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Micro-photogrammetric characterization of cut marks on bones

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ABSTRACT

In the last few years, the study of cut marks on bone surfaces has become fundamental for the interpretation of archaeological sites and prehistoric butchery practices. Due to the difficulties in the correct identification of cut marks, many criteria for their description and classifications were suggested. This article presents an innovative methodology which supplements the microscopic study of cut marks. Despite the benefits of using scanning electron microscopy (SEM) for the two-dimensional identification of these marks, it has a number of drawbacks such as the high costs and, consequently, the limited sample studied. In this article, a low-cost technique for the analysis of cut mark micromorphology from a tri-dimensional perspective is introduced. It provides a high-resolution approach to cut mark characterisation such as morphology, depth, width, and angle estimation as well as section determination, measured directly on the marks on bones. Macro-photogrammetry records quantitative and qualitative information which can be statistically processed with standard multivariate and geometric morphometric tools.

1. Introduction

Lartet (1860), Peale (1870), Lartet and Christy (1875) and Martin (1909) were pioneers in the study of cut marks in the late 19th and early 20th centuries. They observed the presence of marks in archaeological assemblages, but did not engage into any fine-detailed analysis of them. During the 20th century, several scholars observed, classified and described cut marks, amongst which the seminal studies by White (1952, 1953, 1954, 1955), Binford (1981), Bunn (1982) or Shipman (1981) should be emphasized. In the last few years, the analysis of cut marks has become extremely relevant in the interpretation of the archaeological record, as it has offered evidence to interpret such diverse behaviours as hunting by Olduvai hominins 1.8 Myr ago (Bunn and Kroll, 1986; Domínguez-Rodrigo et al., 2007), or the replacement of lithic butchery tools by metal ones during the Holocene (Greenfield, 1999, 2004).

In the past 20 years, cut mark analysis has become more sophisticated. Experimental recreation of cut mark frequencies and their anatomical location on ungulate carcasses were considered (Capaldo, 1997; Domínguez-Rodrigo, 1997), as well as replications of different butchery processes such as filleting, dismembering or evisceration (Binford, 1981; Lyman, 1987; Nilsen, 2001; Galán and Domínguez-Rodrigo, 2013). Others studies focused on discriminating cut marks from other processes such as trampling (Shipman, 1981; Shipman and Rose, 1983; Behrensmeyer et al., 1986; Domínguez-Rodrigo et al., 2009), or characterizing the raw material of the cutting tool: flint, obsidian, metal, quartz (Olsen, 1988; Greenfield, 1999, 2004, 2006a, b; Bello and Soligo, 2008; Yravedra et al., 2009), shell (Choi and Driwantoro, 2007), or bamboo (Spennerman, 1990; West and Louys, 2007). Other research addressed cut mark morphology according to stone tool type (i.e. simple or retouched flakes, handaxes) (Walker, 1978; Shipman and Rose, 1983; Bello et al., 2009; Domínguez-Rodrigo et al., 2009; De Juana et al., 2010; Galán and Domínguez-Rodrigo, 2013).

In these studies, cut mark morphology analyses were restricted to optic microscopy, hand lenses and SEM (Shipman, 1981; Olsen, 1988; Greenfield, 1999, 2004, 2006a,b; Smith and Brickley, 2004; Lewis, 2008), binocular microscope for high resolution pictures (Domínguez-Rodrigo et al., 2009; De Juana et al., 2010; Marín-Monfort et al., 2014), digital imaging techniques (Gilbert and Richards, 2000), three-dimensional reconstruction

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(Bartelink et al., 2001; During and Nilsson, 1991; Kaiser and Katterwe, 2001), 3D digital microscope (Boschin and Crezzini, 2012; Crezzini et al., 2014), and a recent technique based on the use of Alicona 3D Infinite Focus Imaging microscope (Bello and Soligo, 2008; Bello et al., 2009; Bello, 2011; Bonney H., 2014).

These techniques basically recorded the main features of cut mark morphology (i.e. V-section of cut mark grooves) including variable length, width and depth depending on tool type, its raw material and bone morphology, inasmuch as the presence of internal microstriations which may be associated with secondary features such as barbs, shoulder effects or Hertzian cones (e.g. Martin, 1909; Binford, 1981; Shipman, 1981; Shipman and Rose, 1983). Although in most cases cut marks were described following two-dimensional observations, Bello and co-authors have used Alicona to interpret cannibalistic and funerary practices (Bello and Soligo, 2008; Bello et al., 2011a, 2015; Schulting et al., 2015), as well as to study teeth and the use of the mouth as a third hand (Hillson et al., 2010 Bello et al., 2011b). They also applied this method to the interpretation of engraved bones and antlers (Bello et al., 2013a) and the use of these materials as retouch tools and hammers (Abrams et al., 2014; Bello et al., 2013b). Boschin and Crezzini (2012) exemplified their technique in the analysis of archaeological collections to distinguish cut-marks produced by metal from stone-tool damage. The application of 3D technology was also used for engraved pottery (Montani et al., 2012) and prehistoric art (Güth, 2012).

The present article describes a methodology which overcomes the limitations implied in the use of microscopes -i.e. restricted

Table 1
Technical specifications, usage and classification of the tools used.

Tool	Classification	Working	Technical specifications
Trinocular stereoscopic microscope with image sensor.	Passive sensor	An image sensor is installed in the third observation channel of the microscopy and its optical is used as the objective.	• Euromex NOVEX AR Trino (Continuous Zoom 1X a 4X) + Reflex Camera Nikon D5100 (sensor CMOS de 23.6 × 15.6 mm de 16.2 MP) + Camera Adapter T-System. • Motic DM-39C–N9GO A (Fixed Zoom 2X a 4X) with digital camera included (CMOS 1/2″ 3 MP, Pixel matrix 2048 × 1536). • Motic SMZ-143 (Continuous Zoom 1X a 4X) + Reflex Camera Nikon D5100 (sensor CMOS of 23.6 × 15.6 mm of 16.2 MP) + Camera Adapter T-System.
Microscopic multifocal motorized with high-resolution digital camera included	Passive sensor	It corrects the limited field depth of macro-photography when the focal length, focus distance and diaphragm opening are reduced. The user has to focus the furthest and the nearest point of the object. The microscopic function takes those points as a reference and automatically makes a sequence of intermediate images of the same scene, changing the focus point. Finally, it joins those images and generates a single clear photography with each element focused in a precise way.	• Leica M 205C (Continuous Zoom 0.7X a 160X) + Sensor DFC 450 (CCD − ICX282 8.7 × 6.5 mm, 5 MP).
Digital portable microscopic USB	Passive sensor	The images obtained are only visible by computer software. A photograph collection is needed.	• Digital portable microscopic USB Celestron (Continuous Zoom 1X a 4X y 15x fixed). Digital camera (CMOS 1.3 MP, Pixel matrix 1280 × 1024).
Reflex camera + Reverse mounting adapter of objective	Passive sensor	The reverse mounting adapter of objective is an accessory placed between the body of the camera and the objective, which is placed in a reverse position. It simulates a macro objective.	• Reflex camera Nikon D5100 (sensor CMOS of 23.6 × 15.6 mm of 16.2 MP, pixel size of 4.78 μm) + Objective 18–55 mm + Reverse mounting adapter of objective of 52 mm.
Reflex camera + Extension Tubes of Objective	Passive sensor	The extension tubes of the objective are an accessory placed between the body of the camera and the objective, reducing the minimum lens focus distance. It simulates a macro objective.	• Reflex camera Nikon D5100 (sensor CMOS of 23.6 × 15.6 mm of 16.2 MP pixel size of 4.78 μm) + Objective 18–55 mm + Aluminium Extension Tubes of Objective of lengths 12 mm, 20 mm y 36 mm.
Reflex camera + Close-Up lens Macro Filter Set	Passive sensor	The close-up lens macro is a filter screwed at the end of the objective which increasing the image area, creating a loupe effect. It simulates a macro objective.	• Reflex camera Nikon D5100 (sensor CMOS de 23.6 × 15.6 mm of 16.2 MP pixel size of 4.78 μm) + Objective 18–55 mm + 52 mm Close-Up lens Macro Filter Set of 1X, 2X, 4X and 10X.
Reflex camera + Macro Objective	Passive sensor	Sensor system of images invented to focus at short distances, enlarging the elements focused three to four times. The result is high quality photographs.	• Reflex camera Canon EOS 50D (Sensor CMOS (APS-C) of 22.3 × 14.9 mm of 15.1 MP, pixel size of 4.7 μm) + Objective SIGMA 50 mm 1 2.8 dg macro
Metrological Laser Scanner	Active sensor	Metric recorder of an object with coordinates. As result, a 3D model is obtained.	• Hexagon Metrology Absolute Arm 7325SI. Measuring Range 2.5 m. Probing Point Repeatability ±0.079 mm. Probing Volumetric Accuracy ±0.069 mm. Scanning System Accuracy ±0.042 mm. Max. Point acquisition rate: 50.000 Points/s. Line Rate: 30 Hz. Accuracy (2 sigma): 30 μm).
Structured Light 3D Scanner	Active sensor	System made up of a camera, a projector and a calibration board. It must be first calibrated placing the camera and the projector in 15° and 25° angles towards the calibration board. The projection must cover the calibration board completely. The scale of the calibration board is specified in the software, the exposition of the camera is adjusted and the focus of the camera and the projector are verified in the tools. It needs to be calibrated as well. The camera and the projector must be fixed. The object substitutes the calibration board. The pictured is scanned and a 3D points cloud or a 3D model of the object is made.	• David Structured Light Scanner SLS-2. Scan size: 60–500 mm. Resolution: Up to 0, 1% of scan size (down to 0.06 mm). Scanning time: One single scan within a few seconds. Mesh density: Up to 1,2000,000 vertices per scan = ACER K132 + Structured Light Projector + DAVID USB CMOS Monochrome Camera with Lens + DAVID Structured-Light Calibration Panels Set.