Pandora: A new morphometric and statistical software for analysing and distinguishing cut marks on bones

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ABSTRACT

Cut mark studies have experienced a useful development in the last few years. These studies have allowed us to obtain important information about human prehistory spanning from the origin of meat consumption for chronologies around 2.5 Ma, the detection of human hunting behavior during the lower Pleistocene, or even to determine the uses of diverse raw materials on carcases. Amongst the different analyses applied to the study of cut marks, there has been an increasing interest in using morphometry in order to differentiate and characterize the raw materials with which the effectors were made. These techniques have proven to be extremely useful. Nevertheless, this 3D methodology demands the use of expensive equipment and does not allow using an extensive sample, making it a complex and problematic technique. Maté-González et al. (2015) considered an alternative technique, by combining different disciplines involving geometric morphometrics, photogrammetry and multivariate statistics (multidisciplinary methodology). Here, we try to continue with this work presenting *Pandora*, a new open software capable of analysing a useful amount of variables from a statistical and morphometric view, accelerating and simplifying the process.

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1. Introduction

Cut marks on bones can provide useful information concerning human behavior. Cut marks have been reported even in sites dated 2.6 Ma, suggesting an early Pleistocene meat consumption by hominins (De Heinzelin et al., 1999; Semaw et al., 2003; Domínguez-Rodrigo et al., 2005). Cut mark frequency and distribution on bones have been used to recognize predatory behaviors for sites dated 1.5 Ma (Domínguez-Rodrigo et al., 2002, 2007, 2009a, 2014; Pickering et al., 2004; Pobiner et al., 2009; Sahnouni et al., 2012). In other chronologies and contexts, cut marks have permitted the identification and use of metal tools in carcass processing from the Chalcolithic to the Bronze Age, showing a functional use of this kind of tools (Greenfield, 1999).

Since the late XIXth century and beginning of the XXth century, cut marks have been observed, documented and studied (Lartet, 1860; Lartet and Christy, 1875; Martin, 1909). Since then, this type of studies have had a large tradition (Walker, 1978; Shipman and Rose, 1983; Olsen, 1988; Spennerman, 1990; Greenfield, 1999, 2004, 2006a, 2006b; Bello and Soligo, 2008; Bello et al., 2009; Domínguez-Rodrigo et al., 2009b; De Juana et al., 2010; Galán and Domínguez-Rodrigo, 2013; Maté-González et al., 2016), and, nowadays, thanks to the development of new technologies, new study types involving the use of complex technology are flourishing, improving the recognition of these marks. This field has progressed greatly, starting with the development of microscopic analysis with SEM used by Shipman (1981), Shipman and Rose (1983), Olsen (1988), and Greenfield (1999, 2004), followed by high resolution binocular microscope pictures used by Domínguez-Rodrigo et al. (2009b) for cut mark morphological characterization through two-dimensional images and, finally, the implementation of three-dimensional reconstruction systems from 3D digital microscopy (Boschin and Crezzini, 2012; Crezzini et al., 2014), such as the 3D Alicona Infinite Focus Imaging microscope (Bello and Soligo, 2008; Bello et al., 2009; Bello, 2011), or even the use of micro-photogrammetric and morphometric reconstruction of cut marks (Maté-González et al., 2015, 2016).

Although these methods have allowed cut mark characterization, these have some limitations. On one hand some of these techniques are not easily accessible to everybody due to their elevated cost of the expensive equipment (use of SEM or 3D digital microscopes, for instance). On the other hand, using binocular microscopy to obtain high-resolution pictures implies the generation of a 2D image, which does not allow a three dimensional mark characterization. Nevertheless, Maté-González et al. (2015) have introduced the option of carrying out micro-photogrammetric and morphometric reconstructions, developing 3D mark reconstructions using accessible equipment. This new technique allows working with large mark samples (Maté-González et al., 2016) and improves the traditional systems used to analyse these type of marks.

With this paper, we present instructions on the use of the free *Pandora* software. This open access software offers the user a wide variety of tools, such as the application of several statistical and morphometric tests helping to classify and characterize cut marks appearing in archaeological sites. This program allows a great flexibility, automatization and computerization of the data collection process, and can present the data through a large variety of graphs depending on the tests applied.

To demonstrate the technique's results, an experimental case will be carried out throughout this paper as an example of its application to a practical case: the differentiation of cut marks based on the tool's raw material (flint, basalt or quartzite).

2. Methods

2.1. Description and use of the Pandora package

Pandora has been designed to guide the user, step by step, during the data collection and analytical process, simplifying the work required for cut mark microscopic examination. This program has allowed the systematization of all measurements used to classify cut marks, based on the methodology and terminology exposed in Bello et al. (2013) and Maté-González et al. (2015).

Pandora has a series of interactive menus from which the user can make a selection amongst a list of options and configurations, to determine the morphometric and statistical analysis which will be carried out. The main objective of this tool is to obtain a normalized database, allowing different research groups to exchange information and to be able to coordinate studies, synthesizing nomenclature and similar procedures.

Researchers will be able to save their work files in an external file with the extension "*.marks". By doing this, the *Pandora* software would read and process the data and incorporate it into an extensive database, including all other prior data. Because of this, the comparison of cut mark dimensions, characteristics and shapes could be made easier. The successive incorporation of data generated by different experiments and research teams will allow carrying out morphological and statistical tests with a higher resolution and a lower margin of error, since a wider sample will be studied and the data included in it has been collected and analysed following the same methodology during the entire process.

After the three dimensional mark model reflecting the cut mark section has been obtained using photogrammetric methodologies such as those described in Maté-González et al. (2015) or other microscopic techniques like the ones presented in Bello and Soligo (2008), Bello et al. (2009) or Boschin and Crezzini (2012), the images processed should be saved in "*.JPG" format.

Once all the files are located in the same directory, *Pandora* will automatically introduce them to the software database. Automatically, *Pandora* will ask for the specific variables (e.g. "Site", "Raw material", etc.) of each file in the same directory. After this, *Pandora* will once more ask for the specific variables of each of the directory sections, and will ask for image upload. Once the image is open, the program

will request to locate scale points with a click to set the image to scale. After that, we should indicate the seven semi-landmarks (LM) used for cut mark analysis as described by Maté-González et al. (2015). Finally, after placing the last LM, *Pandora* will automatically measure all lengths and existent relationships between them and then save them in a database.

When all images in a given folder have been treated and analysed, *Pandora* will give the user two options:

1) To analyse another directory and introduce new data from another set

2) To analyse the introduced images using statistical or morphometric tests

The tests currently included in *Pandora* are ANOVA (Analysis of Variance), MANOVA (Multiple analysis of variance), PCA (Principal Component analysis) and LDA (Linear discriminant analysis) for the statistical tests, and GPA (General Procrustes Analysis), morphometric data PCA and morphometric data LDA referring to the morphometric tests available.

Thus, as soon as the data has been introduced, using several tests, the analysis of a set of cut marks can be done instantaneously. In this case study, we compare the results of various cut marks produced by different raw materials such as flint, quartzite and basalt.

Installing *Pandora* is free, as it is deposited in a repository Github, allowing a quick update whenever necessary and the latest modifications and corrections can always be available and installed (https://www.github.com). *Pandora* uses basic functions of R (Core, 2015), as well as functions of the MASS package (Venables and Ripley, 2002), CircStats (Agostinelli, 2012), and Geomorph (Adams and Otarola-Castillo, 2013).

The use of the *Pandora* package allows a more systematic and automatic data input and manipulation for cut mark analysis, avoiding any errors derived from the manual data input. Before *Pandora* was developed, cut mark analysis implied a series of steps which substantially slowed down the process, as well as implying the use of various different programs such as Autocad, Excel and R for scaling, morphometrical and statistical analysis. Here, all this can be carried out with one single program.

2.2. Methods described in the cut mark analysis

Following the methods developed and proposed by Bello et al. (2013), a series of measurements have been taken, as well as a the three-dimensional model of the cut marks studied. These measurements mentioned above have been used as numerical variables for the analysis of the studied cut marks (Fig. 1).

As it was observed in Maté-González et al. (2015), marks have a variable longitude and the morphology of the mark section changes according to the point chosen to make the three-dimensional model. In this case, we made several statistical analyses to prove which section of the cut mark was diagnostic for cut mark morphology, proving that any point taken in the cut mark between 30% to 70% of the groove section trajectory is equally diagnostic (see Fig. 2).

Measurements, including WIS, WIM, WIB, OA, D, LDC, RDC, were made on the cut mark section (Fig. 1). 7 Landmarks were chosen (LM1x, LM1y, LM2x, LM2y, LM3x, LM3y, LM4x, LM4y, LM5x, LM5y, LM6x, LM6y, LM7x, LM7y), referring to Cartesian coordinates (x and y) of each of the Landmarks (Maté-González et al., 2015, 2016). Next to the qualitative measurements general data such as "site", "n_site", "n", and "Material" has to be added. The definition of all variables is listed below:

1. "site": Original site from where the bones are coming, or the experiment code.

2. "n_site": Name of the bone in the data base of the own project.

3. "n": Mark number.