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ORIGINAL ARTICLE

New virtual approach to the study of metallurgy through the analysis of slice marks from the Chalcolithic site of Zanjillas (Torrejón de Velasco, Madrid, Spain)

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Abstract
Although the discovery of metal objects is not common in Chalcolithic or Bronze Age sites, the study of bone surface microscopic grooves from animal butchering can yield evidence of the use of metal artefacts in these contexts. Additionally, the presence of slice marks made with metal objects in Chalcolithic and Bronze Age sites has highlighted the use of metal in common practices beyond their ornamental application, as usually expected at the early stages of metallurgy. Here, we present the study of the slice marks found at the Chalcolithic site of Zanjillas, using geometric morphometrics and machine learning algorithms, with the aim of identifying the nature of the tools used for carcass processing at the site. For this purpose, we replicate previous analyses considering slice marks produced with lint flakes and metal tools to generate a referential framework that serves as comparative to the Zanjillas sample. Our results suggest that most of the domestic activities related to carcass skinning, defleshing, or evisceration in Zanjillas were still performed with flint artefacts.

KEYWORDS
chalcolithic, geometric morphometrics, machine learning, metal slice marks, metallurgy, middle Tagus valley, taphonomy, stone tools slice marks

INTRODUCTION

The origin of metallurgy is one of the main processes that contributed to the socioeconomic and ideological change among prehistoric societies in Europe and the Near East (Montero Ruiz & Murillo Barroso, 2016, 2020; Radivojević et al., 2010; Radivojević & Rehren, 2016; Roberts et al., 2009; Rovira, 2004; Rowan, 2018). The use of metals not only influenced the long-term replacement of certain raw materials, that is, the substitution of the lithic industry for the use of metal, but it also implied a technological and ideological change that affected different areas of the life of ancient societies (Roberts et al., 2009). Such changes were, however, not as radical and rapid as Childe (1996) first proposed, but they might have been more moderate, especially in the context of day-to-day activities (Rovira, 2002, 2004).

The appearance of metallurgy would have anyways accelerated the social changes observed in the following millennia. First, the development of metallurgy caused a technological improvement that enabled the production of a whole new series of more durable and resistant objects that would, in turn, have an effect on the agricultural and construction practices. These changes would have thus contributed to the modification of the production systems, increasing productivity and revitalising trade relations in search of new routes for the acquisition of the raw materials required to manufacture the new metal artefacts (Blake & Knapp, 2005; Carter & Philip, 2006; Roberts et al., 2009). Second, the emergence of metallurgy would have also triggered social changes as people had to engage in increasingly specialised tasks, which would have also contributed to an increasing social complexity (Carter & Philip, 2006; Chapman, 2005; Roberts et al., 2009; Rowan, 2018). Nevertheless, despite the importance of metallurgy to the development of prehistoric societies, metal remained as a scarce, highly valuable, and reusable element for a long time, which would explain its sparsity in the Chalcolithic archaeological record (Ackerfeld et al., 2020).

Metallurgy began between the ninth and sixth millennium BP in different areas of the Near East and Turkey (Blake & Knapp, 2005; Carter & Philip, 2006; Maddin et al., 1999; Rowan & Golden, 2009), through the premetallurgical work of cold metal in its natural state. Over time, metallurgy included the heating and smelting of metal in the Near East (Golden, 2009; Yener, 2000), Anatolia (Roberts et al., 2009), and the Balkans (Borić, 2009; Radivojević et al., 2010), contributing to a multiregional origin (Radivojević et al., 2010; Radivojević & Rehren, 2016; Renfrew, 1978) that has, nevertheless, been questioned by proposals suggesting a progressive dispersal (Roberts et al., 2009).

Regardless of its origin and dispersion, metallurgy was not limited to a technological change but involved additional aspects that permeated daily life from different perspectives, including the economy, the ideology, the social organisation, and the culture of past populations (Carter & Philip, 2006; Chapman, 2005; Montero Ruiz & Murillo Barroso, 2016; Murillo Barroso, 2020; Roberts et al., 2009; Rovira, 2004; Rowan, 2018). The first metallurgical evidences are, in fact, not usually linked to functional activities but are rather associated with ornamental uses (Maddin et al., 1991), and ritual and funerary contexts (Budd & Taylor, 1995; Dolfini, 2014; Kienlin, 2014), where metal objects appear as symbolic elements linked to social elites (Hanks & Doonan, 2009; Hansen, 2013; Klimscha, 2013). However, despite this generalisation, there are particular examples such as the one found in the southeast of the Iberian Peninsula, that is, Los Millares, where work implements such as axes, daggers, knives, awls, saws, and arrowheads were primarily produced, whereas ornaments were extremely rare (Lull et al., 2010).

Several techniques have been used to evaluate the functionality of the first metal artifacts, such as traceology, that is, the analysis of wear traces, which requires a proper preservation of the metal objects (Greenfield, 2013). Unfortunately, the preservation of the recovered archaeological material is not always adequate or metal objects are not even found at the sites. With the aim of alleviating these problems, indirect analyses can be conducted to identify the use of metal objects through the study of the traces they might produce on secondary elements such as bones (Greenfield, 2013).

In this line of work, some authors have managed to identify the use of metal tools through the analysis of slice marks from different sites ranging from the Bronze to the Iron Age (Greenfield, 1999, 2000, 2006; Greenfield & Brown, 2016; Greenfield et al., 2018, 2021; Liesau, 1998, 2002; Okaluk & Greenfield, 2022; Yravedra et al., 2009). Moreover, Greenfield (1999, 2000, 2013) was able to verify through microscopic butchering mark analysis the progressive incorporation of metal slicing tools into domestic activity areas (e.g., animal carcass exploitation) over time. The Chalcolithic and Early Bronze Ages in the many study regions were characterised by the continuation of chipped stone tool technology for butchering. Beginning in the Middle Bronze Age, there are increasing frequencies of metal tool slice marks. This process continues through the Iron Age and later periods as is evident by the continued use of chipped stone tools in Iron Age and Classical period sites, particularly wherever there is obsidian (Greenfield & Chaput, 2021; Greenfield & Marciniak, 2019).

The present study delves into the daily uses of pre-Bell-Beaker Chalcolithic metallurgy in central Spain through the analysis of the slice marks identified at the site of the Zanjillas (Torrejón de Velasco, Madrid). Our analysis aims to identify the functional use of metal objects through the study of butchery practices on the basis of the traces generated during carcass exploitation. We believe that investigations in this line could be particularly relevant because the identification of metal-inflicted slice marks in Zanjillas would not only provide one of the earliest pieces of evidence of the use of metal tools for butchery practices in the European Chalcolithic, but it would also contribute to the chronological delimitation of the site. Zanjillas has yielded an important faunal accumulation associated with pottery and lithic industry, which situates the human occupation of the site within the Chalcolithic. However, carbon 14 dating (López et al., 2011) has also provided very ancient chronologies dating back to the Late Neolithic for some of the silos in Zanjillas. If identified, the presence of marks produced with metal tools at the site could additionally support the Chalcolithic dating provided for Zanjillas

The site of Zanjillas (Torrejón de Velasco, Madrid)

Zanjillas (40°18′39.64″N to 3°74′72.39″W) is a pre-Bell-Beaker Chalcolithic site (López et al., 2011; López & Morín, 2011) that dates to the fourth to third millennium BP. The site is located in Torrejón de Velasco, close to the M-404 as it passes through the right bank of the Guatén stream (Figure 1). Carbon 14 dating (López et al., 2011) has provided the following chronological context for Zanjillas stratigraphic units (UE), which ranges from the Late Neolithic to the pre-Bell-Beaker Chalcolithic.

- UE-195002; Beta-252258: AMS advanced: 4590+/−40 BP, Cal BC 3500–3440 (Cal BP 5450–5390) and CAL BC 3380–3330 (Cal BP 5330–5280)
- UE-212001; Beta-252259: AMS advanced: 4940+/−40 BP, Cal BC 3900–3880 (Cal BP 5850–5840) and CAL BC 3800–3650 (Cal BP 5720–5600)
- UE-264001; Beta-252260: AMS advanced: 4350+/−50 BP, Cal BC 3340–2290 (Cal BP 5290–4870)

- UE-467002; Beta-252261: AMS advanced: 4450+/−40 BP, Cal BC 3340–3310 (Cal BP 5290–4960) and CAL BC 2970–2960 (Cal BP 4920–4910)
- UE-489001; Beta-252262: AMS advanced: 4380+/−50 BP, Cal BC 3350–2920 (Cal BP 5300–4880)
- UE-538001; Beta-252263: AMS advanced: 5120+/−40 BP, Cal BC 3980–3800 (Cal BP 5930–5740)

A total of 544 structures have been found in Zanjillas, of which 151 have been excavated. Most structures are circular, with concave floors and irregular soil. Excavation was limited up to a depth of 50 cm because many structures had been partially destroyed by agricultural activities. Most structures have been interpreted as silos and basins, and are located in three different sectors (López et al., 2011; Figure 1):

- Sector 1 is located in the northern area of Zanjillas and contains 41 structures that correspond to small basins and silos, of which 18 were excavated. The material culture found in this sector is mainly constituted by fauna, lithic industry, and few ceramic remains.
- Sector 2 is in the northwest of Zanjillas, where 12 structures have been located and excavated. In this case, the silos are larger and principally contain lithic elements and few ceramic and fauna remains.
- Sector 3 is in the west of the site. In total, 59 structures have been found here, of which 20 were excavated (López et al., 2011). Most of the structures are 30–50 cm deep basins that have been assigned to the Chalcolithic and Early Bronze Age.

In these three sectors, a total of 5188 Chalcolithic ceramic remains were recovered. Ceramic remains were produced by hand and display dark grey and brownish colorations as a result of reduction. Final appearance was improved through surface burnishing and smoothening (López et al., 2011). Among the ceramic types found at the site, pots stand out. The great majority of them show no decorative elements; only one piece is decorated. In addition to ceramics, loom pieces have also been found, as well as 3713 stone tools, which include 3487 knapped stones and 226 polished pieces. More than 95% of the knapped stone tools are made of flint, whereas opal represents 3.65%, quartzite 0.8%, and rock crystal 0.06% (López et al.,

FIGURE 1 Location of the Zanjillas site (Torrejón de Velasco, Madrid, Spain) and visual representation of the three sectors that constitute the site where different types of structures can be observed.

2011). On the other hand, the polished lithic material shows a greater variety of raw materials, including granite, quartzite, slate, sandstone, lacquer, and ophite (López et al., 2011).

Among the knapped stones, the flint tools show a high degree of use with little presence of cortical elements; highly used nuclei mostly take the form of prismatic, discoid, and polyhedral nuclei. Most of the lithic tools are unretouched flakes, though also a small percentage (5%) of retouched tools, including scrapers, denticulate, truncations, notches, arrowheads, composite tools, flakes, and retouched leaves have been identified in Zanjillas. Unlike flint, quartzite stone tools display a less intense use (López et al., 2011). On the contrary, polished stone tools are mainly represented by quartzite pebbles, mills, or smoothers (López et al., 2011). The bone industry is very scarce, and no metal objects have been found at the site.

Regarding the fauna, a preponderance of domestic fauna over wild fauna has been observed (Yravedra, 2011). Among the domestic fauna, ovicaprids are prominent, with mixed herds of sheep and goats, followed by cows and pigs, whereas the wild fauna is represented by horses, deer, and rabbits (Yravedra, 2011). The skeletal profiles indicate that animals were fully represented at the site, and the mortality patterns show a predominance of adults, though some infants and juvenile individuals of pigs, cows, and ovicaprids have also been identified. This might be associated with carcass exploitation, as suggested by the slice marks observed on the bones.

MATERIALS AND METHODS

Sample

The sample employed in the present study includes 70 out of the 169 slice marks identified on fossil bones recovered from the archaeological site of Zanjillas, alongside 259 experimental marks (Supporting Information), including 139 marks generated with flint simple flakes and 120 marks produced with a stainless-steel knife (Molybdenum Vanadium C 0.5 CR 14 MO 0.5 VA 0.25). The experimental sample was generated so as to provide the most accurate referential framework for Zanjillas, because most stone tools found at the site are knapped on flint (López et al., 2011), and we would like to test the hypothesis on the use of metal objects in domestic life areas. The reference sample was also generated to avoid statistical noise and provide the best control over the input variables (Supporting Information).

Archaeological slice marks were identified with the aid of a 20× hand lens (Blumenschine, 1986; Yravedra, 2006) and considering the features described by Binford (1981) and Shipman (1993). Only conspicuous specimens were selected for the study, according to their location on ungulate long bone shafts and their preservation. On the other hand, experimental slice marks were produced across the diaphysis of fresh long bones shafts of *Bos taurus* carcasses by a single right-handed individual, maintaining the cutting angle perpendicular to the bone. According to Maté-González et al. (2019), neither the anatomical element nor size of the animal should be considered a conditioning factor for morphological studies.

Both archaeological and experimental slice marks were digitised using the DAVID structured-light scanner SLS-2 of the TIDOP research group located at the University of Salamanca (Spain). The scanner is capable of generating high-resolution three-dimensional (3D) models of millimetric bone surface modifications following the reconstruction protocols previously described by Maté-González et al. (2017) and Courtenay, Yravedra, Mate-González, et al. (2019). Global Mapper software (https://www.bluemarblegeo.com/global-mapper/) was used to define cross-sectional slice mark profiles on the 3D models. Cross sections were taken between 30% and 70% of the mark length, as any profile along this section has proven to be equally representative and valid for morphometric studies (Maté-González et al., 2015).

Methods

The present study was performed using a combined approach that includes geometric morphometric (GM) techniques and machine learning (ML)-based models that has already been proven useful for the differentiation and classification of metal and flint-inflicted slice marks (Courtenay et al., 2018, 2019; López-Cisneros et al., 2019; Maté-González et al., 2016, 2018, 2019; Maté-González, Aramendi, González-Aguilera & Yravedra, 2017; Maté-González, Aramendi, Yravedra, et al., 2017, Yravedra, Diez-Martín, et al., 2017; Yravedra, Maté-González, et al., 2017).

Slice mark cross sections were first analyzed by means of GM using seven fixed landmarks (Figure 2) that were collected for each mark cross section following the guidelines established in Maté-González et al. (2015). Landmark configurations were then normalized—that is translated, rotated, and scaled—through iterative superimposition procedures (e.g., generalized Procrustes analysis). This step was followed by principal component analyses (PCA), a dimensionality reduction technique that also enables the observation of the sample variance distribution space and the visualization of the underlying changes with the aid of transformation grids (Bookstein, 1989). PCAs were both performed including (e.g., form space) and excluding (e.g., shape space) the variable of size, known in GM as centroid size (CS). All these steps were conducted in the open access software R (v.4.1.x; R Core Team, 2015) using the functions included in the *geomorph* (Adams et al., 2020) and *GraphGMM* (Courtenay, 2022) packages.

Then, principal components (PC) scores representing up to 95% of the total variance were extracted and incorporated into further statistical analyses to assess morphological discrimination and classification. In parallel, differences in size among the slice marks were visualized with the help of the *boxplot* function (Murrell, 2005).

First, the lack of normality in sample distribution confirmed by Shapiro tests ($p < 0.001$) led to the use of robust nonparametric statistical methods (Courtenay et al., 2021; Mohd Razali & Bee Wah, 2011), such as the Wilk's lambda test statistic included in the *RVAideMemoire* R library (Hervé, 2022) to compare the median of the Zanjillas slice mark

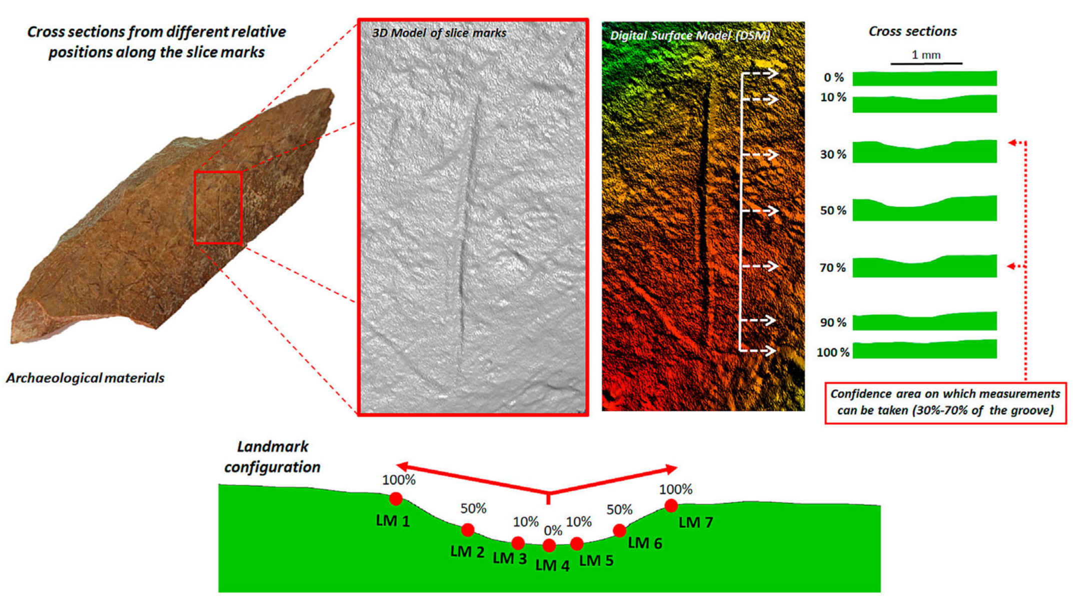

FIGURE 2 Summary of the data collection process, including 3D reconstruction, the extraction of cross-sectional slice mark profiles, and landmarking.

sample with the control experiments generated with flint flakes and metal tools. A *p*-value threshold of 0.003 was adopted for defining statistical significance, as it is more robust against Type I errors (Courtenay et al., 2021).

For classification purposes, ML models and neural networks (NN) were trained by dividing the experimental sample into a training (70% of the sample) and testing set (the remaining 30% of the sample), which is then used for model validation. Among the ML models tested for the present study, the most efficient ones are based on the use of CART trees (classification and regression trees), gradient boosted machines (GBM), and support vector machines (SVM):

- CART trees; they offer comprehensible and robust techniques based on a recursive partitioning of the data in the form of bifurcations, which ultimately end up in terminal nodes as the result of classification. Several parameters can be tuned to enhance prediction performance (e.g., the number of trees, the depth of trees, the number of variables per split, the number of terminal nodes, etc.). The tree-based algorithms used in the present study can be found in the *party* (Hothorn et al., 2006) and *caret* (Kuhn, 2022) R libraries.
- GBM; these algorithms also provide solutions based on the building of trees; though, in this case, the model is more complex and computational expensive as it is built upon an ensemble of trees that successively learn from the preceding one. In order to control the computational effort demanded by the algorithm and minimize a cost function, a hyperparameter grid was built to tweak several parameters, including the number of iterations (100 trees), the depth (4–14), the border count (5–50), the learning rate (0.01–0.5), and the L2 regularisation (0.1–5). Several functions included in the *caret* (Kuhn, 2022) library were implemented. GBM algorithms included in the *caret* (Kuhn, 2022) library were implemented to classify the Zanjillas sample.
- SVM; model for nonlinear multidimensional spaces, where data are divided by a hyperplane that acts as boundary with soft maximized margins that help avoid overfitting of the training data. The separation is defined by the kernel function (Lantz, 2013). For this study, SVM with a radial basis function (RBF) was used (Cortes & Vapnik, 1995). SVM models were tuned through a threshold set on the residuals, a loss function based on the cost parameter and the sigma parameter. SVM's optimal parameters were calculated via Bayesian optimization algorithms (BOAs) (Bergstra & Bengio, 2012; Shahriari et al., 2016; Snoek et al., 2012). SVM applications were performed using the *caret* (Kuhn, 2022) library.
- NN; model that imitates the work of the human brain by generating a structure based on nodes displayed in hierarchical layers. The algorithm includes a backpropagation system that provides a self-correcting method through the adjustment of weights (Lantz, 2013). For the purpose of the present study, a simple NN model that includes up to 20 neurons was employed to make predictions on the Zanjillas slice mark sample. Additionally, a variable decay between 0.01 and 0.5 was tested to improve model performance. The functions included in the *nnet* (Venables & Ripley, 2022) and *caret* (Kuhn, 2022) R libraries were used.

A recursive partitioning of data and a k-fold cross-validation ($k = 10$) was implemented as meta-learning method to avoid overfitting throughout the training and testing phases. Additionally, a layer introducing Gaussian noise was generated to evaluate the possible effects of overfitting in our models (Goodfellow et al., 2015). Gaussian noise was introduced on the first five PC scores (Supporting Information) using the *add. Gaussian.noise* function in the *RMThreshold* R library (Menzel, 2022). Different values were established for each PC considering the original ones; the largest noise was introduced for PC1 ($\epsilon = 0.2$), whereas lower values were introduced for PC2 to PC4 ($\epsilon = 0.02$) and PC5 ($\epsilon = 0.002$).

Differences in prediction performance were evaluated according to kappa, sensitivity, specificity, and balanced accuracy values (Lantz, 2013). Kappa statistics indicate the quality of the match between the model and the documented data, being kappa > 0.8 a signal of powerful predictive performance. Sensitivity and specificity values provide the proportion of true correctly classified examples versus the proportion of false correctly classified examples. These rates are corrected by the balanced accuracy through calculating the average.

RESULTS

According to the results obtained on the morphometric data collected in the form of landmark configurations, the Zanjillas sample resembles the experimental sample generated with the aid of flint flakes. PCA plots in shape (Figure 3) show how the Zanjillas sample mostly falls within the 95% confidence ellipse calculated for the flint slice mark sample along the three first PC scores. The Zanjillas sample is characterised by including shallower and wider mark profiles, whose morphology resembles the one observed in the flint sample, in opposition to the deeper and narrower slice mark profiles generated with the metal knife. Both the flint and metal samples show certain overlap along PC1 (71.79% of total variance), though similarities are more pronounced along the variance distribution expressed by PC2 (22.37% of total variance) and PC3 (2.68% of total variance). The variation range of the Zanjillas sample is more constrained in comparison to the experimental slice marks, though its distribution mostly coincides with the area occupied by metal-inflicted marks along the first three PC scores.

However, according to the pairwise nonparametric MANOVA results considering the first four PCs, the Zanjillas slice mark morphology is significantly different from the medians calculated for the experimental flint and metal samples ($p = 0.001$).

In form space (Figure 4), the association between the Zanjillas sample and the experimental flint group is slightly less marked, though still more prominent than the existing link between Zanjillas and the metal slice marks. Variance expression by the first three PCs (PC1 = 72.7%; PC2 = 19.16%; PC3 = 6.45%) does not differ in great manner in comparison to the PCA in shape space (Figure 3), which suggests that differences in size are not particularly significant for sample morphological distribution. Main differences among samples are again characterised by the depth and width of the mark profiles, being the Zanjillas slice marks mostly shallow and wide. The presence of outliers is, nevertheless, more marked when size is considered alongside shape. This is probably due to the large differences in CS shown by 10 out of the 70 Zanjillas slice marks (Figure 5) that fall outside the variation range calculated for this group. Some of the Zanjillas outliers are even larger than the marks registered in the control experimental samples. Nevertheless, the Zanjillas CS mean is smaller than the CS mean calculated for the flint group and, by far, smaller than the mean metal CS. The MANOVA results confirm again that differences among the three group form medians are significant ($p = 0.001$) despite the overlap observed in bidimensional feature space.

Predictions on the Zanjillas sample indicate that all slice marks coincide with the shape features displayed by the group of marks generated with flint simple flakes. Not only the predictive models are highly accurate (Table 1), but the classifications are performed with high certainty, almost always with at least 90% accuracy. Sensitivity tests on the ML models performed by introducing Gaussian noise suggest that high accuracy rates are not due to overfitting and that models perform similarly well on training and new data (Supporting Information).

On the other hand, similarly accurate models considering not only shape characteristics but also size features suggest that some of the Zanjillas marks cannot be assigned to the flint group, or at least not with such certainty. Such assignations might be rather related to the differences in size observed in Figures 4 and 5. However, the great majority of the Zanjillas slice mark sample is still associated with the flint sample by all models.

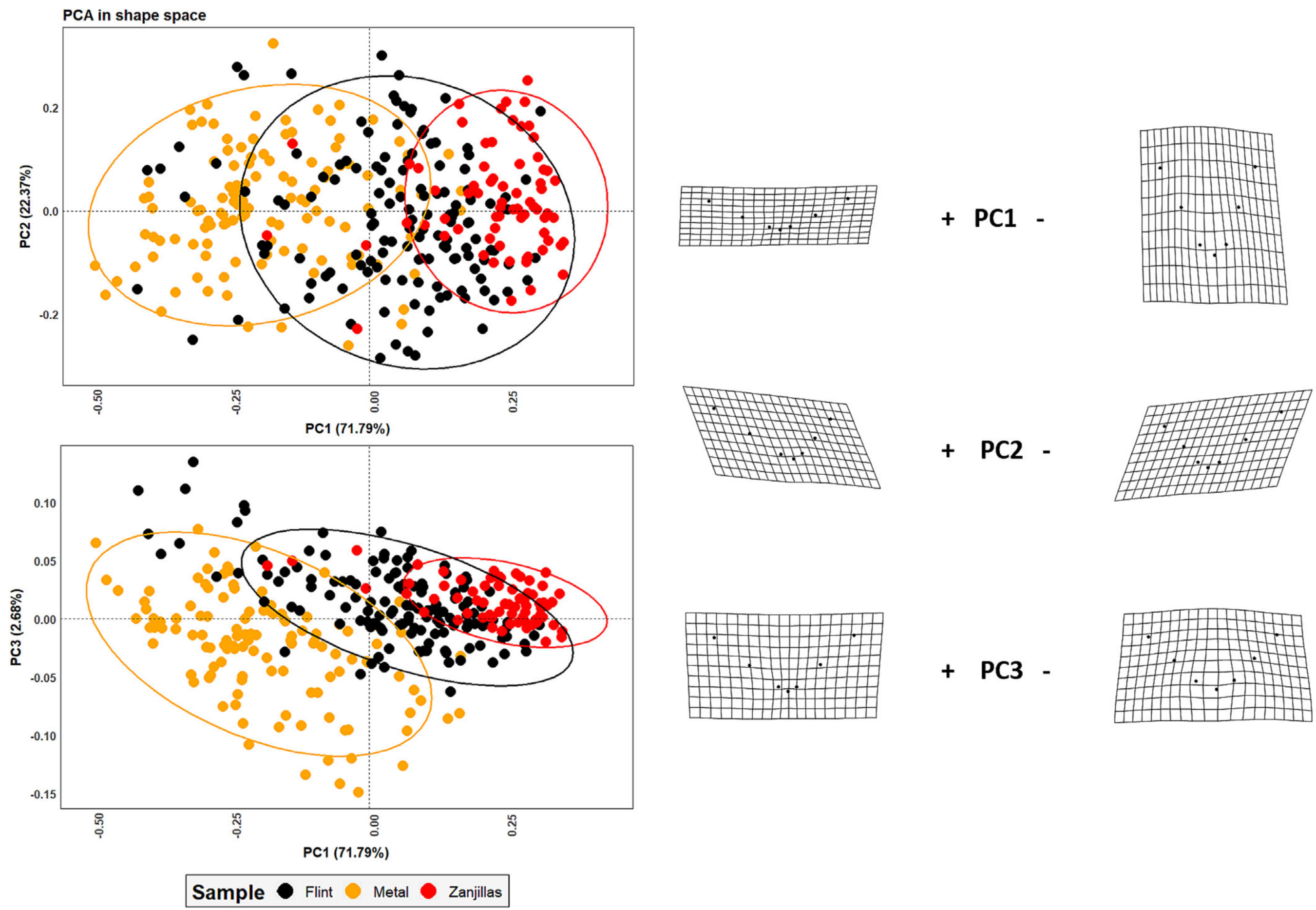

FIGURE 3 PCA plot in shape space on the Zanjillas and the two experimental samples of slice marks generated with metal and flint flakes. Extreme transformation grids calculated for the first three PC scores are included.

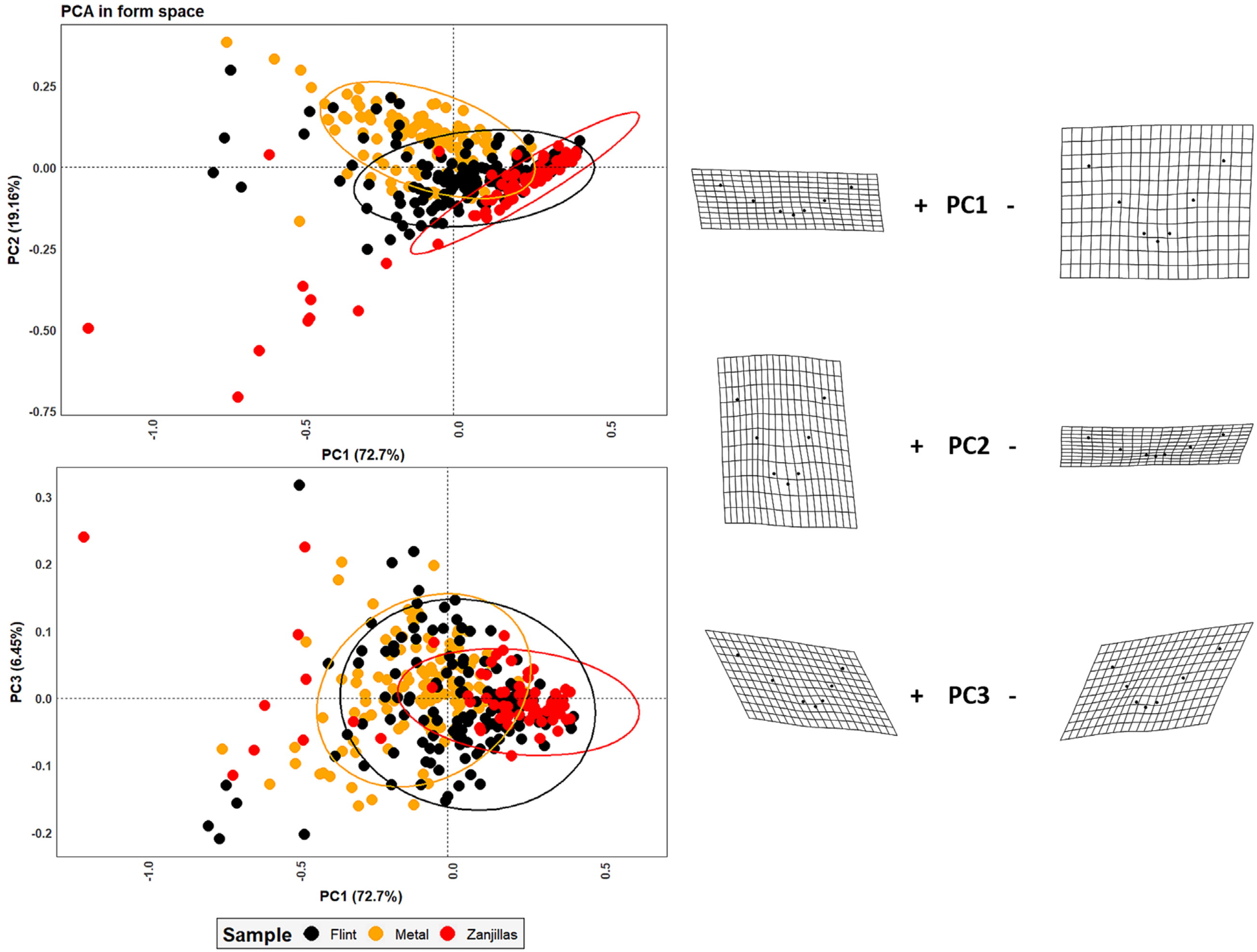

FIGURE 4 PCA plot in form space on the Zanjillas and the two experimental samples of slice marks generated with metal and flint flakes. Extreme transformation grids calculated for the first three PC scores are included.

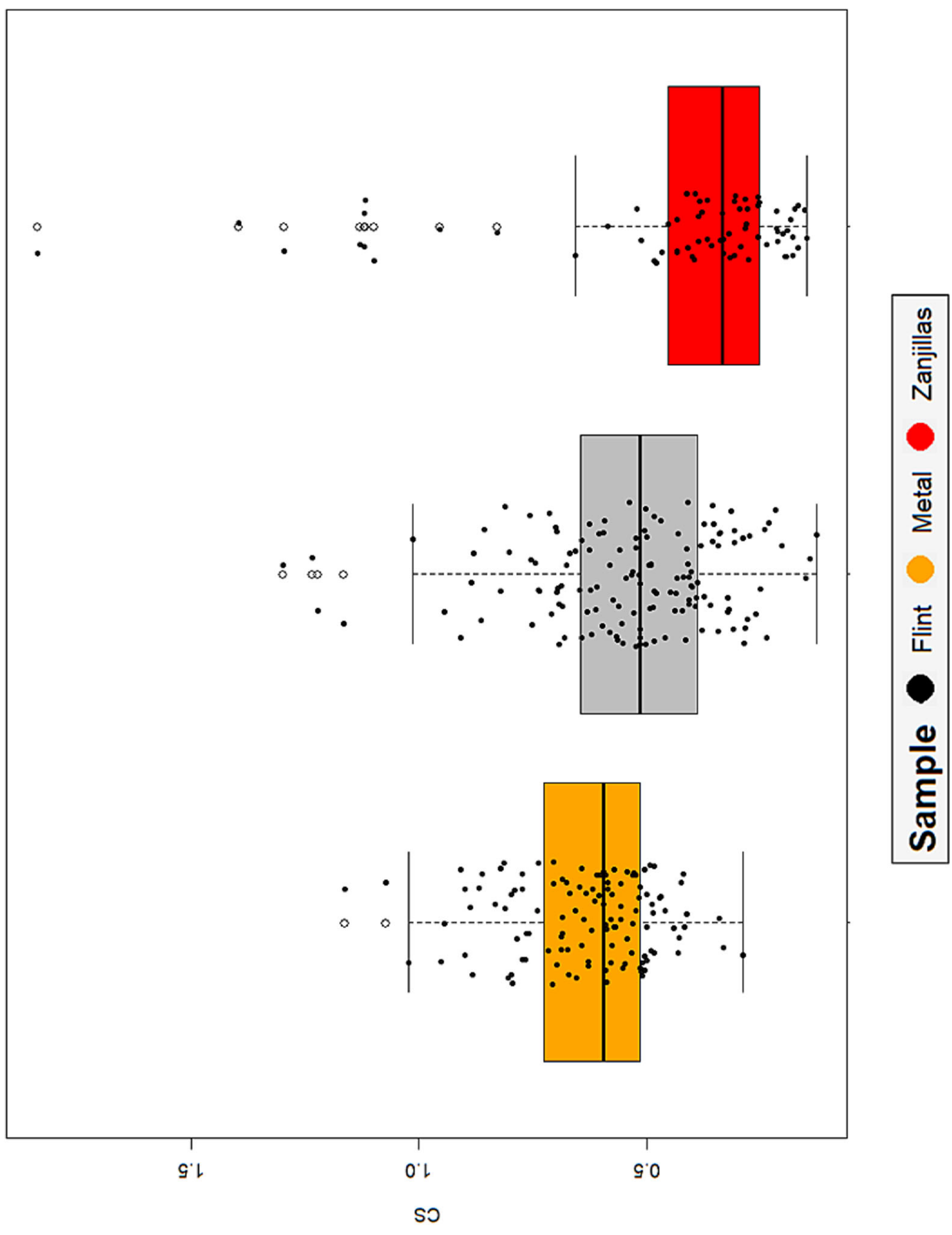

FIGURE 5 Boxplots comparing the centroid sizes of the slice mark sample of Zanjillas and the two experimental samples of slice marks generated with metal and flint flakes.

TABLE 1 Predictive model performance.

Model	Accuracy	Kappa	Sensitivity	Specificity	Bal. accuracy
Shape					
RF	0.9091	0.812	0.9032	0.9130	0.9081
GBM	0.9481	0.8957	0.9444	0.9512	0.9478
SVM	0.9221	0.838	0.9032	0.9348	0.9190
NN	0.961	0.9194	0.9677	0.9565	0.9621
Form					
RF	0.9221	0.8397	0.9355	0.9130	0.9243
GBM	0.9351	0.8698	0.9444	0.9268	0.9356
SVM	0.9091	0.81	0.8710	0.9348	0.9029
NN	0.974	0.946	0.9677	0.9783	0.9730

DISCUSSION AND CONCLUSION

The present study adds to the work performed by other authors on the evaluation of the origins of metallurgy through the analysis of bone surface modifications, particularly of slice (Greenfield, 1999, 2000, 2006, 2013, 2021; Greenfield & Brown, 2016; Greenfield et al., 2018, 2021) and chop marks (Okaluk & Greenfield, 2022). The use of metal tools in domestic contexts in the initial periods of the Chalcolithic is not very well known yet. Usually, Chalcolithic metal artefacts are linked to nonfunctional appliances, because they appear in funerary contexts and, thus, are frequently linked to ornamental and/or symbolic purposes (Budd & Taylor, 1995; Dolfini, 2014; Hanks & Doonan, 2009; Hansen, 2013; Kienlin, 2014; Klimscha, 2013). Only some evidence suggests the incorporation of metal tools in domestic areas in more recent periods, for example, the Bell-Beaker culture (Nuñez Moro et al., 2019). To date, no slicing marks have been observed in pre-Bronze Age contexts (Greenfield, 1999, 2000, 2006, 2013, 2021; Greenfield & Brown, 2016; Greenfield et al., 2018, 2021); however, this does not exclude the possibility of finding metal-inflicted butchering marks in the Chalcolithic–Iron Age record. Therefore, we believe that it is convenient to carry out analyses such as the one presented here in order to determine the raw material used to generate the slice marks observed in pre-Bronze sites. In the Iberian Peninsula, the evidence of metal objects is not only scarce at the beginning of the Copper Age (Díaz del Río, 2001; Montero-Ruiz, 1994), but it is also problematic, as the presence of metal objects does not seem to be associated to a social and symbolic role as in the European context, but it is rather linked to day-to-day activities (Lull et al., 2010; Montero Ruiz & Murillo Barroso, 2016; Rovira, 2004). Some studies have shown that, in those cases where metal objects appear, the proportion of metal artefacts is similar both in funerary and domestic contexts (Costa Caramé et al., 2010; Montero-Ruiz, 1994).

In the area of the middle Tagus River valley, where the discovery of metal in the archaeological record is low, the presence of metallurgy has been linked with both funerary—Juan Barbero (Martínez Navarette et al., 1984) or the cave of Pedro Fernández (Sánchez-Meseguer et al., 1983)—and domestic contexts—the Esgaravita (Díaz del Río & Sánchez, 1988). This evidence is in line with the interpretations provided for the sites situated in the southeast of the Iberian Peninsula that correspond to Los Millares culture, where metal objects bear both a functional and a social role, with the metal tools associated with production practices (e.g., knives, axes) being more abundant than objects liked to symbolic contexts (Lull et al., 2010). However, in comparison, contemporaneous sites in the interior area of the Iberian Peninsula display a less widespread and developed metallurgy, probably also contributing to a less hierarchised and politicised society in the settlements along the Tagus River valley.

Here, we have analyzed a selection of the slice marks observed on the faunal remains recovered from a pre-Bell-Baker Chalcolithic site, without funerary evidence, and where no metal tools have been found. According to our results, the Zanjillas slice mark sample was produced with lithic tools (Figures 3–5). These results are consistent with the material culture documented at the site and also with the chronological and cultural context of Zanjillas that corresponds to the pre-Bell-Baker Chalcolithic culture of the middle Tagus River valley, which is characterised by a low presence of metal tools (Blasco & Ríos, 2010; Díaz del Río, 2001). Only from the Bell-Baker times, a slight increase of metal elements has been observed in the surroundings of the region, for example, Camino de las Yeseras (Blasco & Ríos, 2010), the Ventorro (Priego & Quero, 1992), the Arenero de Soto (Rovira, 1989), or Humanejos (Garrido-Pena et al., 2019; Montero Ruiz & García, 2019), among others. On the other hand, our results do not allow us to determine the exact cultural period of the faunal remains of Zanjillas; according to the material culture, Zanjillas is a Chalcolithic site, but some dating situate the occupation of the site slightly before the Chalcolithic period, in the Late Neolithic.

The combination of GM and ML techniques has thus helped us confirm the absence of metal in Zanjillas in both symbolic and domestic contexts with great confidence.

These results are consistent with previous works performed by other authors (Greenfield, 1999, 2000, 2006; Greenfield & Brown, 2016; Okaluk & Greenfield, 2022), which have not identified the presence of slice marks produced with metal tools in Chalcolithic contexts but in later periods of the Iron and Bronze Age. Therefore, we believe that the generation of proper referential models for each case and the application of the techniques used here could be useful for further studies on Chalcolithic or Bronze Age sites to assess the use and functionality of metal tools in contexts where either metallurgy is scarce or poorly preserved, limiting the application of methods such as traceology, or where metal artefacts appear both in symbolic-bearing and domestic areas.

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DATA AVAILABILITY STATEMENT

Data available in the Supporting Information.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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