Experimental bone toolmaking: A proposal of technological analytical principles to knapped bones

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Abstract:

Since the origins of technology, human groups have used a wide variety of lithic and organic raw materials to make tools. In particular, bone was used as raw material for creating knapped artefacts. Nevertheless, the recognition of these technological elements in the archaeological record has generated some debate, since modern taphonomy has shown that certain non-anthropic agents create modifications that can mimic knapped bone tools. For this reason, the criteria for identifying archaeological bone tools and pseudo-tools have still not been clearly defined.

As a contribution to this subject, here we present the results of an experimental programme of intentional anthropic marrow fracturing of fresh and semi-fresh bovine long bones. After marrow removal, some of the diaphyseal fragments obtained were selected to be used directly as tools, while others were slightly retouched. The aim was to describe the bone toolmaking process and the simple and retouched tools obtained experimentally according to technological criteria. The technological analysis approach was based on an adaptation of the Logical Analytical System (LAS), which uses structural categories within an operative chain rather than techno-typological features. LAS has been widely used to analyse Pleistocene lithic assemblages and is here applied for the first time to the study of bone industry.

The results allow us to present new analytical criteria with which to describe simple and retouched bone tools from a holistic perspective, combining technological and taphonomic terminology. Our intention is to improve the criteria for differentiating intentional retouching in bone tools from other modifications to bone remains generated by non-anthropic agents. The final goal of this study is to further the interdisciplinary study of minimally modified bone tools, proposing a technological method for studying knapped bone tools.

Keywords: bone tools; technology; taphonomy; methodology; Logical Analytical System; knapping

1. Introduction

From the appearance of early human cultures, human groups used bones as a raw material for making tools. Osseous artefacts are present at archaeological sites from the Early

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Pleistocene in Africa (*e.g.*, Backwell & d'Errico 2004; 2008; d'Errico *et al*. 2022; Pante *et al*. 2020) and Middle Pleistocene in the Near East and Europe (*e.g.*, Baumann *et al*. 2020; Biddittu & Segre 1982; Doyon *et al*. 2021; Patou-Mathis 1999; Rabinovich *et al*. 2012; Tartar 2012).

Early bone tools were manufactured using basic techniques, such as percussion, and the artefacts are characterised by their low degree of modification compared with Upper Palaeolithic bone industry, where more complex manufacturing techniques (*e.g.*, perforation, grooving, polishing, sawing, *etc*.) became widespread. Principally, their identification is based on certain morphologies that resemble those of contemporary lithic industry or of having some recognisable active parts (Bonnischen & Will 1980; Villa *et al*. 1999).

Non-anthropic agents can generate alterations that mimic this minimally modified bone industry, including morphologies reminiscent of coetaneous lithic tools: pointed ends, sharp fracture patterns, pseudo-retouching, continuous notches, bone surface modifications, and wear in localised areas, among other things. Modern taphonomy recognises these problems of equifinality with other taphonomic agents (*e.g.*, carnivore action, trampling, abrasion, *etc*.) that create pseudo-tools (*e.g.*, Backwell & d'Errico, 2004, 2008; Behrensmeyer *et al*. 1986; Blumenschine *et al*. 1996; Bromage 1984; d'Errico 1993; Domínguez-Rodrigo *et al*. 2009; Olsen & Shipman 1988; Shipman & Phillips-Conroy 1977; Shipman 1981; Villa & Bartram 1996).

The knapping and utilisation of bone elements have been reproduced experimentally because of the need to interpret some faunal assemblages in which the presence of used bones, knapped bone tools or pseudo-tools has been documented (*e.g.*, Biberson & Aguirre 1965; Bonnischen & Will 1980; Daujeard *et al*. 2014; Freeman 1983; Mallye *et al*. 2012; Mozota 2013; Standford *et al*. 1981; Vincent 1993). When knapping bones for technological purposes, there are certain differences compared with knapping lithics. The osseous raw material presents a variety of possibilities and limitations. Bone has a heterogeneous anisotropic structure that reacts differently to mechanical deformation according to its microstructure. Unlike rocks, it is an elastic and flexible material, (Dauvois, 1974; Lyman, 1994: 72-81), which in its original stage (*i.e.*, unmodified) also presents anatomical variability that conditions the characteristics of the supports and tools obtained.

Technological studies of minimally modified bone industry, which includes knapped tools, have followed different trends. At the beginning of the 20th century, these elements were described in greater or lesser detail, but there was no attempt to systematise their study (*e.g.*, 1907; Breuil 1932; 1938; Martin 1906;). Subsequently, analysis models involving descriptions that are more detailed began to appear, in which categories of tools were established based on morphotypological criteria (*e.g.*, Aguirre 1984; Barandiarán 1967; Cabrera & Bernaldo de Quirós 1978; Camps-Fabrer 1974: 143-224; Delpech & Sonneville-Bordes 1977; Hallet *et al*. 2021; Sadek-Kooros 1972). Other researchers selected other approaches, as they considered that typology did not adequately describe the characteristics and variability of the assemblages. These included the technological approach, which focuses on the reconstruction of the operative chain, similar to that used in stone tool reduction sequences (*e.g.*, Biberson & Aguirre 1965; Cabrera Valdés 1984; Mania 1995; Vincent 1993: 34-89). More recently, the morpho-functional approach, combining the form of the tool with the activities for which it was designed (*e.g.*, Baumann *et al*. 2020; Ono 2006; Villa *et al*. 2021). In many of these studies, there was a tendency for individual researchers to develop their own criteria for classifying and technologically analysing bone tools although they did not necessarily explain them in detail (Olsen 1984: 55-99). In addition, yet other studies considered the need to apply an interdisciplinary approach to study this type of artefact (Backwell & d'Errico 2008; d'Errico *et al*. 2022; Bonnichsen & Sorg 1989; Mateo-Lomba *et al*. 2020; Pante *et al*. 2020; Shipman & Rose 1988; Stammers *et al*. 2023).

Aware of this lack of a standardised method, from a technological perspective, in studies of knapped bone tools, we want to help resolve this issue. Therefore, our main aim is to propose basic common technological terminology and a simple set of analytical principles by describing an experimental bone toolmaking process from bone breakage to shaping.

2. Material and methods

An experiment was performed to reproduce the initial stages of the operative chain of the minimally modified bone industry, *i.e.*, the procurement and the shaping of blanks. Next, a series of analytical criteria for classifying fractures were introduced following the Logical Analytic System approach (LAS) (Carbonell *et al*. 1983; 1999).

2.1. Experiment: Bone breakage and shaping

The tools were obtained from a multi-stage experiment. First, 45 meatless bovine long bones, both fresh (n=32) and semi-fresh (n=13), were broken to obtain marrow and bone blanks (Table 1). The bones were obtained from a local butcher, where the carcasses were defleshed. Some were broken within a few days (fresh bones), while others were left to dry in the open air for six months (semi-fresh bones). The activity was performed using an unmodified quartzite cobble and a chopper of the same material, as hammers, and a schist anvil as a support. The technique used was direct percussion. After the recovery of the marrow, some fragments were selected (by A.O.) based on two categories. Some diaphyseal fragments were chosen to be used directly (n=75), and other fragments were selected to be used as blanks (n=37) and subsequently shaped with quartzite pebbles through direct percussion by the same person (Table 2). The criteria for selecting simple tools were that they should have a suitable shape for grasping and an active edge appropriate for the tasks to be performed. The absence of visible cracks and large areas of cancellous bone and appropriate dimensions and shape were the most important factors for the blanks. None of the fragments were cleaned to remove fat or any remaining meat or other tissues. The lithic tools used (*i.e.*, the hammers) in this experiment were described in a previous work (Mateo-Lomba *et al*. 2020: 53). The whole experiment was videoed and photographed.

Table 1. Number of skeletal elements (*Bos Taurus*), bone freshness, and type of hammerstone used in the bone breakage. All humeri, radius-ulna and tibiae were broken in a fresh state.

	Type of hammerstone		
Element	**Chopper**	**Cobble**	**Total**
Femur	18	18	36
Fresh	11	12	23
semi-fresh	7	6	13
Humerus	3	2	5
Radius-ulna	1	1	2
Tibia	1	1	2
Total	**23**	**22**	**45**

Table 2. Number of fragments to be used directly (simple tools *sensu* Mateo-Lomba *et al*. 2020) and blanks. All humeri, radius-ulna and tibiae were broken in a fresh state.

	Simple tools	Blanks	Total
Femur	66	29	95
Fresh	39	21	60
semi-fresh	27	8	35
Humerus	5	4	9
Radius-ulna	1	0	1
Tibia	3	4	7
Total	75	37	112

2.2. Analytical criteria

2.2.1. Identification and fracturing analysis

Only cattle long bones (*Bos taurus*) were broken. Then, each fragment was analysed using zooarchaeological and taphonomic methods recording exact element, position, portion, and side (Saladié *et al*. 2011).

All fragments, before and after retouching, were analysed according to bone breakage analysis criteria. The length of the shaft (L1: <1/4; L2: between 1/4 and 1/2; L3: between 1/2 and 3/4; L4 >3/4 of the total length) and shaft circumference (C1: <1/2; C2: >1/2; C3: complete circumference) were noted (Villa & Mahieu 1991). Moreover, the outline (longitudinal, transverse, curved), angle (right, oblique, mixed), and fracture edge (smooth, jagged) of each fracture plane were considered; along with any bone surface modifications observed due to intentional breakage of the assemblage, such as percussion marks, notches, adhering flakes, cortical and medullary scars, and the presence of cortical and medullary flakes (Blumenshine & Selvaggio 1988; Blumenshine 1995; Bunn 1983; Cáceres Cuello de Oro 2002: 88-92; Capaldo & Blumenschine, 1994; Pickering 2002; Vettese *et al*. 2020; Villa & Mahieu 1991). However, the description of the complete experimental set is beyond the scope of this paper and will be the subject of an additional publication.

2.2.2. Logical Analytical System

The bone tools obtained in this experiment were technologically analysed following criteria adapted from the Logical Analytical System (LAS) (Carbonell *et al*. 1983; 1999; Rodríguez 2004; Ollé *et al*. 2013). This is a system for analysing technological processes based on structural categories within a production sequence, without considering typologies (Table 3).

The bone tool production chain (Figure 1) starts when a bone (Natural Base; NB) is selected with the intention of fracturing it to use its products as raw material. As a result of the modification of the whole bone (first generation), fractured bones (Negative Bases; 1GNB) and products of this breakage (Positive Bases; 1GPB and fragments) are obtained. These products can be classified into fractured bone (which is the one that preserves the epiphysis; 1GNBE), diaphyseal fragments (1GPB) that can be blanks, simple tools (*sensu* Mateo-Lomba *et al*. 2020), or fragments smaller than 4 cm without clear technological features (FRAG). If any of the elements are modified again, a new phase (second generation) is initiated. Objects previously classified, as 1GPB become a negative base (2GNB) which, if modified, will have smaller flakes (2GPB) extracted from it. The negative products of the second generation can be subdivided at a theoretical level into retouched tools (2GNBC) and supports (cores) for future exploitation (2GNBE). The process could continue in the same way in successive generations. In this work we will only focus on elements of the first two generations.

Table 3. Common terms used in the technological analysis according to LAS (modified from Carbonell *et al*. 1999; Ollé *et al*. 2013). * It is difficult to distinguish products from different generations; therefore, all simple products from diaphysis are usually referred to as Positive Bases (PB).

Logical Analytical System	Common terms	L.A.S. adaptation
Natural Base	Complete bone	_
First Generation Negative Base (1GNB)	Bone fracturing negative products (>4 cm)	1GNBE (Exploitation): epiphysis
First Generation Positive Base (1GPB)	Bone blanks (diaphyseal fragments, simple tools) and cortical and medullary flakes	Positive Base*: diaphyseal fragment
Second Generation Negative Base (2GNB)	Products that have been flaked	2GNBE (Exploitation): cores on blanks
		2GNBC (Configuration, or shaping): retouched tools
Second Generation Positive Base (2GPB)	Small flakes (debris) detached when flaking First Generation Positive Bases	Positive Base*: small flakes
Fragments (FRAG)	Bone fracturing detached products (<4 cm) without clear technological features	

Besides the structural groups, we adapted the morphotechnical and morphopotential analysis perspectives (Carbonell *et al*. 1999; Ollé 2003: 19-25; Vergès 2003: 7-15) to the different categories of tools. The morphopotential of the tools has already been described in a previous work (Mateo-Lomba *et al*. 2020). Thus, the previously presented experimental set of tools was extended and new complementary descriptions were added from a technological perspective.

As for the morphotechnical study of positive bases (PB), specifically bone tools, the attributes used in the lithic industry *sensu stricto* cannot be applied to this category due to the intrinsic characteristics of the raw material. Thus, we decided to describe these tools according to the methods applied in taphonomic studies to long bone breakage. The characteristics used were the outline, angle, and edge type of each of the fracture planes, the preserved portion of the circumference of the diaphysis and the length of the shaft, as well as the identification of the cortical and medullary flakes (Blumenschine & Selvaggio 1988; Bunn 1981; Cáceres Cuello de Oro 2002: 84-92; Villa & Mahieu 1991). Other technological elements such as a description of the general morphology of the positive base and the degree of corticality (Rodríguez *et al*. 2004: 12, 14) present in the LAS studies (Table 3) were added.

In the case of the 1GNBs, the previously mentioned criteria used for studying bone breakage were also applied, together with an analysis of the general morphology of the analysed element and its corticality, as mentioned above. (Table 4). In corticality, the variables are noncortical (NCO), noncortical dominant (<50% cortical, NCO(CO)), cortical dominant (>50% cortical, CO(NCO)), and totally cortical (CO) (Rodríguez 2004: 14).

The 2GNBC were analysed from the bone breakage analysis perspective, as described above, as well as in terms of their general morphology and corticality. In addition, the analysis of 2GNBC attributes can be applied directly using the same methods as employed for the lithic industry (Rodríguez *et al*. 2004: 15) (Table 5). The attributes of knapping faces, removal disposition (or scars, according to taphonomical terminology), extent of the retouched edge, and for retouching: angle, depth, extent, direction, delineation, morphology, and location were considered. Finally, the horizontal and sagittal delineation of the edge was described.

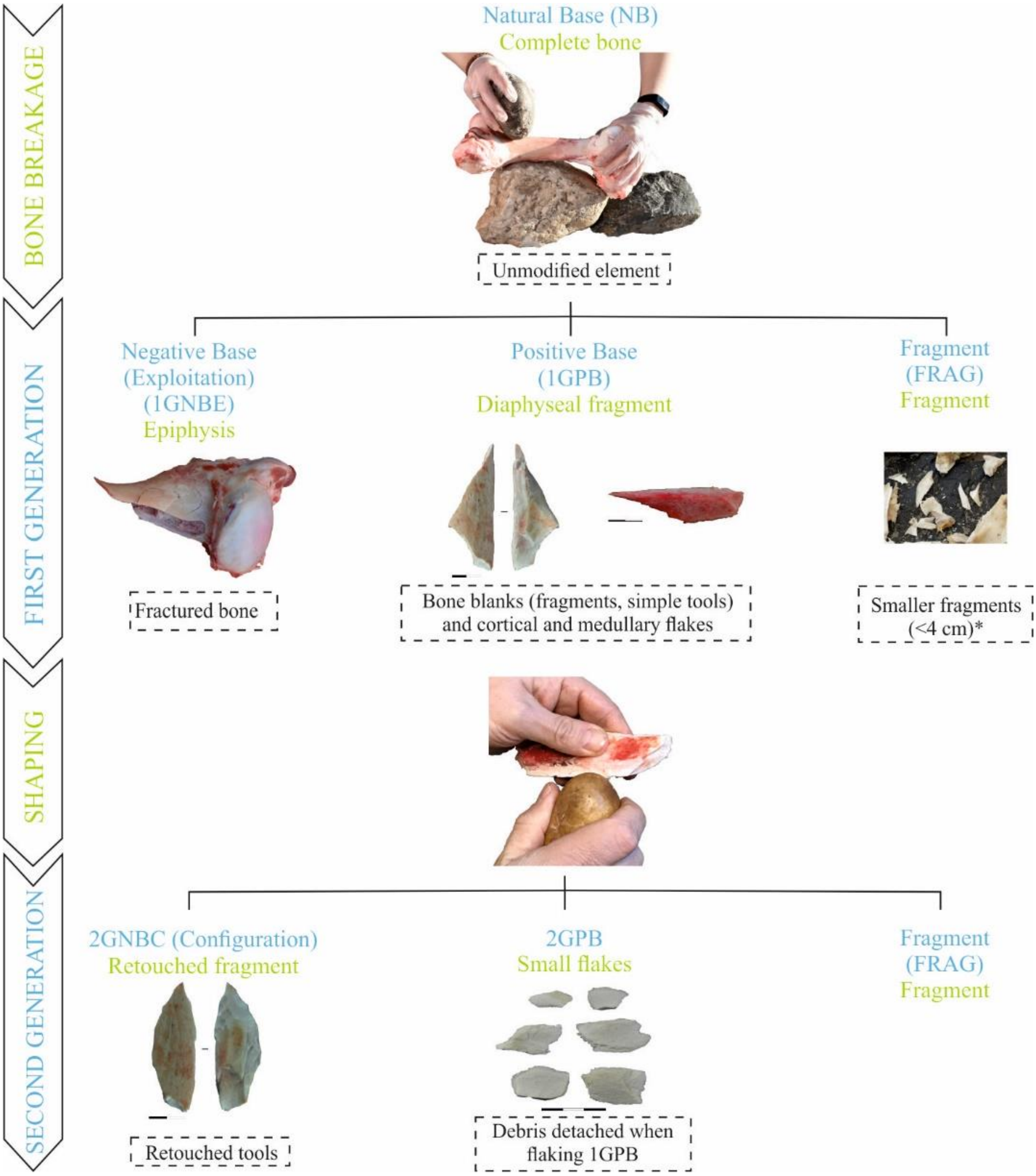

Figure 1. Structural categories according to the Logical Analyical System adapted (blue) and common terms used in taphonomy (green). * See Table 2.

Table 4. Criteria for analysing Positive Bases (PB) and First Generation Negative Bases (1GNB). *Medullary flakes and cortical flakes are only used in the PB analysis.

Fracture plane			**Shaft**		**Medullary flake***	**Cortical flake***	**General morphology**			**Corticality**
Outline	**Angle**	**Edge**	**Circumference**	**Length**			**Horizontal**	**Sagittal**	**Transversal**	
Longitudinal	Right	Smooth	C1	L1	Yes	Yes	Rectangular (RTG)	RTG	RTG	Noncortical (NCO)
Transverse	Oblique	Jagged	C2	L2	No	No	Trapezoidal (TRP)	TRP	TRP	Totally cortical (CO)
Curved	Mixed		C3	L3			Triangular (TRG)	TRG	TRG	Noncortical dominant (NCO(CO))
				L4			Pentagonal (PTG)	PTG	PTG	Cortical dominant (CO(NCO))
							Polygonal (PLG)	PLG	PLG	
							Circular (CIR)	CIR	CIR	
							Oval (OV)	OV	OV	

Table 5: Criteria for analysing 2GNBC, adapted from Rodríguez (2004).

Knapping faces	Unifacial (U)
	Bifacial (B)
	Trifacial (T)
	Multifacial (M)
Removals disposition	Unipolar (Up)
	Bipolar opposite (Bo)
	Bipolar orthogonal (Bor)
	Multipolar orthogonal (Mor)
	Multipolar centripetal (Mc)
Extent of the retouched edge	Retouched zone equivalent to less than 1/8 of the edge (NC)
	Retouched zone equivalent between 1/8 and 3/8 of the edge (C)
	Retouched zone equivalent between 3/8 and 5/8 of the edge (2C)
	Retouched zone equivalent between 5/8 and 7/8 of the edge (3C)
	All edge is occupied by the retouches (4C)
Angle of the retouched edge	Shallow-acute or Plain (P): 0-30o
	Acute or simple (S): 31-60o
	Steep or Abrupt (A): 61-90 o
Depth of the retouch with respect to the edge	Very marginal (vm)
	Marginal (m)
	Deep (d)
	Very deep (vd)
Extent of the scars originated because of the retouch	Very marginal (vm)
	Marginal (m)
	Extensive (e)
	Very extensive (ve)
	Total (t)
Direction of the retouch	Direct (d): removals on the cortical surface
	Inverse or indirect (i): removals on the medullary surface
	Alternate (a): one edge with removals on the cortical surface and removals on a different edge on the medullary surface
	Alternating (al): removals on the cortical surface that change to the ventral surface on the same edge
	Bifacial (b): removals present on the same edge in both cortical and medullary surfaces
Delineation of the retouch	Continuous (c)
	Non continuous (nc)

	Notch (n)
	Denticulate (dent)
Morphology of the retouched edge	Straight (str)
	Convex (cx)
	Concave (cc)
	Sinuous (sin)
Localization of the retouched edge	Cortical
	Ventral or Medullary
Frontal edge morphology	Convex (cx)
	Concave (cc)
	Straight (str)
	Denticulate (dent)
	Sinuous (sin)
Sagittal edge morphology	Incurved (inc)
	Straight (str)
	Sinuous (sin)

2.2.3. Tool orientation and metric analysis

The tools were oriented with the most pointed end, or the most shaped end, facing upwards, corresponding to the distal end, following the conventions of Camps-Fabrer (1977) and González Doña (1984). The upper horizontal face corresponds to the cortical surface and the lower one to the medullary surface, which are equivalent to the dorsal and ventral faces, respectively, in stone tools. Three planes were used for the volumetric description: horizontal, transversal, and sagittal. The measurements taken (in mm) were the length of the major axis, the greatest width, and the major thickness.

2.2.4. Statistical analysis

To assess possible size differences between simple and retouched tools, we performed an ANOVA test to compare the means between the two samples for length, width and thickness.3. Data results

The assemblage produced in this experiment comprised 75 simple tools (1GPB) and 37 retouched tools (2GNBC) (see Supplementary materials). We also obtained 1GNBE (fractured bones), fragments and 2GPB (debris detached when retouching 1GB), which are not going to be described in this paper. 23 bones were broken with unmodified cobble and 22 with chopper. From the former, 472 fragments were obtained (54.19%; >2cm: n=364, 53.53%), and of the latter, 399 (45.81%; >2cm: n=316, 46.47%).

In terms of dimensions, the 1GPB presented a mean length of 97.44 mm (stand. dev. 29.41), a mean width of 38.43 mm (stand. dev. 10.21), and a mean thickness of 17.45 mm (stand. dev. 5.89). In contrast, the retouched tools had a mean length of 110.04 mm (stand. dev. 37.34), a mean width of 39.83 mm (stand. dev. 7.36), and a mean thickness of 19.1 mm (stand. dev. 4.88) (Figure 2). The results of the statistical test show that there is no strong evidence for equal or unequal means when considering length (ANOVA F=3.788, p =0.05418), but there is significant evidence for equal means in the case of width (ANOVA

F=0.5511, *p* =0.4595) and thickness (ANOVA; F=0.1924, *p* =0.6618). Thus 1GPB and 2GNB samples are not statistically different in terms of size.

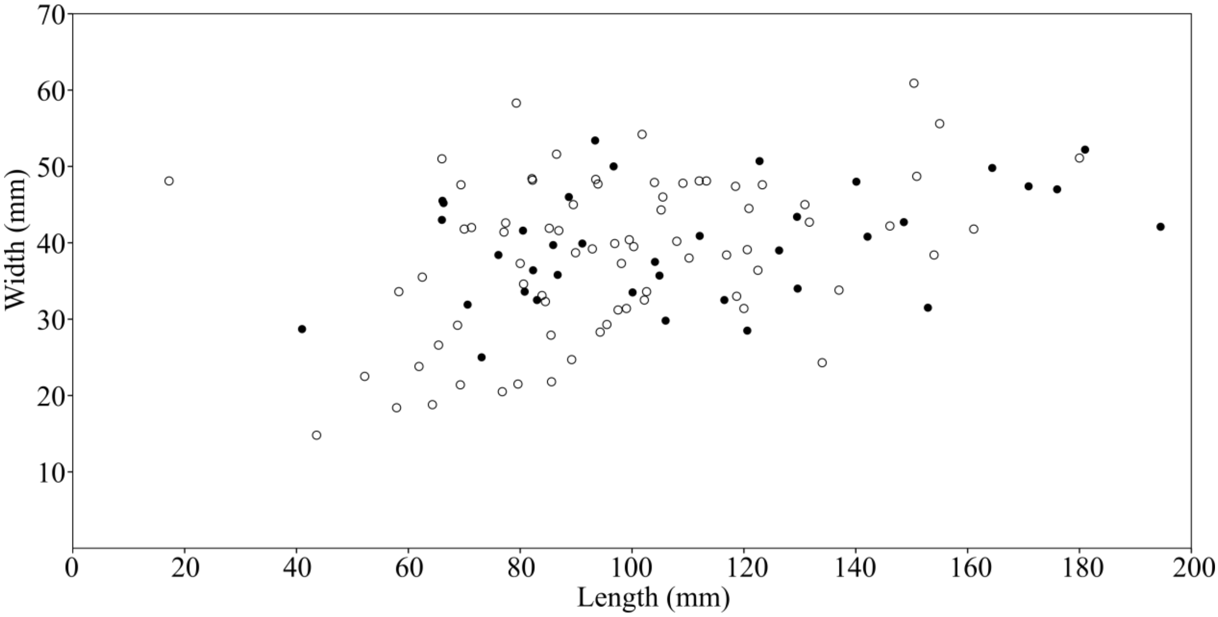

Figure 2. Dimensions of the experimental bone artefacts presented in this work (mm). Empty dots correspond to 1GPB and filled dots correspond to 2GNBC.

The 75 simple tools presented 324 fracture planes, the majority of which were curved and oblique (Figure 3). Most of the tools retained less than 1/3 of the circumference of their original diaphyses (n= 64, 85.33%). Diaphysis length was less than ¼ of the original length in most of the assemblage (n=62, 82.67%). There were 2 medullary flakes and 5 cortical flakes within this assemblage. Complete notches, overlapping notches and micro-notches were also documented. The removals produced by fracturing were minor elements that were present on both the cortical (n=15, 20% of the assemblage) and medullary (n=2, 2.67% of the assemblage) surfaces. If the degree of corticality is considered, those pieces that preserved a greater part of the cortical surface were predominant (n=53, 70.67%) (Figure 4) (See Supplementary material).

The 1GPB showed a heterogeneous horizontal morphology, the most abundant being polygonal (n=42, 56%); in the case of the sagittal morphology, the trapezoidal shape predominated (n=55, 72%), and the transverse morphology, most were semi-circular in shape (n=51, 68%) (See Supplementary material). Direct percussion retouching requires an acute angle on the percussion platform. Normally the intersection of the cortical or medullary surface was used. In contrast to knapped lithic elements, greater force was required in the case of fresh bone, as due to its elasticity and strength the bone absorbs part of the force applied, meaning it was more difficult to control the extractions (Baumann *et al*. 2020). In general, larger supports were selected for the shaping of the retouched tools, as they offer a greater surface area for this and can be held in a more ergonomic way. As semi-fresh bones lose some of their elasticity in the drying process, they were easier to knap. Indeed, knapping caused fewer accidental breakages and required less energy and a better control in the depth and extent of scars was reached. In both cases, a good selection of percussion planes and striking precision were necessary. The presence of internal cracks in the blank to be knapped or lack of control in the knapping could lead to uncontrolled breakage of the supports.

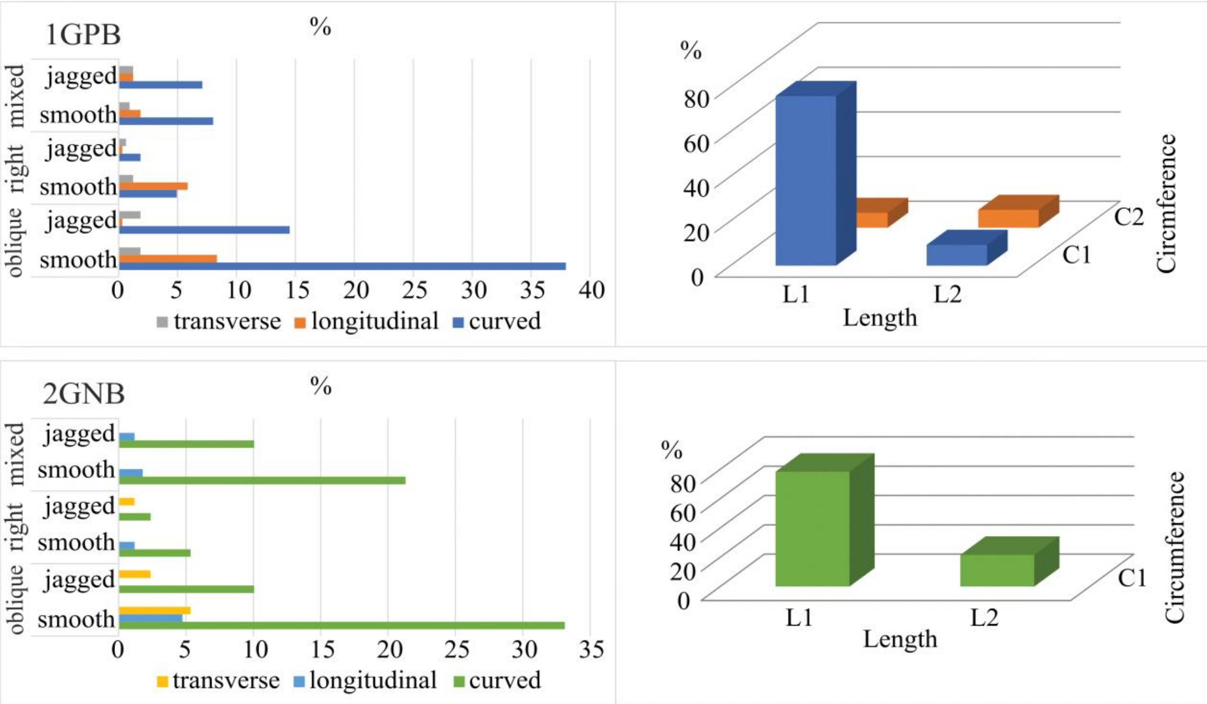

Figure 3. Fracture planes on 1GPB and 2GNB (left) and shafts lengths and circumferences (right).

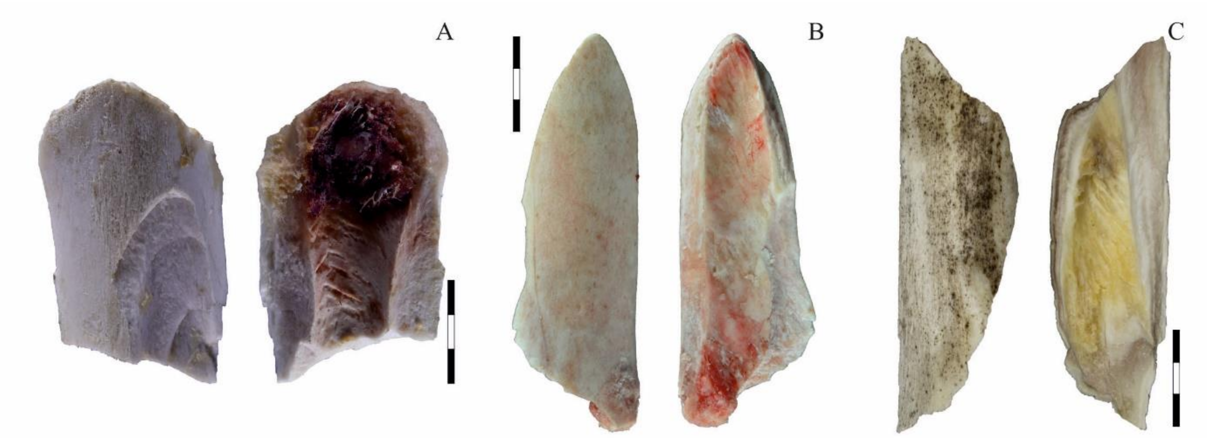

Figure 4. 1GPB tools. A and B were obtained during fresh bone breakage. C was obtained during semi-fresh bone breakage. Scale bars: 3 cm.

The 37 retouched tools (2GNB) had 169 fracture planes, the most abundant of which, as in the case of the PBs, were the curved and oblique ones. The entire assemblage had a preserved circumference of less than 1/3 and most had a length of less than ¼ of the original (n=29, 78.38%) (Figure 3). Among the shaped tools, complete notches were also documented.

The unifacial tools (n=24, 64.86%) showed a majority (n=15, 62.5%) of cortical area. Most of the removals were unipolar (n=20, 83.33%), but the sample set showed some variability as other strategies such as bipolar opposite, bipolar orthogonal and multipolar centripetal removals were also generated. Most of the samples showed a retouched area of less than 3/8 of the edge. This retouching was mostly plain (n=18, 75%) and marginal in extent (n=,1770.83%). It was also predominantly marginal (n=23, 95.83%) in terms of the depth of the retouching. The retouched area in this group of tools showed a direct (n=13, 54.17%) but also an indirect (n=11, 45.83%) retouch direction. A generally continuous delineation (n=21, 87.5%) was observed in the retouching; the morphology was both straight (n=8, 33.33%) and convex (n=16, 66.67%). Finally, the retouching was mostly found on the cortical surface (n=13, 54.17%), although it was also located on the medullary surface (n= 3, 12.5%), fracture planes (n=7, 29.17%) and both medullary surface and fracture planes (n=1, 4.16%).

The bifacial tools (n=13, 35.14%) also showed a majority of cortical area (n=10, 76.92%). The removal disposition in this group of tools was heterogeneous, the most common being unipolar (n=7, 46.67%), but there were also bipolar opposite (n=6, 40%) and bipolar orthogonal (n= 2, 13.33%) removals. The centripetal character was generally more extensive than in the unifacial tools, as the retouched area was almost half of the edge in most cases (n=9, 69.23%), but the shaping of some tools also affected a larger edge surface. The observed retouching was predominantly plain (n=12, 92.31%) and the whole set showed marginal retouching depth. The extent of the scars was mostly marginal (n=10, 76.92%) while the rest of the set was more extensive. Only in one case was there deep extensive retouching on the medullary face but this was marginal on the cortical face. The retouching was principally bifacial (n=10, 76.92%), although some was alternate (n=2, 15.39%) and alternating (n=1, 7.69%). The delineation of the retouching was in all cases continuous, with the retouched edge having heterogeneous morphology, either straight (n=7, 53.85%) or convex (n=6, 46.15%). Finally, the retouching on the bifacial tools was predominantly on the cortical surface and fracture planes (n=7, 53.85%) (Figure 5).

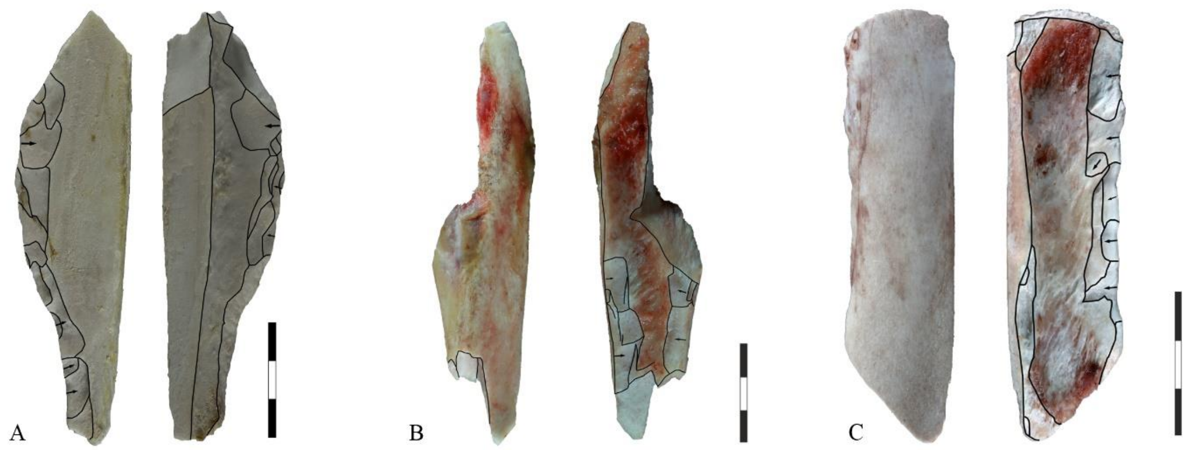

Figure 5. 2GNB tool. A: bifacial tool. B: example of bipolar opposite removals disposition. C: unifacial and unipolar tool. All were obtained during fresh bone breakage. Scale bars: 3 cm.

In this experimental set, the knapping removals presented similarities and differences according to the state of freshness of the tool when knapped. There were 77 tools created from fresh bone (1GPB = 48; 2GNB = 29) and 35 from semi-fresh bone (1GPB = 27; 2GNB = 8) (Table 2). The angle of the retouched edge was mostly plain in both sets (n=23, 79.31% in the fresh and n=7, 87.50% in the semi-fresh), but only in the fresh set was there abrupt retouching (n=1, 3.45%). The depth of retouch in the two cases was homogeneous, since in both it was marginal (100%). However, further differences were observed in the extent of the scars originating from the retouching. In the fresh tools, marginal retouching predominated (n=23, 79.31%) while in the semi-fresh tools, marginal retouching was identified (n=4, 50%) but there was also very marginal (n=2, 25%) and extensive (n=2, 25%) retouching. Conversely, some of the fragments obtained in the first phase of the experiment (*i.e.*, breakage to obtain the blanks) exhibited scars (5.2%), notches (3.8%), or pseudo-retouching (0.6%), similar to the anthropic techniques for manufacturing knapped bone tools (Figure 6).

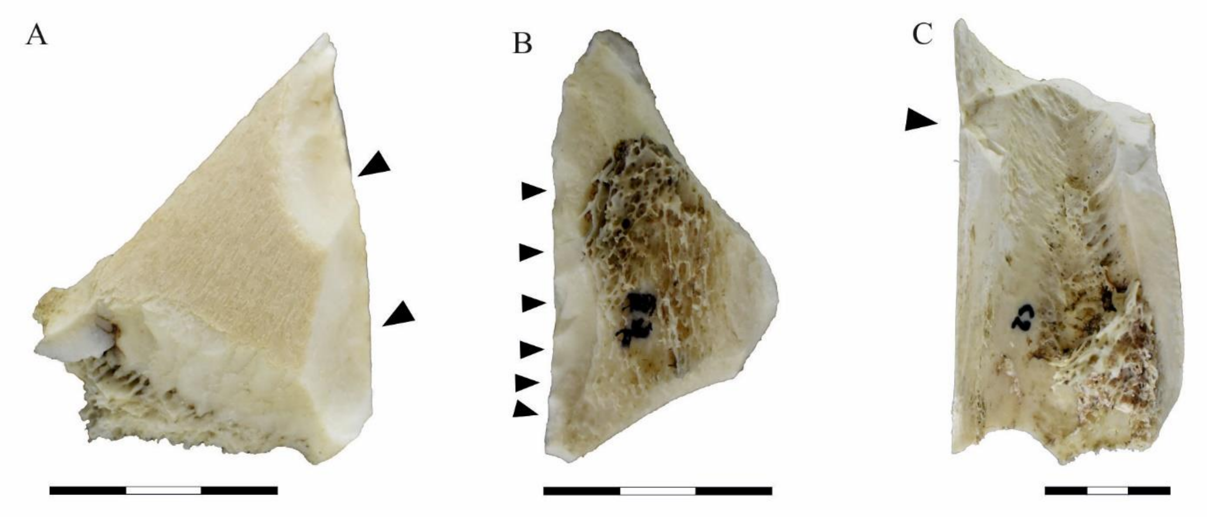

Figure 6. Modifications obtained during bone breakage. A: continuous cortical conchoidal scars. B: pseudo-retouching. C: complete notch. Scale bars: 3 cm.

4. Discussion

The experiment presented here replicated the initial part of the operative chain of osseous artefacts, from the initial breakage to their shaping (or not) through the retouching of each elements according to their intended use in a particular activity.

The experimental set of tools obtained is heterogeneous, as it includes 1GPB, 2GNB and fragments. In both the 1GPB and 2GNB groups, there is a clear predominance of curved fracture planes and a high degree of bone breakage. We observed an interesting increase in mixed angles and jagged surfaces in 2GNB, which contrasts with the PBs because of the blank shaping. In the case of the 1GPB, the morphologies were determined by the characteristics of the bone itself, as an elongated support with an incurved shape along the sagittal plane (due to the anatomy of the bone diaphysis and its medullary canal), but also by the shapes generated by fresh fracturing with a hard hammerstone. The group of 2GNB tools was diverse, as it included artefacts with one or two knapped faces and involved different strategies in terms of disposition and location of the removals. The shapes and characteristics of these artefacts were designed by the knapper according to a mental scheme based on the activities they planned to do with them, but taking as a blank the products obtained from nutrition-related bone breakage.

The morphometric analysis indicates variability in the shapes and sizes of the tools, with the retouched ones being the largest. These sizes were selected because this set of bone tools is intended to be used by hand, and small sizes would not be suitable for handling ergonomically to accomplish tasks such as scraping, sawing and cutting. The fragments originated during the breakage of bone determine the shape of the simple tools (or PB). These are elongated elements due to the nature of the blank used (diaphysis long bones). However, the general shape and characteristics of the potential active edge conditioned largely the fragments selection. Conversely, the shapes and characteristics of the retouched elements (or 2GNB) were designed according to a mental scheme based on effectively achieving the planned activities. Indeed, there is limited variability in typological terms, as only simple forms were considered.

Complementarily, the bone breakage pattern analysis of the experimental assemblage revealed patterns typical of fresh breakage (Villa & Mahieu 1991). The presence of notches and scars, both on the medullary and cortical surfaces, as well as cortical and medullary flakes, together with the presence of percussion marks on the surface are defining elements of intentional breakage by an anthropogenic agent (*e.g.*, Blumenschine & Selvaggio 1988; Bunn 1983; Pickering & Egeland 2006; Vettese *et al*. 2020). All these elements have been identified in this experimental assemblage. However, both fracture scars and notches were distinguishable from the removals produced during the shaping and retouching of the bone tools in this study. Retouching and knapping did not produce notches; it generated groups of removals of similar sizes, oriented perpendicularly to the edge of the tool and of continuous delineation. In the case of extractions produced during nutrition-related fracturing, both cortical and medullary extractions usually appeared isolated and presented variable dimensions.

The method used in this work was suitable for analysing the experimental set of knapped and minimally modified bone industry. The criteria, which are taken from taphonomic and technological research, make it possible to describe the assemblage based on homogeneous analytical criteria, thus systematising the technological analysis of these assemblages. Other analysis systems, such as those based on morphological typology, may not capture all the variability of the assemblages in sufficient detail (Dibble 1991). Conversely, other works use -without any adaptation- common methods applied in studies of lithic industry to investigate minimally modified bone tools (*e.g.*, Pante *et al*. 2020; Sano *et al*. 2020; Villa *et al*. 2021).

The LAS has been applied to the study of Pleistocene lithic industry assemblages (*e.g.*, Ollé *et al*. 2013) but, until now, it had not been applied to bone industry studies. It has been used, partially, in a previous work (Mateo-Lomba *et al*. 2020), to describe the edge morphopotential of a set of experimental bone tools. This work proposes an adaptation of this analysis system to a new raw material. This represents a new step in terms of describing the attributes of the knapped bone tools and minimally modified bone industry, looking for standardised procedures and considering those tools within their operational sequence. It is therefore a methodological proposal to systematise the study of these artefacts with defined criteria, as proposed by Romagnoli *et al*. (2015) for the study of various materials such as shells.

The criteria suggested by Villa *et al.* (1999) and Villa & Bartram (1996) for identifying the knapped bone industry were mostly technological, including the recognition of the classical attributes used to study lithic industry. Our results indicate a coincidence between their criteria and those presented in this paper. For retouched tools (2GNB) we consider:

(a) continuous and regular delineation of the retouching,
(b) more complex reduction strategies such as bifaciality and
(c) bipolar or even multipolar removals,
(d) as well as a certain degree of symmetry to be the most diagnostic criteria for identifying knapped bone artefacts.

Another diagnostic element is the identification of sets of wide, parallel striations, concentrated at one point of the active edge, arranged perpendicularly or obliquely to that edge, and located on the face opposite a removal (Mateo-Lomba *et al*. 2020: fig. 5). In our experimental sample, other elements, such as the size, depth and angle of the retouches were quite heterogeneous characteristics, so these should be considered secondary diagnostic elements when studying this type of tool. In this vein, results obtained from other bone tool knapping experiments (*e.g.*, Baumann *et al*. 2020) have highlighted that there are differences in the scars produced on the knapped bones when using hard or soft hammers. Hard hammers, such as those used in our experiment, produce marginal removals whereas the use of a soft hammer would produce plainer and more extensive retouches, or scaly morphology. Moreover, the presence of notches and scars on both the cortical and medullary surfaces could also originate through the action of anthropic or non-anthropic agents (Capaldo & Blumenshine 1994; de Juana & Domínguez-Rodrigo 2011; Galán *et al*. 2009; Moclán &

Domínguez-Rodrigo 2018; Pickering & Egeland 2006), so this cannot be used as a determining criterion.

Experiments on knapped bone tools are essential for understanding how bone responds to different manufacturing techniques. Bone knapping has been revealed as a task that requires some skill and adaptability due to the different physical properties with respect to the knapping of lithic raw materials. Although several bone knapping experiments have been published (see references in the Introduction), few describe the products obtained (Baumann *et al*. 2020; Freeman 1983; Sadek-Kooros 1972; Vincent 1985; 1993; Walker 1999: 26-34). These works report the process involved in the experiment and the type of retouching achieved with different degrees of detail, sometimes pointing out the difficulties encountered in controlling the knapping due to the anisotropic nature of the bone blank. The majority employed freehand retouching through direct percussion, except for Romandini *et al*. (2014) who retouched the tools while they were supported on an anvil. In this sense, it would be interesting to perform more knapping experiments using anatomical elements belonging to larger animals and using soft hammers. A greater thickness of cortical surfaces would allow us to explore other types of configurations and create experimental sets similar to some of the most paradigmatic archaeological knapped bones, such as those from Olduvai Gorge (Pante *et al*. 2020), Konso (Beyene *et al*. 2013), Castel di Guido (Radmili & Boschian, 1996: 145-164); Fontana Ranuccio (Biddittu *et al*. 1979), Bilzingsleben (Brühl 2003).

5. Conclusions

The technological analysis method explored in this work represents a starting point for the analytical and systematised description of the technical characteristics reflected in the knapped bone tools. By using the LAS, an analysis of each tool is proposed, inserting it into the process of its operative chain and without having to resort to typological classifications, which can be problematic on certain occasions, as in the case presented here of minimally modified bone artefacts. Furthermore, adapting a lithic industry analysis system to bone industry allows for a synchronic and diachronic comparison between sets of artefacts obtained from different raw materials at archaeological sites. Thus, new information is added to our understanding of the technical and economical behaviours in each assemblage considering all artefacts recovered from archaeological contexts.

This research combines terminology and analysis criteria extracted from taphonomic and lithic technology studies, allowing future comparations between tool assemblages made from different raw materials. Consequently, bone artefacts are described from a holistic perspective, considering their own characteristics as well as those of the operative chain.

We hope that this new proposal for the interdisciplinary study of knapped bone tools can contribute to the recognition of minimally modified bone tools in archaeological contexts and to solve some of the problems of equifinality recognised in some assemblages containing pseudo-tools.

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Elaboración experimental de herramientas óseas: una propuesta de principios analíticos tecnológicos para los huesos tallados

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Resumen:

Desde los orígenes de la tecnología, los grupos humanos han utilizado una gran variedad de materias primas líticas y orgánicas para fabricar herramientas. En particular, el hueso se utilizó como materia prima para crear artefactos tallados. Sin embargo, el reconocimiento de estos elementos tecnológicos en el registro arqueológico ha generado cierto debate, ya que la tafonomía moderna ha demostrado que ciertos agentes no antrópicos generan modificaciones que pueden ser muy difíciles de distinguir de las herramientas óseas talladas. Por esta razón, los criterios de identificación de las herramientas y pseudo-herramientas arqueológicas en hueso aún no han sido claramente definidos.

Como contribución a este tema, presentamos aquí los resultados de un programa experimental de fracturación antrópica intencional de 45 huesos largos de vaca frescos y semi-frescos. El objetivo de esta actividad era doble: la obtención de la médula y de fragmentos óseos diafisarios. Algunos de estos fragmentos se escogieron para ser utilizados directamente como herramientas, mientras que otros fueron seleccionados como soporte. A continuación, los soportes se retocaron mediante percusión directa con percutor lítico. El objetivo de este experimento era describir el proceso de elaboración de herramientas óseas y, asimismo, describir los propios útiles simples y retocados obtenidos experimentalmente de acuerdo con criterios tecnológicos. El enfoque del análisis tecnológico se basó en una adaptación del Sistema Analítico Lógico (SLA), que utiliza categorías estructurales dentro de una cadena operativa en lugar de ceñirse a características tecno-tipológicas. El SLA se ha utilizado habitualmente para analizar conjuntos líticos del Pleistoceno mediante una serie de principios analíticos, y aquí se aplica por primera vez al estudio de la industria ósea tallada, aunando también criterios empleados por la tafonomía en el análisis de la fracturación de huesos largos.

Los datos presentados en el presente trabajo consisten en una descripción del conjunto experimental de acuerdo con la metodología interdisciplinar que se propone. Se han realizado un total de 112 herramientas óseas, tanto BP1G (lascas) como BN2G (elementos retocados). Se trata de un conjunto heterogéneo, marcado por morfologías y tamaños condicionados por la propia naturaleza de los soportes y la técnica de fracturación, pero también por el esquema mental de las actividades que se planea hacer con ellas.

Los resultados aportados nos permiten presentar nuevos criterios analíticos con los que describir las herramientas óseas simples y retocadas desde una perspectiva holística, combinando terminología tecnológica y tafonómica. Nuestra intención es mejorar los criterios para diferenciar los útiles óseos tallados de otras modificaciones generadas por agentes no antrópicos y que pueden llevar a interpretaciones erróneas sobre los agentes formadores de los yacimientos arqueológicos. En este sentido, para las herramientas retocadas consideramos que las características más diagnósticas serían: delineación continua y regular del retoque, estrategias de reducción más complejas como la bifacialidad o la presencia de extracciones bipolares o multipolares, como también un cierto grado de simetría. Además, estos criterios de análisis permitirán comparar conjuntos de artefactos de diferentes materias primas, incluyendo las líticas. El objetivo final de este estudio es profundizar en el estudio interdisciplinar de los útiles óseos mínimamente modificados, proponiendo un método tecnológico para el estudio de las herramientas en hueso talladas.

Keywords: herramientas óseas; tecnología; tafonomía; metodología; Sistema Lógico Analítico; talla