian samples of the study along the canonical variate axes CV1 and CV2 (A), and CV1 and CV3 (B). M_2' shape changes associated with the CVs are depicted at the end of each axis.

and Italy both before and after the Conquest. This last observation removes Rome as central to the system, and points to a much more regional structuration of pig husbandry in the Roman Empire where Italian and Gallic territories share the same level.

4.2. Geographical diversity of Gallic and Roman pigs' morphology

As previously mentioned, it is necessary to go beyond the simple opposition between Gaul and Italy due to the differences that appear to exist even within these territories. As we have seen, the molar

centroid size of pigs increased in northern and central France, while remaining constant in southern animals and decreasing in Italian herds. These trends, without being significantly influenced by the environmental differences among sites, not only oppose Gallic and Italian herds, but also those of the southern and the northern half of Gaul. In this way, the territory seems to be segmented into several areas where pastoral characteristics differ. These growth dynamics were recorded for cattle in the north of Gaul (Duval et al., 2012), yet only affected the growth speed, intensity and magnitude. If more southern territories are included, other patterns such as size stagnation or decrease appear. These particularities of the south of Gaul and Italy appear to be in keeping with the agropastoral specificities of these regions. The southern peculiarities may reflect, for example, a contrast between the early conquered *Narbonensis* and the rest of Gaul in terms of growth pattern; or a strong regional identity within an agropastoral strategy more reliant on caprines than suids (Leguilloux and Lepetz, 1996).

However, the most important confirmation provided by our study is the local and regional origin of the Gallic pigs from the Roman period. This phenotypic persistence before and after the Roman Conquest is supported by previous analyses conducted on cattle bones (Duval et al., 2013). This hypothesis suggests that each locality drove the morphological changes of their own herds at their own pace, according to available resources, the chosen economic strategy and, to a much lesser extent, environmental characteristics. This trend is particularly noticeable in the north of Gaul, where the proximate sites studied delivered extremely close dental forms. Italy was not an exception to the rule, and far from influencing the Gallic model, had a very different logic adapted to its own cultural and agropastoral context. This new analysis therefore, appears to confirm not only the phenotypic and morphological diversity of livestock in Gaul, but across the whole Empire.

With this in mind, it can be argued that the Roman model could have driven the economic need for change, but that the farmers themselves (regardless of regional boundaries and based on indigenous breeds, at least for pigs) exploited and transformed available livestock on site through the application of new farming methods. This evolution seems to have been principally zootechnical (improved nutrition, animal protection, mating selection) and probably without genetic transfer from exogenous livestock or new husbandry techniques. The influence of Rome, therefore, did not affect the animals directly or the expression of change, but acted as the catalyzer within these different native economic models.

4.3. Phenotypic diversity: reflective of a differential supply?

Certain results have also allowed the further study of site supply. The northern sites, due to their close proximity, were able to rely on a shared pig husbandry catchment area with an economy centered on a common territory. However, other areas provide more ambiguous information. In the remote sites of the centre and south of Gaul, differences in the animal's shape were generated despite a strong regional structure. The Roman sites of area B, for example, are clearly distinct from Iron Age Levroux. The peculiarity of Levroux could be due to its status, as it was regarded as a centralized hub for the preparation and sale of pigs from numerous surrounding farms (Frémondeau et al., 2013). Similarly, the sites of Nîmes (chief-town of its territory) and Aix-en-Provence (butcher shop which specialized in pork), held an important and specific position in the supply chain which could explain the uniqueness of their herds.

5. Conclusion

In light of this study, our initial purpose to confront Gaul and Italy, driven by a strong historiographical tradition, seems to be

irrelevant. It appears that the confrontation of these two territories is not supported on any agropastoral ground. In contrast, analysis reveals a much higher complexity, reflecting the heterogeneity of the people within the Trans- and Cisalpine, or across other provinces. Beyond these entities, there is a more restricted fragmentation of which we can not reasonably draw boundaries, but which relies on a strong local breeding strategy. There is no origin or gradient of geographical progression to find, therefore, but rather the expression of a local cultural and agropastoral reality, which affected the herd management strategies and, subsequently, the animal's morphology. Consequently, within the context of a changing economic environment across the Empire, each territory, relying on local herds and according to its own abilities (livestock characteristics, feeding resources, skills) and its economic growth propensity has agreed to make a change in its husbandry practices. For this reason, the Empire must not be considered as a sum of confronting provinces, but rather as a conglomeration of relatively autonomous, and regionally identifiable territories, all of which were affected by a global model.

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References

- Albarella, U., Dobney, K., Rowley-Conwy, P., 2009. Size and shape of the Eurasian wild boar (*Sus scrofa*), with a view to the reconstruction of its Holocene history. *Environ. Archaeol.* 14 (2), 103–136.
- Albarella, U., Johnstone, C., Vickers, K., 2008. The development of animal husbandry from the Late Iron Age to the end of the Roman period: a case study from South-East Britain. *J. Archaeol. Sci.* 35, 1828–1848. Elsevier.
- Baylac, M., 2012. Rmorph: a R Geometric and Multivariate Morphometrics Library. Baylac, M., Friess, M., 2005. Fourier descriptors, Procrustes superimposition, and data dimensionality: an example of cranial shape analysis in modern human populations. In: Slice, D.E. (Ed.), *Modern Morphometrics in Physical Anthropology*. University of Chicago, Chicago, pp. 145–166.
- Bookstein, F.L., 1997. Landmarks methods for forms without landmarks: morphometrics of group differences in outline shape. *Med. Image Anal.* 1, 225–243.
- Caumul, R., Polly, P.D., 2005. Phylogenetic and environmental components of morphological variation: skull, mandible and molar shape in Marmots (*Marmota, Rodentia*). *Evolution* 59 (11), 2460–2472.
- Colomer, A., Gardeisen, A., 1992. Premier bilan sur la consommation des animaux d'élevage et de chasse dans la ville de Lattara (fin du IV^e av. n. è. - milieu du 1^{er} s. de n. è.). *Lattara* 5, 91–110.
- Colominas, L., Saña, M., 2009. Animal husbandry in the North-East of Catalonia from the 1st to the 5th Century AD: improvement and importation. *Stud. World Roman Period* 4, 9–26.
- Colominas, L., Schlumbaum, A., Saña, M., janvier 2013. The impact of the Roman Empire on animal husbandry practices: study of the changes in cattle morphology in the north-east of the Iberian Peninsula through osteometric and ancient DNA analyses. *Archaeol. Anthropol. Sci.* <http://dx.doi.org/10.1007/s12520-013-0116-9>, 16 p.
- Cucchi, T., Barnett, R., Martinkova, N., Renaud, S., Renvoise, E., Evin, A., Sheridan, A., Mainland, I., Wickham-Jones, C., Tougaard, C., Quere, J.-P., Pascal, M., Heckel, G., O'Higgins, P., Searle, J.B., Dobney, K.M., 2014. The changing pace of insular life: 5000 years of microevolution in the Orkney vole (*Microtus arvalis orcadensis*). *Evolution* 68 (10), 2804–2820.
- Cucchi, T., Fujita, M., Dobney, K., 2009. New insights into pig taxonomy, domestication and human dispersal in island south east Asia : molar shape analysis of *Sus* remains from Niah Caves, Sarawak. *Int. J. Osteoarchaeol.* 19, 508–530.
- Cucchi, T., Hulme-Beaman, A., Yuan, J., Dobney, K., 2011. Early Neolithic pig domestication at Jiayu, Henan Province, China: clues from molar shape analyses using geometric morphometric approaches. *J. Archaeol. Sci.* 38, 11–22.
- Dray, S., Dufour, A.B., 2007. The ade4 package: implementing the duality diagram for Ecologists. *J. Stat. Softw.* 22 (4). American Statistical Association, 20 p.

- Duval, C., Évolution et diversité de la forme du cochon entre l'âge du Fer et la période moderne en Gaule et en France. Régionalisme, acquisitions zootecniques et implications historiques., Université François-Rabelais, Tours (Unpublished PhD).
- Duval, C., Frémondeau, D., Lepetz, S., Horard-Herbin, M.-P., 2014. L'élevage du porc : un savoir-faire gaulois ? Apport croisé des études isotopique et ostéométrique des os de cochon. In: Blancaert, G., Malrain, F. (Eds.), Évolution des sociétés gauloises du second âge du Fer, entre mutations internes et influences externes, Actes du 38e colloque international de l'AFEAF (Amiens, 29 mai-1er juin 2014). Revue Archéologique de Picardie n° spécial (forthcoming).
- Duval, C., Horard-Herbin, M.-P., Lepetz, S., 2013. Morphological changes in domestic cattle in Gaul, from the second century BC to the fifth century AD: diversity of herds in the Seine valley (France) and northern Gaul. *J. Archaeol. Sci.* 40, 3977–3990.
- Duval, C., Lepetz, S., Horard-Herbin, M.-P., 2012. Diversité des cheptels et diversification des morphotypes bovins dans le tiers nord-ouest des Gaules entre la fin de l'âge du Fer et la période romaine. *Gallia* 69–2, 79–114. CNRS Éditions.
- Ervynck, A., Lentacker, A., Müldner, G., Richard, M., Dobney, K., 2007. An investigation into the transition from forest dwelling pigs to farm animals in medieval Flanders, Belgium. In: Albarella, U., Dobney, K., Ervynck, A., Rowley-Conwy, P. (Eds.), *Pigs and Humans 10,000 Years of Interaction*. Oxford University Press, Oxford, pp. 171–196.
- Evin, A., Cucchi, T., Cardini, A., Strand Vidarsdottir, U., Larson, G., Dobney, K., 2013. The long and winding road: identifying pig domestication through molar size and shape. *J. Archaeol. Sci.* 40, 735–743.
- Evin, A., Flink, L.G., Balaşescu, A., Popovici, D., Andreescu, R., Bailey, D., Mirea, P., Lazăr, C., Boroneanţ, A., Bonsall, C., Vidarsdottir, U.S., Brehard, S., Tresset, A., Cucchi, T., Larson, G., Dobney, K., 2015. Unravelling the complexity of domestication: a case study using morphometrics and ancient DNA analyses of archaeological pigs from Romania. *Philos. Trans. R. Soc. B Biol. Sci.* 370.
- Fercoq du Leslay, G., Lepetz, S., 2008. Manger dans les sanctuaires : salaisons et viande fraîche à Ribemont-sur-Ancre. In: Lepetz, S., Van Andringa, W. (Eds.), *Archéologie du sacrifice animal en Gaule romaine. Rituels et pratiques alimentaires, Archéologie des Plantes et des Animaux*, 2. Éditions Monique Mergoïl, Montagnac, pp. 201–206.
- Frémondeau, D., 2012. Rythmes saisonniers des élevages porcins archéologiques : propositions pour un protocole d'analyse isotopique (Unpublished PhD thesis). Muséum national d'Histoire naturelle, Paris, 436 and 121 p.
- Frémondeau, D., Horard-Herbin, M.-P., Ughetto-Monfrin, J., Balasse, M., 2013. L'alimentation des troupeaux porcins et la production de viande à Levroux Les Arènes (Indre) : une analyse isotopique. In: Colin, A., Verdin, F. (Eds.), *L'âge du Fer en Aquitaine et sur ses marges. Mobilité des hommes, diffusion des idées, circulation des biens dans l'espace européen à l'âge du Fer*, Actes du 35e colloque international de l'AFEAF (Bordeaux, 2-5 juin 2011), pp. 747–752.
- Gardeisen, A., 1999. Économie de production animale et exploitation du milieu au cours du quatrième siècle avant notre ère. *Lattara* 12, 537–568.
- Gardeisen, A., 2003. Contribution de l'archéozoologie des grands mammifères à l'étude d'un espace ouvert en contexte urbain. La zone 123 (Lattes/Saint-Sauveur, Hérault). In: Buxo, R., Chabal, L., Gardeisen, A. (Eds.), *La place 123 de Lattara. Recherches pluridisciplinaires sur un espace urbain du IV^e s. avant notre ère*, *Lattara* 16, pp. 169–184.
- Gardeisen, A., 2008. Terrestres ou volants : les animaux dans la ville antique de Lattes. In: Janin, T., Py, M. (Eds.), *Lattara/Lattes (Hérault). Nouveaux acquis, nouvelles questions sur une ville protohistorique et romaine*. Gallia, 65CNRS éditions, Paris, pp. 185–192.
- Gardeisen, A., 2009. Gestion des animaux de bouche au cours du V^e s. av. notre ère dans le Midi méditerranéen (-475/-375) : un aperçu lattois. *Lattara* 21, 419–428.
- Goodall, C.R., 1995. Procrustes methods in the statistical analysis of shape revisited. In: Mardia, K.V., Gill, C.A. (Eds.), *Current Issues in Statistical Shape Analysis*. University of Leeds Press, Leeds, pp. 18–33.
- Horard-Herbin, M.-P., 1997. Le village celtique des Arènes à Levroux. L'élevage et les productions animales dans l'économie de la fin de l'Âge du Fer, Levroux 4. *Rev. Archéol. Centre*, 12e supplément, 206 p.
- Jaillette, P., 2012. SULLA PECORA AD VRBEM ITER FACIVNT. In: Crogiez-Pétréquin, S., Jaillette, P. (Eds.), *Société, Économie, Administration dans le Code Théodosien*. Presses Universitaires du Septentrion, Lille, pp. 405–425.
- Johnstone, C.J., 2004. A Biometric Study of Equids in the Roman World (Unpublished PhD thesis). University of York, Department of Archaeology, York, 500 p.
- Klingenberg, C., 2011. MorphoJ: an integrated software package for geometric morphometrics. *Mol. Ecol. Resour.* 11, 353–357.
- Leguilloux, M., 1997. A propos de la charcuterie en Gaule romaine. Un exemple à Aix-en-Provence (ZAC Sextius-Mirabeau). *Gallia* 54, 239–259. CNRS éditions, Paris.
- Leguilloux, M., Lepetz, S., 1996. L'élevage en Narbonnaise et en Gaule du nord : continuités ou ruptures ». In: Fiches, J.-L. (Ed.), *Le III^e siècle en Gaule Narbonnaise. Données régionales sur la crise de l'Empire*, Actes de la table ronde du GDR 954, Aix-en-Provence, La Baume, 15–16 septembre 1995, Sophia Antipolis. Éditions APDC, pp. 257–275.
- Lepetz, S., 1996a. Effets de la romanisation sur l'élevage dans les établissements ruraux du Nord de la Gaule. L'exemple de l'augmentation de la stature des animaux domestiques. *Rev. Archéol. Picardie n° spécial* 11, 317–325.
- Lepetz, S., 1996b. L'animal dans la société gallo-romaine de la France du nord. *Rev. Archéol. Picardie n° spécial* 12, 174 p.
- Lepetz, S., 2010. Pratiques alimentaires dans un quartier d'Amiens au I^{er} siècle. Les restes osseux animaux du site "Le Palais des Sports". In: Binet, E. (Ed.), *Evolution d'une insula de Samarobriava au haut-Empire - Les fouilles du "Palais des sports/Coliseum" à Amiens (Somme)*, *Revue Archéologique de Picardie, Amiens, n° spécial*, 27, pp. 409–422.
- Mackinnon, M., 2001. High on the hog: linking zooarchaeological, literary, and artistic data for pig breeds in Roman Italy. *Am. J. Archaeol.* 105 (4), 649–673.
- Mackinnon, M., 2010. Cattle 'breed' variation and improvement in Roman Italy: connecting the zooarchaeological and ancient textual evidence. *World Archaeol.* 42 (1), 55–73.
- McGuire, J.L., 2010. Geometric morphometrics of vole (*Microtus californicus*) dentition as a new paleoclimate proxy: shape change along geographic and climatic clines. *Quat. Int.* 212 (2), 198–205.
- Méniel, P., 1984. Contribution à l'histoire de l'élevage en Picardie du Néolithique à la fin de l'âge du Fer. *Rev. archéol. Picardie numéro spécial, Société de Préhistoire du Nord et de Picardie, Amiens*, 56 p.
- Monteiro, L.R., 1999. Multivariate regression models and geometric morphometrics: the search for causal factors in the analysis of shape. *Syst. Biol.* 48, 192–199.
- Paradis, E., Claude, J., Strimmer, K., 2004. APE: analyses of phylogenetics and evolution in R language. *Bioinformatics* 20, 289–290.
- Polybe, 1970. *Histoires*, Livre II. Traduction P. Pédech, Association Guillaume Budé. Collection des Universités de France, Les Belles Lettres, Paris, p. 123.
- Renaud, A., 2012. Alimentation carnée et gestion des populations animales sur le territoire de la cité de Nîmes (Hérault et Gard, II^e s. av. - II^e s. ap. J.-C.). Université Paul Valéry - Montpellier III, UMR5140 - Laboratoire d'Archéologie des Sociétés Méditerranéenne, Montpellier, 699 p. (PhD manuscript).
- Rodet-Belarbi, I., 1989. La faune à Argentomagus : élevage, artisanats, rites. Université de Paris I - Panthéon - Sorbonne, 596 p. (PhD manuscript).
- Rohlf, F.J., 2010a. TpsDig 2 - Thin Plate Spline Digitizer. *Ecology and Evolution*. State University at Stony Brook, NY. <http://life.bio.sunysb.edu/morph/>.
- Rohlf, F.J., 2010b. TpsRelw 1.49 - Thin Plate Spline Relative Warp. *Ecology and Evolution*. State University at Stony Brook, NY. <http://life.bio.sunysb.edu/morph/>.
- Rohlf, F.J., Slice, D., 1990. Extensions of the procrustes method for the optimal superimposition of landmarks. *Syst. Biol.* 39, 40–59.
- Rowley-Conwy, P., Dobney, K., 2007. Wild boar and domestic pigs in Mesolithic and Neolithic southern Scandinavia. In: Albarella, U., Dobney, K., Ervynck, A., Rowley-Conwy, P. (Eds.), *Pigs and Humans 10,000 Years of Interaction*. Oxford University Press, Oxford, pp. 131–155.
- Strabon, 1967. *Géographie*, Livre V. L'Italie, Traduction F. Lasserre, Association Guillaume Budé. Collection des Universités de France, Les Belles Lettres, Paris, pp. 39–121.