# *DO PATTERNS OF BONE BREAKAGE DIFFER BETWEEN COOKED AND UNCOOKED BONES? AN EXPERIMENTAL APPROACH*

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## *Summary*

*This paper presents results from controlled experiments on breakage of cooked and uncooked (fresh) bones. The data do not uphold the distinctions between cooked and uncooked bones noted in some ethnoarchaeological studies. Spiral and longitudinal fractures are equally frequent in cooked and uncooked (fresh) bones. The fracture patterns of bones may be influenced by many factors, including the unique structure of each skeletal element, species of animal, and specific treatment of the bone. The experiments demonstrate that the pattern of fractures should not be used as the sole means to determine whether an archaeological specimen of a bone was fractured before or after cooking.*

## *Résumé*

***La morphologie de la fracturation osseuse diffère-t-elle sur les os frais et les os cuits ? Une approche expérimentale.***

*Cet article présente les résultats d'une expérimentation, en conditions contrôlées, sur les fractures qu'on peut observer après rupture d'os frais ou cuits. Les données obtenues ne confirment pas les différences que certains chercheurs avaient remarquées sur la base d'observations ethnographiques. En effet, les fractures longitudinales et spirales sont aussi fréquentes sur les os frais que sur les os cuits. La morphologie des fractures peut être influencée non seulement par la cuisson mais aussi par plusieurs autres facteurs comme la structure des divers éléments squelettiques, l'espèce de l'animal et le traitement spécifique de l'os. Les expériences effectuées montrent que la morphologie des fractures ne peut pas être utilisée comme seul moyen pour identifier si un os de provenance archéologique a été fracturé avant ou après la cuisson.*

## *Zusammenfassung*

***Unterscheiden sich die Frakturmerkmale gekochter und roher Knochen? Ein experimenteller Beitrag.***

*In diesem Beitrag werden Versuchsergebnisse zu den Brucheigenschaften gekochter und roher Knochen vorgestellt. Die Resultate bestätigen Unterschiede, welche schon bei ethnoarchäologischen Untersuchungen festgestellt worden sind, nicht. Zum Beispiel kommen Längs- und Spiralbrüche bei erhitzten und rohen Knochen gleichermaßen häufig vor. Die Morphologie der Brüche wird sowohl durch den Knochen selbst, als auch durch andere Faktoren wie Skeletteil, Tierart und Vorbehandlung bestimmt. Die Versuche haben gezeigt, daß die Bruchmuster nicht zur Unterscheidung gekochter und roher Knochen herangezogen werden können.*



## *Key Words*

*Bone fracture pattern, Uncooked (raw bones), Cooked bones.*

## *Mots clés*

*Morphologie des fractures des os, Os frais, Os cuits.*

## *Schlüsselworte*

*Bruchmuster bei Knochen, Rohe Knochen, Gekochte Knochen.*


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The importance of the analysis of bone breakage patterns in zooarchaeological studies was recognized since the beginning of this century. Pioneer experiments on bone fracture were performed by Martin (1910) (using original hammerstones from La Quina) in order to explain the occurrence of particular shapes of bone fragments in French Paleolithic sites. Later on (e.g. Breuil, 1939; Dart, 1957, 1959) the presence of particular kinds of fractures have been used to argue for hominid accumulation of bones and their subsequent use as tools. More recently this same kind of research has been very controversial in debates regarding the peopling of the Americas (e.g. Bonnichsen, 1979; Morlan, 1980; Irving *et al.*, 1989).

That humans are not the only agent of bone fracture was acknowledged already by Pei (1938), but his example was followed only recently when several studies were focused on the investigation of geological (stream action, rock falls, etc.) and biological processes (especially carnivore action) that can cause bone modification (e.g. Bonnichsen and Sorg, 1989, and references therein). Furthermore, bone structure itself and its properties as a material subject to different kind of stresses are now being considered with more attention by several authors (e.g. Bonnichsen, 1979; Morlan, 1980; Johnson, 1985; Gifford-Gonzalez, 1993).

Recently Gifford-Gonzalez (1993) pointed out that, despite the extensive literature on bone breakage, there are still many gaps that need to be filled with further research. In particular very few studies (e.g. Gifford Gonzalez, 1989; Oliver, 1993) focus on how bone fracture patterns are influenced by food processing strategies (e.g. cooking).

In their papers Gifford Gonzales (1989) and Oliver (1993), analyzing bones from Dassenetch and Hadza camps respectively, reported different patterns of breakage for cooked and uncooked bones. The cooked ones showed a transverse fracture with a rough edge (usually associated with dry bones), while raw bones displayed a spiral and smooth morphology (often attributed to green bones). The authors suggested that the peculiar pattern found in cooked specimens could be related to variations of moisture content and to changes in the microscopic structure of the bone caused by heating that produces an accelerated "aging" and therefore a response to stresses that is similar to dry or fossilized bones; but they assume that other factors may be important as well.

If the difference in fracture morphology between cooked and raw bones is easily identifiable and actually verified, several applications to archaeological studies will become possible: for example, it could be investigated when early fire started to be used for cooking and in general more information could be obtained on details of food processing activities.

In order to give a contribution to fill the gap evidenced by Gifford-Gonzalez (1993), and with the aim of testing the possibility of an evaluation of the difference between cooked and raw bones, controlled experiments on breakage of roasted limbs were conducted.

## Materials and methods

For the present work, 20 lamb (*Ovis aries*) "hind-shanks" (tibia and metatarsal) were used.

In the first part of the experiment eight intact hind-shanks were roasted, during periods of different lengths of time, in a conventional oven preheated at a temperature of 200°C. The temperature of the meat near the bone was measured at regular time intervals. The meat was then stripped from the bone and the tibia and metatarsal were disarticulated. Meat and bones were weighed before and after cooking. The bones were then broken by striking them with a round hammerstone (weight ≅ 0.5 Kg) while holding the proximal end and with the distal epiphysis resting on a stone anvil. The position of the last blow (i.e. the one that actually broke the bone) was recorded. The experiments always stopped as the bone was broken (usually resulting just in the proximal and distal segments, rarely with some splinters) and fracture patterns were observed.

As a reference, five fresh bones were defleshed, bone and meat were weighed separately and the bones were then broken with the same technique as the cooked sample.

Since in some ethnographic cases the meat is removed from the bones before they are cooked (e.g. Binford, 1978; Zierhut, 1967; Oliver, 1993), an experiment simulating this situation was also carried out. The meat was stripped from seven bones, meat and bones were separately weighed, and the bones were then cooked for different lenghts of time in the oven preheated at its maximum temperature (slightly over 230°C). After they cooled off, the bones were weighed again and then processed as before.

The description of the pattern of bone fracture is a complex problem since the approaches used by different authors are variable and there is no agreement about the exact meaning of the terms and methods employed (Biddick and Tomenchuk, 1975; Bonnichsen, 1979; Morlan, 1980; Myers *et al.*, 1980; Shipman *et al.*, 1981; Marshall, 1989; Villa and Mahieu, 1991). Following Gifford-Gonzalez (1989), in this paper bone fractures are described using terms such as spiral, transverse, longitudinal, irregular for the general outline, and smooth or rough for the edge surfaces; however, because of the complexity of the breaks, it was sometimes necessary to combine different terms.

## Results and discussion

In table 1 weight data, time of cooking, and final meat temperature for the eight bones cooked in the oven with the meat on are reported. The mean total weight loss after roasting (i.e. water and melted fat) was 23%. In table 2 indications of the weight of the five raw specimens are given and in table 3 the corresponding information for the sample of seven bones cooked without meat together with the time of exposure to heat are listed. In this last case, bone weight loss ranged from 6% to 16% according to roasting time and initial mass of the hindshank.

In the same tables there is also the description of fracture morphology for tibiae and metatarsals. As it is possible to observe from the reported results, no major difference was detected in the fracture morphology of the three sets of bones. Despite the use of the same method to break tibiae and metatarsals of all samples, the pattern of the fracture was very variable (tabs. 1, 2, 3) with a prevalence of spiral and longitudinal breaks. Transverse fractures that, as reported above, are said to be associated with cooking, were very rare (only one from each set of tibiae (fig. 1) and one on a proximal metatarsal). Even though in the roasted specimens transverse breaks were actually present on the bones that were heated for longer periods of time, this kind of fracture was found also on a raw tibia.

It is interesting to point out that the preliminary experiments carried out with lamb bones roasted without meat on an open fire followed a similar trend: transverse breaks were in fact present on the specimens cooked for longer periods of time, but also in that case some raw bones displayed this kind of morphology.

The great variability of the fractures observed in the three samples and the fact that very often the morphology appeared to be irregular suggested that actually many factors may affect, in different degrees, the shape of the break. In this sense, according to these experiments and to the data reported in the literature, the processing method employed, the skeletal element, the species, the age of the animal as well as the state of the bone (e.g. fresh, dry, cooked, raw, mineralized) appear to be relevant in fracture patterning, as it will be discussed below in more detail.

*Processing method*. The different methods of breaking bones reported in the literature (e.g.) hammerstone and anvil, bone suspended between two anvils and hit with a stone, bone struck against a hard object, "crack and twist" (Dart, 1957; Sadek-Kooros, 1972; Bonnnichsen, 1973; Binford, 1981) do not seem to produce different morphologies and there are even some examples of the lack of a strong relationship between cooked bones and transverse fractures (Dart, 1959; Bonnichsen, 1973). On the other hand, as in this experiment, the same method of breakage may produce different patterns.

Probably, more important factors in shaping the fracture on the bone seem to be the tool used and the purpose of the break. For example Gifford-Gonzalez (1989) suggested that a cause of transverse-rough breaks, found in the assemblage that she analyzed, could be the use of pangas instead of hammerstones. Furthermore, longitudinal frac-

Table 2: Raw bones. SP = spiral; T = transverse; L = longitudinal; I = irregular; R = rough; S = smooth.

| Specimen | Total weight (kg) | Pattern Tibiae | | Pattern Metatarsals | |
|---|---|---|---|---|---|
| E | 1.090 | SP | S + R | SP-I | R |
| F | 0.750 | SP-L-I | S | SP-I | R |
| M | 0.840 | I-SP | S + R | SP-I | R |
| N | 0.600 | SP-I | R | SP | R |
| O | 0.525 | T-I | S + R | SP | R |

Table 1: Bones cooked with meat on (oven temperature 200°C). SP = spiral; T = transverse; L = longitudinal; I = irregular; R = rough; S = smooth.

| Specimen | Total Weight (kg) | Cooking Time (min) | Meat Temperature (°C) | Pattern Tibiae | | Pattern Metatarsals | |
|---|---|---|---|---|---|---|---|
| A | 0.820 | 90 | 76.7 | SP | S | SP | S |
| B | 0.860 | 75 | 71.2 | SP-L | S | SP-L | S |
| C | 0.625 | 90 | 82.3 | SP-I | R | SP-I | R |
| D | 0.700 | 75 | 76.7 | SP-L | S | SP-I | S |
| G | 0.800 | 60 | 71.2 | SP-I | R | SP | R |
| H | 0.750 | 105 | 83.4 | SP-L-I | S | SP-L | R+S |
| I | 0.780 | 60 | 66.7 | SP-I | S+R | SP-I | R |
| L | 1,000 | 105 | 82.3 | T-I | S | SP | R |

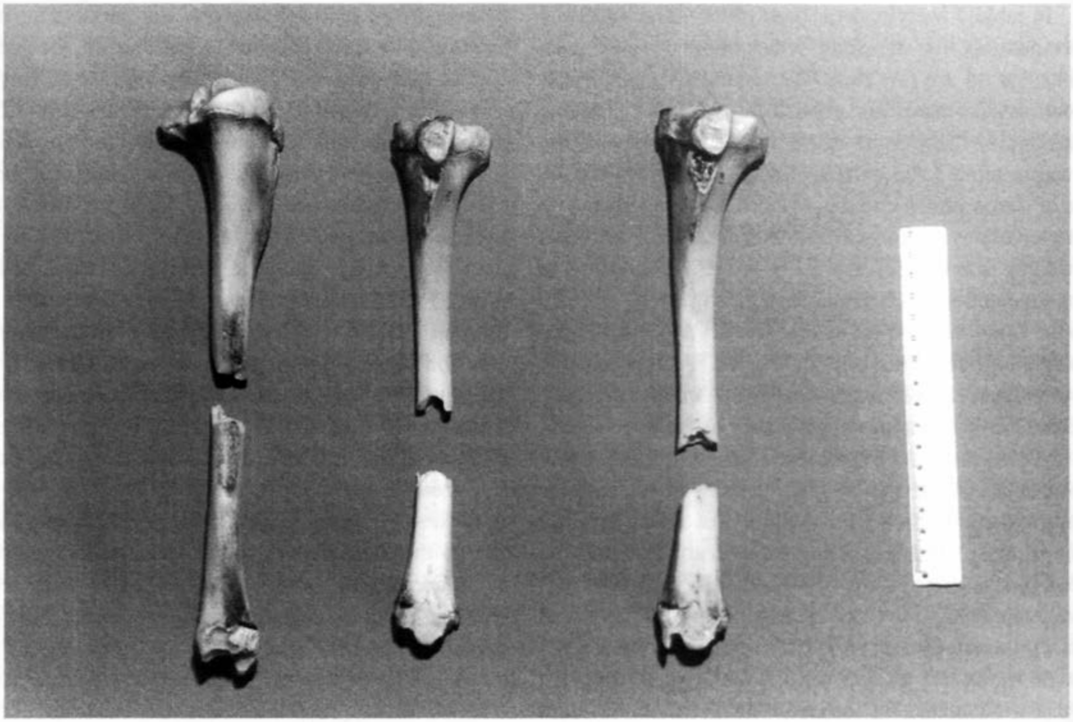

Fig. 1: Experimental lamb. Tibiae showing transverse fracture pattern (from left to right: specimens L, O, R).

Table 3: Bones cooked without meat on (oven temperature > 230°C). SP = spiral; T = transverse; L = longitudinal; I = irregular; R = rough; S = smooth; d = distal; p = proximal.

| Specimen | Total Weight (kg) | Cooking Time (min) | Pattern Tibiae | | Pattern Metatarsals | |
|---|---|---|---|---|---|---|
| P | 0.550 | 20 | I-SP | R | dSP R // pT | R |
| Q | 0.700 | 20 | I-SP | R | SP | R |
| R | 0.725 | 30 | T-I | R | SP | R |
| S | 0.850 | 15 | SP-I | R | SP-L | R |
| T | 0.800 | 20 | SP-I | R | L-I | R |
| U | 0.850 | 25 | SP-L-I | S + R | I-SP | R |
| V | 0.875 | 30 | SP-I | R | I-SP | R |

tures may be created in some bones (e.g. metapodials, radii), when they are hit along the shaft or on the proximal epiphysis, in order to expose the marrow more completely (Noe-Nygaard, 1977; Stiner, 1994; and personal observation on archaeological specimens); while transverse fracture may be produced intentionally when processing carcasses for boiling (Stiner, pers. comm., 1994).

As far as the present experiment is concerned, many specimens displayed an irregular breakage pattern (tabs. 1, 2, 3) that in many cases was due to the presence of a transverse portion within a general regular morphology. Such transverse portion of the break was usually associated with the location of the last blow in both cooked and raw specimens even though a round hammerstone was always used (fig. 2).

*Skeletal element.* It is well known that different bones of the same individual are built in different ways in order to play their specific role during the life of the animal, and even within the same bone different portions may react differently to stresses.

In the experiments reported in this paper, tibiae and metatarsals from the same animal - thus processed in the same way - in some cases showed different fracture morphologies (tabs. 1, 2, 3; fig. 3) that presented almost always a rough surface in the case of the metatarsals. The analysis of breakage morphologies indicated that the pattern presented by the tibiae was usually more regular than that observed on metatarsals: in fact the latter ones often presented a transverse portion of the break on the posterior side of the bone where the walls of the marrow cavity are thinner (fig. 2, bottom row).

It must be also pointed out that ethnographic information reports that different skeletal elements may be treated differently according to the situation, the personal taste and cooking procedure (e.g. Yellen, 1977, 1991; Binford, 1981; Jones, 1993) and therefore the resulting fragments are the products of these different strategies.

*Taxon*. The bones of animals of different species have their specific densities (Kreutzer, 1992; Lyman *et al.*, 1992) and mechanical properties (Currey, 1984), therefore they can display different break morphologies when fractured, nevertheless preliminary experiments, carried out with cattle and horse bones (raw and cooked without meat), showed patterns that were similar to those obtained with the lamb samples. Furthermore, different taxa may be processed for food with different tools and methods according to their size, quality and quantity of marrow, etc. (Marshall, 1986; Yellen, 1991; Oliver, 1993).

*Age*. Bone composition varies with age mainly because of changes in mineralization; as a consequence also mechanical properties may change dramatically (Currey, 1984). All individuals used in the present investigation were yearlings and the prevalence of spirals may be due to their young age.

*State of the bone*. What changes may occur as a consequence of roasting? The first one is, of course, moisture

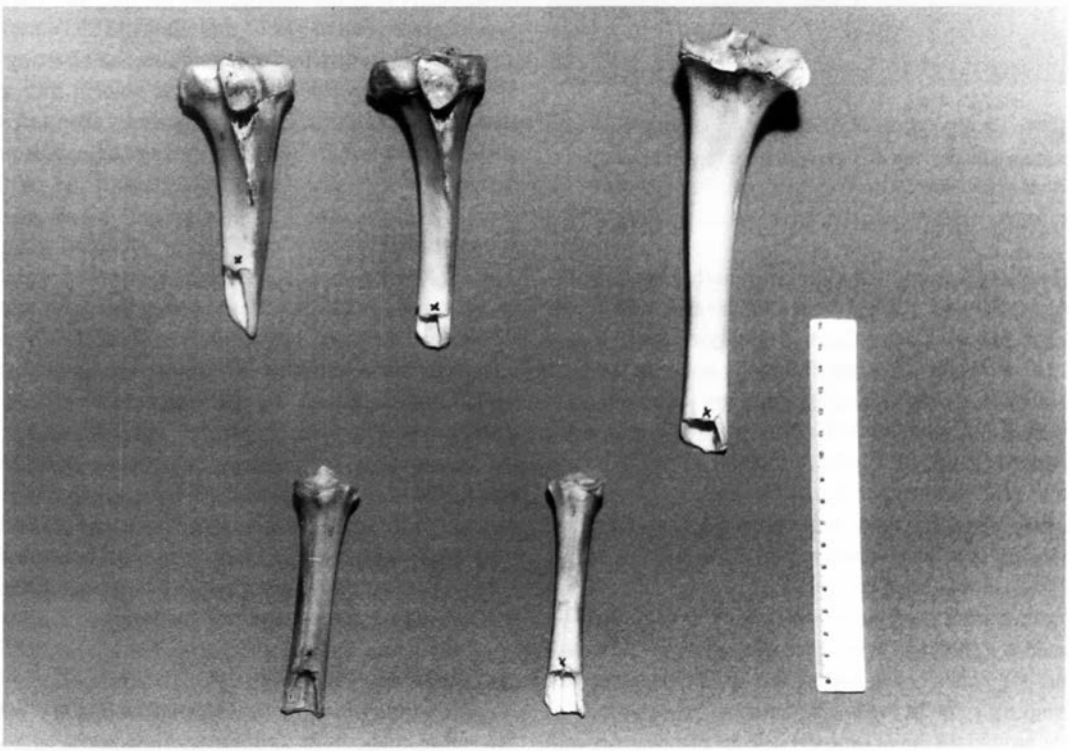

**Fig. 2**: Experimental lamb. Tibiae and metatarsals showing the transverse portion of the fracture in coincidence with the position of the last blow (marked with an X) (from left to right: tibiae A, I, E; metatarsals Q, L). The metatarsals display a transverse part also on the opposite (posterior) side of the bone.

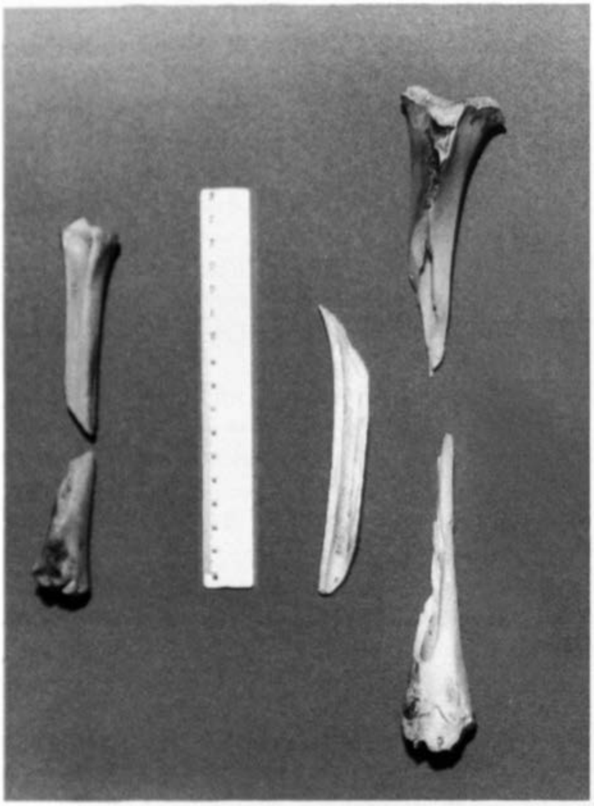

Fig. 3: An example of experimental lamb. Tibia and metatarsal displaying different patterns (specimen D).

loss. The morphology of the breaks reported by Gifford-Gonzalez (1989) for cooked bones (transverse with rough edge) is in fact similar to that commonly ascribed to dry bones. Nevertheless, also the difference between dry and fresh is not clearcut because sometimes dry bones may display green bone fractures (Myers *et al.*, 1980; Shipman, 1981; Stanford *et al.*, 1981; Haynes, 1983) and fresh bones, when the breaks are not parallel to the direction of collagen fibers, may show fractures with irregular and splintered contours similar to those observed on dry bones (Shipman, 1981).

Another important question is how dryness can be influenced by cooking: as pointed out before, weight loss after roasting bones is due both to the loss of water and fat. Furthermore it should be considered that the presence of the meat around the bone protects it from extreme desiccation that may occur to the specimens roasted without meat.

Gifford-Gonzalez (1989, 1993) suggested that also heat may cause changes in the structure of the bones that may in turn influence fracture patterns. During the experiments with lamb hindshanks, the temperature actually reached by the bones during roasting in the oven, especially in the case of the specimens with meat on (tab. 1), may be not sufficient to induce, in the bone structure, remarkable alterations (Shipman *et al.*, 1984) capable to cause differences in the breakage morphologies. This hypothesis can be supported by the studies of Sedlin (1965) who asserted that the effects of heating on physical properties of bones are reversible at least within a certain range of temperatures. Furthermore, while fish bone collagen starts to melt at 60°C, mammalian bone collagen is probably more resistent (Richter, 1986). At the same time, Villa *et al.* (1986) reported that aminoacid analysis of modern samples of cooked bones showed cromatographs identical to unheated samples, and Bonar and Glimcher (1970) evidenced that X ray diffraction patterns of samples of bone collagen heated up to 80°C were identical to those of unheated specimens.

Although bones cooked without meat may be exposed to higher temperatures, especially when layed directly on the bed of coals, it should be considered that the treatment lasts usually only for short periods of time (i.e. 1-5 minutes according to Yellen, 1977 and Jones, 1993) and consequently they may not show evidence of charring (Kent, 1993). It is therefore possible that also in this case the structure of the bone is not remarkably changed, as suggested by the results obtained during the experiments on the open fire.

## Conclusions

Results obtained from the controlled experiments on breakage of lamb hindshanks, together with an evaluation of the data present in the literature, do not seem to uphold a clear distinction between the fracture patterns of cooked and raw bones. Many different factors, such as processing method, skeletal element, species and age of the animal as well as wether bones are cooked or raw, may be concurrent in shaping the fracture morphology. Therefore it is suggested that, although further research is needed, the relationships transverse break - roasted bone and spiral break - raw bone appear at present not strong enough to be used alone in archaeological interpretations.

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