Chapter 15
Culinary Processing and Preservational Effects on Bone

Most discussions of technology in relation to animals in hominin evolution focus on those of animal *acquisition* – cooperative hunting, projectile weapons, traps, fishing and fowling tools. Less attention has been accorded to uniquely human *processing* technologies and techniques that enhance or extend nutrient availability from animal tissues – earth ovens, stone-boiling, heat-retentive stone and ceramic cooking ovens and vessels, management of fermentation. The latter are equally unique to genus *Homo* and have supported distinctive features human physical and social evolution for over 2 million years.

As used here*, culinary processing* refers to the handling animal tissues for consumption after carcass acquisition and butchery and before consumption. "Culinary processing" is preferable to "cooking" because not all such handling of animal tissues involves the application of heat. Extracting and whipping marrow before consumption, for example is a culinary technique that do not involve heating. With culinary processing, *preservational processing* permits deferred consumption of animal tissues by impeding bacterial decomposition, as in drying meat into jerky or mincing jerky to mix with other ingredients for deferred consumption, or by governing its course, as cheese-making or meat fermentation. Preserved foods can be transferred to consumers outside the immediate social circle of their production as gifts, reciprocal exchanges, or commodities for market.

Chapters 14 and 15 artificially divide the continuum of human animal processing, simply to break up a large body of material into more manageable segments. This chapter actually argues for a *chaîne opératoire* approach that unites primary and secondary butchery with culinary and preservational processing, thereby facilitating functional analysis of the end products that archaeologists analyze. It opens with an evolutionary perspective on technologically aided food preparation. This is followed by discussions of gaps in zooarchaeological knowledge of heat-aided culinary handling. It next presents a case for the use of a *Chaîne opératoire* approach. It then outlines the nutritional advantages of pyrotechnical culinary processing and

D. Gifford-Gonzalez, *An Introduction to Zooarchaeology*,
https://doi.org/10.1007/978-3-319-65682-3_15

preservational processing, followed by a survey of distinctive signatures of culinary and processing on bone. The chapter ends with a discussion of whether and how culinary processing can be discerned archaeologically.

15.1 Culinary Processing in Evolutionary Perspective

Culinary processing of all types is a kind of "outsourcing" of the digestive process and pre-processing of meat has considerable antiquity in our ancestry. Hammerstone percussion marks and cut marks on two-and-a-half million year-old African ungulate testify to hominin extraction of marrow and removal of muscle, preceding the use of fire by 1–2 million years (Semaw 2000; de Heinzelin et al. 1999). Slicing up raw meat before consumption requires no more than a simple stone flake, and pounding before mastication only involves a hammerstone and anvil.

Heat-aided culinary processing is widely understood to confer evolutionary advantages by enhancing nutrient availability and reducing risk of bacterial and parasitic infection (see 15.4 **Nutrient Gains through Culinary and Preservational Processing**). Less apparent than these is the radical reduction of the time and energy spent on mastication that pre-processing techniques and technology confer on genus *Homo*. Wrangham (2009:139–142) notes that chimpanzees spend on average 6 h a day chewing the raw fruits and leaves comprising their diet, whereas humans spend 0.6–1.2 h a day chewing cooked or otherwise pre-processed foods. The divergence between genus *Homo* and earlier hominins' chewing-related energy expenditure appears to have begun in Africa 1.9–1.8 million years ago, with *Homo erectus*, a species that spread from Africa into temperate western and tropical east Eurasia by 1.7 million. *Homo erectus* fossils present a paradox: their bodies and brains are about 50% larger than those of earlier hominins, which would demand much more energy to maintain, yet their fossils have smaller teeth and osteological evidence for reduced chewing muscles and gut size, compared to those of earlier hominins. Paleoanthropologists agree that these traits testify to a major dietary shift but debate what, specifically, enabled it nearly 2 million years ago. Wrangham (2017) and his coworkers (e.g. Carmody et al. 2011) contend this anatomical transition was enabled by fire-mediated food processing from the very emergence of the *H. erectus* lineage. This assertion is complicated by lack of direct evidence for control of fire before 500,000 years ago. Others have proposed this shift could have been enabled by incorporating substantially more animal foods into the diet before the regular use of fire (Leonard et al. 2007; Ungar et al. 2006), or by new social behaviors facilitating food sharing (Leonard et al. 2007).

Using human lab volunteers, Zink and Lieberman (2016) explored whether technologically aided pre-processing (pounding, slicing,) without heating could reduce the masticatory stresses imposed by the raw diets of foods suggested for pre-*Homo erectus* hominins by dental wear and stable isotope studies: tubers and other roots, or "underground storage organs" (USOs), and meat. Experimental subjects were monitored for the number of chews and the muscular force exerted while chewing varied samples until the subject felt ready to swallow. They then spat out the chewed bolus, each of which was assessed for particle size and structure. Pre-processing trials were first done with raw USOs and meat, presented in unmodified chunks, pounded, and sliced forms. Outcomes were compared to those of trials using cooked USOs and meat in the same forms. Zink and Lieberman found that slicing raw meat improved subjects' ability to chew it into smaller particles, being on average 41%, more efficient than pounding. For raw USOs, pounding was more efficient than slicing and would have reduced the number of chews per year by 5% and simultaneously lowering mastication force demands by 12%. Zink and Lieberman argue that increasing (sliced) raw meat consumption could have significantly reduced *Homo erectus* chewing cycles per year, estimating that increasing meat to one-third of dietary intake diet would have reduced chews by 13% and masticatory force exerted by 15%. Such a proportion of meat in the *Homo erectus* diet is probably unrealistically high, even considering scavenging and hunting together as sources of animal foods. However, the experiment showed that non-pyrotechnical food processing with simple tools confers a significant reduction in the time and energy spent processing food.

One hint that that pre-cooking meat processing and consumption could have existed in significant levels was reviewed in Chap. 5: the zoonotic transfer of *Taenia simbae* from the large African carnivore – ungulate cycle into hominins, where it evolved into *T. saginata* and *T. asiatica* (Hoberg et al. 2001). *Taenia* genomics estimates this occurred about 1.7 million years ago, coinciding with the first few hundred thousand years of *H. erectus*' existence. Eating an increased amount of raw ungulate meat would have facilitated the entrenchment of this tapeworm into *H. erectus*.

15.2 Gaps in Zooarchaeological Studies of Bone Modification

Because the nutritional benefits offsetting animal acquisition costs are nearly always realized in the context of culinary handling, this area should be an area of considerable interest in studies of animal use by ancient and modern hominins. However, zooarchaeological research on cut mark and bone fracture patterning has preponderantly involved raw carcasses and bones. This probably a reasonable focus for those studying very early hominins, but most archaeofaunal samples younger than 450,000 years were produced by fire wielding hominins (Attwell et al. 2015).

Why does raw versus cooked bone matter? Heat-aided culinary processing can affect bone modifications and frequencies in three ways:

1. Heating shortens collagen fibrils in bone, decreasing elements' resilience under dynamic loading and other stresses, producing different fracture outlines and break surface textures from those in uncooked bone.
2. Heating gelatinizes the collagen fibers in connective tissues, reducing the need for cutting edge to remove muscle from bones. Skeletal elements in carcass

segments cooked "bone-in" may therefore diverge in cut mark rates from the same elements from which raw muscles were removed.

3. Cooking can "reset" the relative nutritive value of body segments compared to their value when raw, resulting in revised decisions about transport versus discard. The advent of cooking technologies could thus alter skeletal element frequencies in transported versus discarded assemblages (Chap. 19). Lupo and Schmitt (1997) report experimental data that suggest a shift in handling vertebrae, which have costs of stripping meat when raw that exceed those of transporting the unstripped segments to base for cooking and easier defleshing.

It is possible that some of the variation in cut mark frequencies on cervid bones reported by Lyman (1995) could result from situational differences in body segment cooking methods, which in turn would have altered the likelihood that cuts would be inflicted. This may be difficult to assess empirically but it is worth exploring with bone color shifts and changes in surface texture, fracture outlines, and break surface texture typical of thermal stress (see Sect. 15.6 below).

Why is our knowledge of raw carcass and bone handling greater than that of cooked carcasses and elements? Paleoanthropological researchers have strongly influenced the last 40 years' zooarchaeological methods, as have studies of mass-processing herd-living ruminants. These include research on prehistoric bison kills (e.g. Frison 1974; Wheat 1972) and Binford's (1978, 1981) actualistic butchery research with Nunamiut people, who obtained over 90% of their sustenance from hunting migratory caribou herds. Mass kills challenge butchers to recover as much from raw carcasses as possible over a short time span, and processing efficiencies approach those of industrial mass production. Mass processing is actually exceptional among most hunting peoples. Ethnoarchaeological research shows most hunting peoples kill a single large animal at a time and at a steadier rate through the year (Bunn 1993; O'Connell et al. 1990; Bartram et al. 1991; O'Connell and Marshall 1989). Chapters 19 and 20 will show that such hunters are often motivated to transport an entire carcass, albeit in parts, from the acquisition locale to a home base for further processing and consumption (Emerson 1993; Lupo 2006). Initial processing and transport decisions are made during primary and secondary butchery when carcasses may be raw. These are influenced by many factors (Chap. 19) including *a priori* knowledge of intended culinary or preservational tactics (Gifford-Gonzalez 1989). Groups with domestic animals slaughter them near where they will be consumed, reducing but not eliminating selective discard (Chap. 19).

Some decades ago, motivated by some "unusual" fracture patterns in an ethnoarchaeological assemblage that I had not directly observed being created – which we now know are breaks on heat-stressed elements – I encountered the lack of investigations on heat-aided bone processing (Gifford-Gonzalez 1993). At that point, the most systematic research on culinary bone modification was that done on human cannibalism (e.g. White 1992), begging the question of why this analytic area had been so weakly developed in zooarchaeology. Besides crediting the factors noted above, I asked whether the raw bone focus might also stem from zooarchaeologists' unconscious privileging of animal acquisition and a reciprocal devaluation of culinary activities, which are culturally gendered activities (see also Montón Subias 2002; Bosch et al. 2011). I noted that, with the exception of Binford (1978) and Yellen (1977) – I would now include Oliver (1993) – even ethnoarchaeological research, including my own, has stinted on deliberate attention to the outcomes of culinary processing. The same question was raised about 20 years later by Graff and Rodríguez-Alegría (2012), in relation to "the menial art of cooking" in archaeology, with an interesting discussion of reasons why. I argued that the problem with researchers' cultural stereotypes that divert attention away from this energetically critical end-stage of food processing is not one of "political incorrectness." The problem is that they produce methodologically flawed analyses. Since then, a number of researchers have advanced understandings of heat-aided culinary processing and its effects on bone, as ensuing sections will attest.

15.3 Vertebrate Bodies, Behavioral Chains, *Chaîne Opératoires*

Binford (1977) stressed that vertebrate bodies present consistent challenges to human consumers, from primary and secondary butchery through further processing operations. Lyman (1987) and O'Connor (1993) reiterated Binford's (1978) point that butchery is not an event but rather a *process*, being a series of acts in a continuum of operations from acquisition of a vertebrate body to post-consumption discard of its bony remnants. Processing and consuming animal bodies requires that tasks be accomplished in a somewhat fixed order – some actions must by necessity precede others. This principle is at the core of Schiffer's (1987) concept of the behavioral chain, Americanist lithic technology studies' "reduction sequence" (Andrefsky 2005), and the *chaîne opératoire*, or operational chain, approach developed in European lithic studies (Lemonnier 1986; Pelegrin et al. 1988), which had also been employed in ceramic analysis (e.g. Habicht-Mauche 2006; Vitelli 2007).

In any given *chaîne opératoire*, some operations cannot be undertaken until others have been accomplished. Knowledge of such sequences derives from prior observations of the material properties and the sequences of operation employed to produce final forms, whether a bifacial stone tool, a ceramic vessel, or a bronze axe head. Each case depends upon the inherently uniform properties of specific material to build expectations about the temporal sequence of operations people must undertake to produce a final product (Gifford-Gonzalez 2008).

These approaches are intrinsically *product-focused*. They generate expectations about the nature and temporal order of processing activities, hallmarks of those stages, and even contexts of the work accomplished in each stage. For example, unsmelted ore, slag, and a finished cast iron hoe blade testify to different stages in the *chaîne opératoire* of iron artifact production. All may not originally occur in the same spatial contexts – e.g. the ore originates in a mining operation, the slag at a smelter location, the finished hoe at a smithy.

Applying the *chaîne opératoire* approach to carcass processing integrates butchery, preservational processing, meal preparation, consumption, and discard operations. Because it is a product-focused approach, it can generate expectations about the *sequence* of human actions on the "raw material" of vertebrate bodies. It approaches modifications to bone as a time-sequenced order, governed in part by anatomy, in part by available tools (Seetah 2008), and in part by the cultural and socially structured choices by the actors involved. It creates expectations about the signatures of sequential processing episodes and to some extent helps define the possible variety of localities at which specific operations can occur. This framework permits zooarchaeologists to ask what stage or stages in a carcass handling sequence are represented in a given sample. To give a concrete example, in tetrapod vertebrates it is virtually impossible to inflict cuts on the ventral surfaces of the ribs and thoracic vertebrae before the rib cage is opened, and the thoracic viscera are removed. Consistent appearance of cut marks on the ventral surfaces of archaeofaunal specimens thus testifies not only to the infliction of cut marks but also, by logical extension, to prior stages in the chain of operations upon an animal carcass, such as extraction of the viscera, which may itself leave no direct evidence. With knowledge of the specific constraints offered by an animal species' anatomy – processing a salmon will differ from processing a sheep – a detailed scenario for such an operational chain can be developed to guide analysis.

In 1993, in the manner of simultaneous inventions, O'Connor (1993) and I (Gifford-Gonzalez 1993), used flow-charts to propose that butchery should be viewed as a sequence of operations producing more or less predictable outcomes. Sadly, we did not immediately convert the entire English-speaking zooarchaeological world to our way of thinking. A decade later, in his critical assessment of the gaps in archaeological study of forager culinary practices, Miracle (2002:67) argued that studies of ancient food and consumption would benefit from a *chaîne opératoire* approach because, "food is material culture created by technical and social acts," further noting:

> The productive and consumptive activities of an individual actor are series of decisions, each historically contingent (to some extent dependent on prior decisions or existing constraints), but always, selected from a range of alternatives.

Seetah (2008) reiterated the call to view butchery as a form of *chaîne opératoire* that begins with an entire animal and ends with meals and other useful products.

Figure 15.1 presents a simple model of the chain of human *actions* affecting an animal carcass in a hunting system, and of the material *modifications* and *discards* that those actions produce. It assumes prey are usually acquired at a distance from the locality to which hunters ultimately return. It does not predict conditions under which various carcass parts may be transported or abandoned (O'Connell et al. 1988, 1990). Such a model creates expectations concerning the *possible products* of each *sequential phase* in the chain of carcass processing. It shows the movement of animal bodies in space as well as through time and uses the term "locale," rather than "site," to denote places where specific processing operations occur. This aims to maintain the distinction between the *places* where human activities occur in a landscape and the *archaeological entities* formed by those activities' material

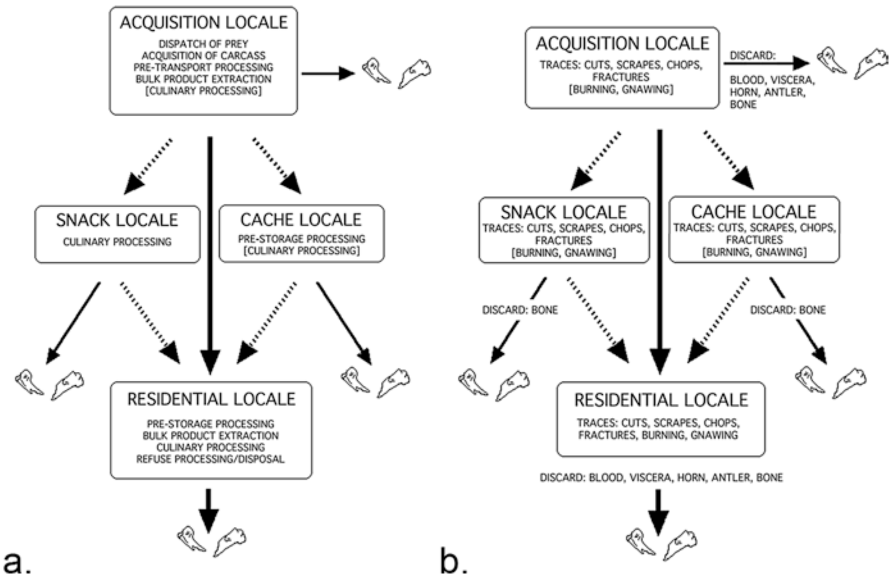

Fig. 15.1 A product-focused approach to following the flow of vertebrates as food, from whole carcass to debris, here exemplified by large hunted prey. (**a**) Frequently occurring locations of acquisition and processing, with expectations of handling occurring at each stage. (**b**) Traces expected to be produced by the handling tactics at each locality (Illustration by author, redrawn after Gifford-Gonzalez (1993:191, 192, Figs. 11.1, 11.2, and 11.3), with permission of Southern Illinois University Press)

by-products and other processes. Schiffer (1987), Binford (1980) and others have noted that archaeological sites are not occupied, they are formed. The operational chain represented in Fig. 15.1 does not collapse these categories because some processing locales may leave few archaeologically visible traces ("sites"), but their existence may indirectly be reflected by attributes of specimens that passed through them and accumulated at another locale. Figure 15.2 shows a similar flow of operations and material effects in a pastoralist system that I have found useful for organizing my thinking about sites documented during ethnoarchaeological research with Dassanetch agropastoralists in northern Kenya. It could also be modified for smaller-scale use of livestock in farming systems. The final stages in this chain of operations reap the nutritional gains of animal acquisition, and these will be dealt with in the next section.

15.3.1 *Functional Inferences from Cut Mark Placement*

The *chaîne opératoire* approach to carcass processing would benefit from any functional interpretations of bone surface modifications that could testify to a stage or stages of the process. However, this has proved more challenging than once hoped.

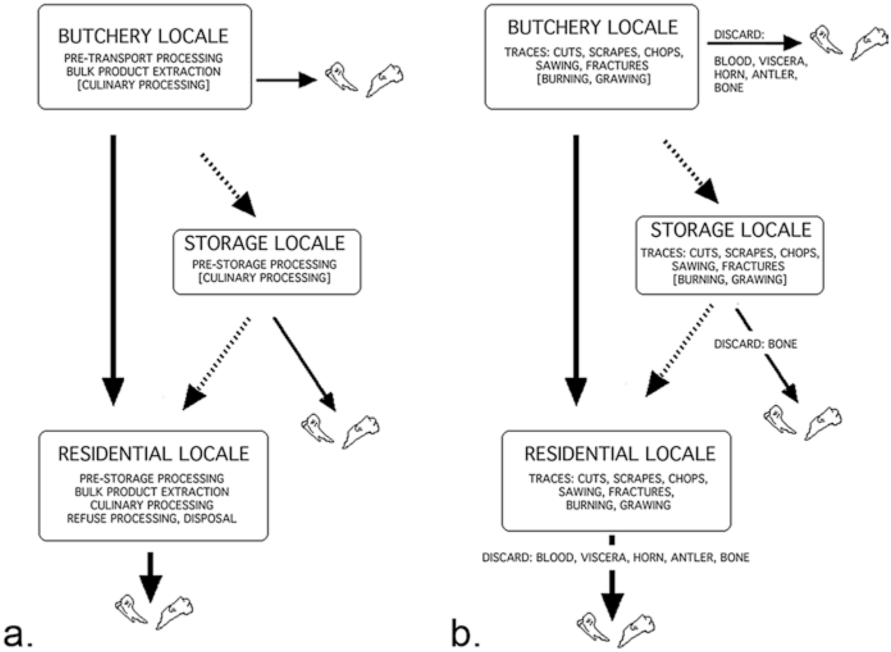

Fig. 15.2 A product-focused approach to following the flow of vertebrates as food, from whole carcass to debris, here exemplified by large domestic prey. (**a**) Common locations of acquisition and processing, with expectations of handling occurring at each stage. (**b**) Traces expected to be produced by the handling tactics at each locality (After Gifford-Gonzalez (1993:193, Figs. 11.1, 11.2, and 11.3), with permission of Southern Illinois University Press)

Cut marks (Chap. 14) can sometimes be read for their functional meaning, but Lyman's caution about their epiphenomenal nature, as well as their situational variability, should be kept in mind. Binford (1981) published an illustrated list of cut and chop marks on caribou skeletal elements processed by Nunamiut people, ascribing each the immediate functional goals: skinning, dismemberment, and defleshing (his "filleting"). His ultimate goal was to build a "dictionary" for inferring similar, functionally oriented behavior from archaeofaunal evidence. Binford acknowledged that this work built on that of Guilday et al. (1962). His approach also followed in the footsteps of Frison and coworkers, who had for some time been inferring the sequence and functional meaning of butchery marks in North American bison kill sites (e.g. Frison and Reher 1970; see also Frison and Todd 1987). Binford's coding system for each mark described its location on a skeletal element that did not impute an intention or goal. However, his illustrations grouped marks according to their function, with cuts on the scapula that he associated with dismemberment illustrated separately from those associated with meat removal (Fig. 15.3).

Some zooarchaeologists began to use Binford's 1981 functional attributions of cut marks to infer the nature of butchery operations undertaken at specific sites. Others contested, amplified, or attempted to systematize cut mark descriptions.

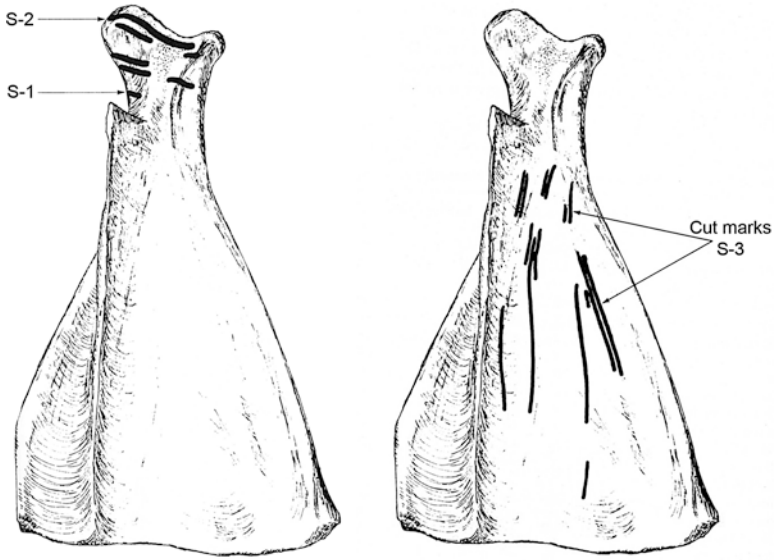

Fig. 15.3 Binford's examples of cut mark placement on the scapula for dismemberment (left) and defleshing (right) (From Binford (1981:98, 122, Figs. 4.6 and 4.29). Used with permission of Estate of Lewis R. Binford and Elsevier/Academic Press)

Many noted that Binford represented cuts only on epiphyseal ends of long bones, while many cut marks associated with flesh removal are on diaphyses (Marean 1998; Blumenschine 1988; Egeland et al. 2004). Thus, Binford's descriptive system omitted the variation produced by divergent tactics of dismemberment and meat removal, falling short of the "uniformitarian" dictionary he'd hoped to produce. Lyman (1987) proposed a numerically coded system to describe the location, orientation, and nature of cuts and other modifications to bone, which could be used in computer data manipulation. I argued that it is best to retain a focus on the soft tissues (muscles, tendons, ligaments) severed, because similar cutting edge interventions can accomplish different goals (Gifford-Gonzalez 1989). For example, the ruminant artiodactyl elbow joint is so tightly buttressed by bone and connective tissue as to prevent dismemberment by simple, transverse cutting. Butchers lacking metal chopping tools may open the inner side of the elbow joint by severing the biceps brachii muscles inserting on the palmar side of the radioulna. This exposed the inner joint for leverage and dislocation. So, although cuts around the biceps muscle insertion on the radius are technically "defleshing" marks, here, they are functionally implicated in dismemberment. Frison et al. (e.g. Frison and Reher 1970) had in fact been describing soft tissues severed by their anatomical names and inferring sequence and function *after* the aggregate of evidence is assessed in light of the knowledge of operations dictated by bison or other artiodactyl anatomy. This approach parallels the longstanding tradition of forensic anthropology and pathology forensic investigators.

It is useful to summarize a few generally agreed upon points regarding the placement and intensity of cuts on skeletal elements and what they tell us about handling. This outline should be read while bearing in mind Lyman's cautions about cut marks as epiphenomena (Chap. 14).

1. Barring the use of metal chopping tools, dismemberment by cutting and chopping usually focuses at or immediately adjacent to the joints of the skeleton (Chap. 19).
2. Removing muscle from long bones often leaves cut marks on diaphyseal surfaces. Mid-shaft cut marks are inflicted when the connective tissue (fascia) that covers muscles and attaches to the periosteum, are repeatedly "snipped" to remove the flesh from the bone.
   a. Dissection class instructors encourage separating fascial attachments manually blunt dissection, using knuckles or the side of the hand to force connective tissues apart. Muscles can be separated from the skin and periosteum with minimal cutting, even in larger animals.
   b. Refraining from cutting avoids breaching fascial "wrappers" of muscles removed, protecting the meat from bacterial and other contamination.
   c. With smaller prey such as rabbits, much muscle removal can be accomplished by hand. Larger-bodied animals require cutting some muscle origins and insertions.
3. Disparate approaches to skinning may be applied when the aim is to remove an entire skin for other uses, as outlined by Binford (1981:106–107).
4. Historic archaeologists note that some body segments used in roasts (with shoulder, pelvic, upper long bones) often display long cut marks, or carving marks, inflicted while portioning a cooked roast (e.g. Crader 1984), a serving style that emerged in the eighteenth century (Deetz 1996).

The next section deals exclusively with heat-aided techniques because non-pyrotechnical meat processing has previously been reviewed in this chapter.

15.4 Nutrient Gains Through Culinary and Preservational Processing

Heating *denatures* protein by weakening its component amino acids' internal bonds, opening their molecular structure to digestive enzymes. Cooking at 40–60 °C (104–140 °F) denatures meat protein, making it more digestible, while cooking at over 65 °C (150 °F) gelatinizes connective tissues' collagen fibers in and around muscles, rendering the meat very tender (Wandsnider 1997). Heating to 65–70 °C (150–178 °F) also kills bacteria and parasites in meat.

In heat-based handling, different artifacts and techniques produce divergent concentrations of retrievable nutrients. Table 15.1 shows the nutrient yields two widely

Table 15.1 Comparison of protein and total lipid yields of various cuts of domestic animal meats in raw, braised (container-cooked), and broiled types of cooking treatment (USDA Agricultural Research Service 2008)

Cut of meat and treatment	Protein (g/100 g)	% Change	∑ lipid (g/100 g)	% Change
Beef, top round				
Raw	21.5	–	9.4	–
Broiled (equivalent to roasting)	30.2	+40%	9.6	+3%
Braised (equivalent to boiling)	33.8	+57%	11.4	+22%
Pork, boneless sirloin				
Raw	20.6	–	6.3	–
Broiled (equivalent to roasting)	30.5	+48%	8.4	+33%
Braised (equivalent to boiling)	26.5	+29%	8.6	+36%
Pork loin, rib, bone-in				
Raw	20.2	–	13.6	–
Broiled (equivalent to roasting)	28.8	+43%	15.5	14%
Braised (equivalent to boiling)	26.7	+32%	15.1	11%
Lamb, leg & shoulder, cubed				
Raw	20.2	–	5.3	–
Broiled (equivalent to roasting)	28.1	+39%	7.3	+39%
Braised (equivalent to boiling)	33.7	+67%	8.8	+67%
Lamb, whole shoulder				
Raw	16.6	–	21.5	–
Broiled (equivalent to roasting)	24.4	+47%	19.3	−10%
Braised (equivalent to boiling)	28.7	+73%	24.6	+14%

used modern cooking methods: *broiling*, roughly equivalent to roasting near a fire, and *braising*, roughly equivalent to pot boiling. Heating drives off the water from meats, concentrating the remaining protein, increasing its digestibility, and retarding spoilage. Broiling in an oven broiler captures hot liquid fats and other fluids in a pan for use in sauces. However, those who barbecue know that meat exposed to an open fire loses these fluids, as they drip into the fire or to the ground. Braising entails browning and cooking meat in a container, capturing the fat and other fluids released during cooking; it differs from stewing only in that it does not add water to the juices from the meat. Table 15.1 shows that container-based cooking generally captures more lipids and yields more available proteins; roasting pork appears to produce more lipids than braising, but this counts the fluids captured in a metal pan, unlikely in pre-ceramic and metallurgic eras. Gains in ease of digestibility and lipid capture confer significant advantages on lactating females and younger children with developing nervous systems (Chap. 5, Leonard et al. 2007; Speth and Spielmann 1983). This may account for the widespread adoption of ceramic and metal containers, even by mobile foragers, in prehistoric and historic times.

Wandsnider (1997) discusses traditional techniques and technologies for processing animals with varying proportions of collagen fibers to muscle and proportions of fat to lean meat. In the first case, she states:

> Muscle with little collagen, such as that attached to the dorsal portion of the spine on a large quadruped, needs only a *brief exposure to moderate temperatures;* broiling, pan-frying, and roasting suffice in this case. When more connective tissue is present, as will be true for most carcasses of wild species, *longer exposure to moist heat* is needed to convert the collagen to gelatin; i.e., braising and stewing is recommended…(Wandsnider 1997:10).

Ethnographies attest to consistently different cooking techniques applied to cuts with differing proportions of fat to protein (Wandsnider 1997:12–14):

1. Species with low lipid to protein ratios were prepared by boiling, as were dried meats.
2. Meats from species with low lipid to protein ratios and slightly less lean species may be roasted for under an hour in ash, hot sand, or over coals.
3. Meats with relatively high lipid to protein ratios were moist-cooked, especially pit roasted.

We associate techniques for handling meat with metal technology – frying pans, cooking pots, stove ovens – but counterparts for these can be found in non-metallurgical, and even non-ceramic technologies. Roasting is done over or near open flame (Fig. 15.4a). Boiling (Fig. 15.4b) can be accomplished by placing heated rocks into tightly woven baskets, hide vessels, or pits lined with clay or hides (Thoms 2008, 2009). Alternatively, stone containers can be preheated in fires for cooking moist foods by remnant heat. Moist heat can be applied using closed containers (the "Dutch oven" technique), by encasing a whole animal or segment in clay and baking it in embers, or pit roasting – with the pit actually being a very large closed container. The latter is an efficient means of cooking large amounts of fatty meat, simultaneously tenderizing the muscle and capturing rendered fat and drippings with plant foods included in the leaf or hide wrapping.

Wandsnider's (1997) ethnographic survey reported that pit roasting of wild animals was seasonal, timed to when the prey were fattest. Very large animals – bison, bears, and pigs – were cooked nearly 24 h. She hypothesized that such prolonged heat treatment would have shortened fatty acid chains via lipid hydrolysis, promoting digestibility by hunting peoples unaccustomed to fatty foods. These ethnographies also testify that pit roasting depended on coordinated labor, often from several households, and it frequently involved feasting.

15.4.1 Marrow Cooking Before Extraction

Oliver (1993) and I (Gifford-Gonzalez 1989) reported roasting of meat-stripped long bones of large ungulates by Hadza foragers and Dassanetch agropastoralists as a method of cooking marrow before consumption, and Yellen (personal communication, 1988) also observed marrow cooking during from his ethnoarchaeological work with !Kung foragers. Hadza individuals placed defleshed long bones of larger ungulates directly in embers of a fire, set them aside to cool, and cracked them open by percussion to extract marrow (Oliver 1993). Exposure to heat shrinks the

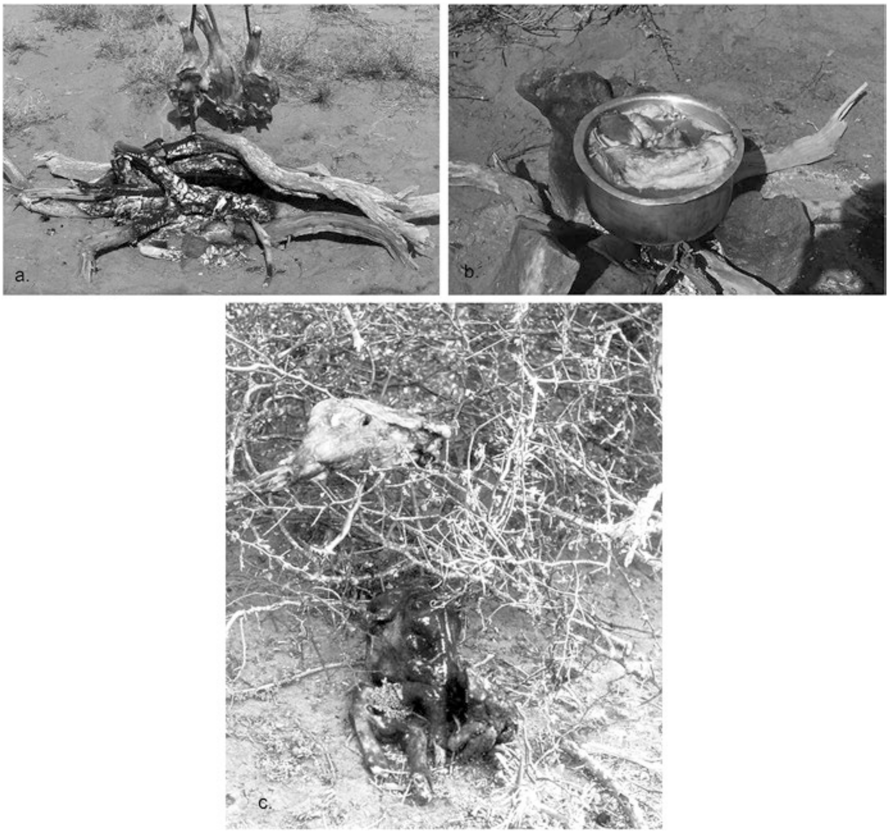

Fig. 15.4 One sheep, three modes of culinary processing, and three types of thermal alteration. (**a**) roasting limb units, with bones of distal ends directly exposed to thermal stress, traditional "food for men" among the Kenyan Dassanetch; (**b**) boiling fatty lumbar and sacral spine, plus heart and other fatty entrails, traditional "food for women" among the Dassanetch; (**c**). singed head, metacarpal- and metatarsal-to-toe units on ground, awaiting scraping of charred skin and cracking to extract within-bone nutrients, bones directly and heavily exposed to thermal stress, consumed by both genders and all ages. Note roasted limb segment stored in tree branches above. (Photos by the author)

endosteal lining of marrow cavities around the marrow, producing smaller, more readily removed billets of cooked fat. Oliver notes that marrow from smaller ungulates was often consumed raw in the field or liberated by cracking and boiling in cooking pots at camp. Long bones broken after such direct heating have transverse fracture outlines and rougher break surface textures (Chap. 11).

15.4.2 Bone Pounding and Consumption

Oliver (1993) reported that Hadza foragers pounded and consumed hemopoetic tissues in cancellous articular ends of long bones. This practice, as well as chewing the cancellous ends of smaller bones, may have been more widespread than once credited in the literature (Chap. 12).

15.5 Preservational Processing and Storage of Animal Products

Preservation and storage of animal products is so widespread among anatomically modern hunter-gatherers and food producers as to seem a normal facet of the human life. However, food storage are unique to the genus *Homo* and was critical to human colonization of high latitudes with restricted growing seasons. Storage can only emerge and be sustained as an adaptive feature when all members of a local and regional population tacitly consent to resource sequestering at the household or foraging group level. Such conditions are absent among common chimpanzees, where dominant animals appropriate animal prey and favored plant foods from lower ranking animals. Thus, storage typical of human societies rests not only on technological innovations but also on a distinctive "social contract," which history tells us is breached in times of societal disruption.

It's possible to view the practical aspects of preservational processing as one end of the culinary processing continuum, since cooking itself retards spoilage and extends the use-life of meat and other animal products, if only for a few days. However, maintaining this distinction may facilitate zooarchaeological study of the emergence of food storage. Lest one assume food storage is strictly the province of farmers and pastoralists, Stopp (2002) detailed Labrador Inuit peoples' storage and preservation tactics, including drying and smoking fish and mammal meat, dehydrating blood and semi-digested lichen from caribou stomachs to be rehydrated and drunk as an infusion by traveling hunters, and fermenting seal oil and caribou blood. Households and co-residing domestic groups produced and accessed preserved foods for their own use or for exchange.

Common preservational methods are:

1. **Slicing meat and sun drying it, or smoking it over fires**. This is applicable at primary or secondary butchery locales and later in processing. It extends meat's use-life, and by evaporating off water, reduces meat weight to be transported (Chap. 19).
2. **Freezing or deep cooling carcass segments**. In high latitudes, hunters and farmers use freezing temperatures to store prey (Binford 1978). This is applied at primary or secondary butchery locales and in later preservational processing. Before artificial refrigeration, farm animals were slaughtered just as the cold

season began (Bowen 1988). Yellow marrow was extracted raw at mass kills and cold stored to be mixed with lean meats over the winter months (Enloe 1993).

3. **Bone grease extraction.** Grease rendering is undertaken using bones of multiple animals with high bone grease levels. Bones from which marrow and meat have been removed are broken into smaller fragments and simmered in a container until fat coalesces on top of the water, when it is skimmed off and stored for consumption with lean meat.
4. **Blood coagulation.** Coagulation can be employed for immediate consumption through simple passive means, as do East African pastoralists who eat clotted blood "puddings." Cooked and denatured blood is often used as a binder for meat and fat scraps in sausages of stuffed intestines, which are preserved by boiling, drying, smoking, or stored after cooking in vegetable oil. Such storage strategies will probably leave few definitive archaeological traces but should be borne in mind as a food processing option, even in non-agricultural contexts.
5. **Management of milk and meat fermentation.** Like 3., fermentation can serve both culinary and preservational ends. Persons who do not produce lactase can more readily digest heated and fermented milk products than they can non-fermented ones. These storage strategies will probably leave few definitive archaeological traces but dairying will affect the living age structure, and thus the mortality structure, of managed herds (Chap. 22).

Stored bone marrow, bone grease, and dairy products extend the time span over which EFA's extracted from animals in peak condition can be consumed by those most in need of them year round, and lean animals can be consumed for their protein with the aid of stored fats (Chap. 5).

The history of dairying in Eurasia has been revolutionized by stable carbon isotope characterization of lipid residues in the fabric of ceramic containers (Copley et al. 2005a, b, c). This has enabled discerning milk fats and also other animal body fats: the adipose tissue signature of pigs can be distinguished from that of ruminants, and both of these from that of horses.

15.6 Diagnostic Traces of Culinary and Preservational Processing

Bone modifications inflicted during food preparation and preservation resemble those made during primary and secondary butchery, necessitating sound arguments from multiple lines of osteological and contextual evidence to make a case for their association with culinary or preservational practices, A *chaîne opératoire* approach provides a framework for reading the aggregate pattern of modifications on specimens as products of a structured sequence, from which can be generated expectations about the stages in a sequence of behaviors when bone surface and fracture modifications could have occurred. Although cooked sections of vertebrate bodies may be readily defleshed with minimal further cutting, the sawing, chopping, and cutting marks associated with primary butchery and other pre-culinary dismemberment will remain on cooked specimens. These, plus signs of thermal stress (*15.6.2 Thermal Alteration: Color, Bone Surface Changes, Bone Fracture Patterns* below), pot boiling (*15.6.6 Evidence of Pot Boiling: Pot-sizing, Pot-Polish* below), and even human chewing marks can elucidate the chain of operations that carcass parts underwent.

Rough specification of a chain of operations from faunal evidence in turn enables recruitment of other, independent lines of evidence – artifactual, architectural, spatial – that could more closely specify the most likely contexts of production (O'Connor 1993; Seetah 2008). This in turn could facilitate consideration of the *locales* and *personnel* involved in the spatial and social dimensions of vertebrate processing (Gifford-Gonzalez 1993; Miracle 2002).

15.6.1 Cut Mark Placement

Cut mark placement related to primary and secondary butchery of uncooked bone has been discussed earlier. When segments of the axial skeleton or limbs are thoroughly cooked, subsequent dismemberment and meat removal can proceed with little cutting tool intervention, simply using with hands or teeth. Bone cooked in body segments and later dismembered and defleshed offers fewer opportunities for a functional reading of cut mark patterning. However, comparative experimental analyses of cutting edge marks on similar skeletal element assemblages subjected to raw butchery and to defleshing after roasting and boiling is, so far as I know, not been done.

15.6.2 Thermal Alteration: Color

Heat can modify vertebrate skeletal elements during cooking, during some forms of refuse disposal, or in cases where a hearth is built on deposits containing them. Naturally occurring fires can also modify bones on land surfaces, in caves or rock shelters, whether or not humans initially handled the bones. Analysts seeking to infer human behavior from thermal alteration of bone face equifinality issues paralleling those of cuts versus trample marks (Chap. 14). As with the former, inferring the probable source of thermal alteration requires systematically examining them and their contexts. One can assess whether thermal alterations display redundant locations on portions of elements that are logical in terms of bone-in cooking techniques (see below) and whether the specimens' archaeological context suggests intentional human application of heat.

Zooarchaeologists' interest in thermal bone modification overlap with those of forensic scientists, who have conducted considerable experimental work in this area, summarized by Fairgrieve (2008). Zooarchaeological and forensic research

Table 15.2 Temperatures at which color change transitions occur in mammalian bone. Overlapping temperature ranges reflect the statistical nature of color transitions of experimental specimens under thermal stress

Temperature °C	Color	References
20 ≤ 285	Neutral white, pale yellow, yellow	(Shipman et al. 1984)
285–525	Brown, reddish brown, very dark grey-brown	(Gejvall 1969; Shipman et al. 1984; Fairgrieve 2008)
300	Black (cortical bone)	(Holden et al. 1995b)
600	Gray, gray-blue	(Holden et al. 1995b)
1000–1200	White	(Holden et al. 1995b)

indicate that bone exposed to fire or high heat (as in an oven) changes color in generally predictable ways. Bone covered with flesh is less likely to display such color shifts than is bone directly exposed to heat. Because soft tissues shrink during cooking, elements at ends of body segment, prominent processes of elements, or sections of elements close to the skin are most likely to be heat stressed.

Most zooarchaeologists know that bone subjected to high heating turns color as its organic component oxidizes, however, ascribing color shifts in archaeofaunal bone to thermal stress requires caution. Some minerals that penetrate bone during diagenesis can mimic colors developed by heating. Shahack-Gross et al. (1997) applied Fourier transform infrared (FTIR) spectroscopy to differentiate Hayonim Cave specimens burned black from those blackened by manganese oxide deposits. The spectrographic analysis also identified some specimens that were both burned and manganese stained. Shipman et al. (1984) also noted that thermal color changes could be overprinted by diagenetic staining.

Shipman et al. (1984) experimented with heating fresh mammal bone without protection of soft tissues, documenting color shifts and using SEM to monitor structural changes in bioapatite. Color shifts initially manifested as partial browning, advanced to deep brown and black, then changed to blue-gray and finally white. Shipman et al. cautioned that these color shifts do not develop at the same temperatures in all bone specimens in their sample, instead undergoing color changes best described statistically. Experiments with human bone by Holden et al. (1995a, b) more firmly established temperature ranges at which color shifts and microscopic changes in collagen and bone apatite occurred. Their correlation of color shifts with temperature ranges is much the same as observed by Shipman et al., with minor changes. Holden et al. used only one skeletal element, the femur, and one species, humans, which may account for the tighter clustering of temperatures and color changes in their results. Table 15.2 summarizes the color shifts and the temperature ranges they occur, from these and other experiments.

Holden et al. (1995a, b) and Fairgrieve (2008) stress that observed color changes result from the *bone's* temperature and not that of surrounding air or matrix. Bone can reach a high temperature by being exposed to a high temperature over a short period, or by being accumulating an incremental heat load that it cannot disperse while being exposed to lower ambient temperatures. The cumulative thermal stress of a specimen's highest temperature governs its color changes. Therefore, a specimen's color only indicates that it reached a given temperature range, not the specific temperature levels under which this occurred.

Blackening of bone is often called carbonization in the literature, referring to the consumption of the organic component of bone, while calcination refers to the gray-through-white color shifts associated with major crystal structure reorganization of bioapatite (e.g. Fairgrieve 2008; Stiner et al. 1995).

For zooarchaeologists, the key finding of such experimental research is that the color shifts and ultrastructural changes discerned by SEM occur at *much higher* temperatures than those ranges involved in roasting or boiling meat (Table 15.2). Water boils at 100 °C (212 °F). Roasts are seldom cooked at more than 175–345° (350–400 °F). The color shift to partial browning begins around 285 °C (545 °F), a higher temperature than any standard oven settings. Exceptions are bone portions exposed directly to heat during roasting, which can accumulate heat as outlined above and undergo color shifts.

Given the persistent problem of inferring cooking from bone condition, and the understanding that boiled bones lack perceptible color shifts, several researchers have explored alternative avenues for distinguishing thermal alteration to bone. Shipman et al. (1984) noted changes in crystal structure and X-ray diffraction properties of bone heated to high temperatures and explored whether X-ray diffraction could distinguish thermally stressed bones that had been subjected to lower temperatures, such as would the case with boiled bone. They subjected a sample of European Mesolithic specimens lacking any color shifts to SEM examination, which indicated that the specimens possessed hydroxyapatite crystals larger than typical of fresh bone but similar to those in specimens experimentally heated to around 645 °C. However, the specimens lacked other ultrastructural changes produced by this level of heat. Shipman et al. (1984) inferred that the Mesolithic sample's large apatite crystal structure was the product of diagenetic transformation (Chap. 16), and that X-ray diffraction could not distinguish culinary-level thermal stress on archaeofaunal specimens.

Taylor et al. (1995) explored whether geochemical signatures in bone could discern heat-stressed specimens, including those with no color shifts. Although thermal exposure caused changes in bone geochemistry, Taylor et al. (1995) found that these effects overlapped with those attributable to diagenetic effects alone. Nicholson (1992, 1993) conducted experiments parallel to those of Shipman et al. with bird, fish, and other vertebrate elements, which revealed development of similar features under thermal stress, with some intertaxonomic differences, as well as divergent durabilities of burnt specimens of different taxa.

Reseachers have explored whether other technological techniques for assessing bone microscopic structure could characterize structural changes – either in collagen or hydroxyapatite – associated with boiling, with some success. Koon et al. (2003, 2010) used Transmission Electron Microscopy (TEM) based approach to monitor changes in the organization of the collagen with boiling. They found that shifts in collagen structure took place at temperatures under 100 ° C, with fibrils assuming a "beaded," "dumbbell" form. Koon et al. (2003) note that similar changes can be seen in modern materials buried in a moor environment for 7 years. However, specimens from a single archaeological sample show divergences. Interpreted as reflecting boiling and lack of boiling within the sample (see also 2010). Bosch et al. (2011) analyzed sections of a modern human element boiled for 2, 4, and 5 h, using gas adsorption technique, X-ray diffraction and scanning electron microscopy (SEM) coupled with energy dispersive X-ray spectroscopy, to explore the efficacy of each approach, using their results as a baseline for exploring textural changes in Neolithic bone samples. Only SEM imaging revealed a boiling-related change, in progressive smoothing of the basic bone surface structure at the more extreme durations of boiling. They attribute this to changes in collagen, which nonetheless is somewhat protected by the mineral matrix. Their examination of the Neolithic bone sample revealed that some specimens resembled those boiled for about 4 h, but not for so much as 6 h, while specimens that did not show these structural changes displayed non-homogeneous disrupted surfaces, which they attribute to the action of algae and fungi (Chap. 16). Other divergences between archaeological specimens putatively boiled and unboiled specimens were noted in gas adsorption profiles, but, lacking experimental analogues, their sources are unclear. On one hand, these findings are less than encouraging to the many zooarchaeologists who lack the equipment or funds to use TEM or SEM to discern such microscopic alterations on substantial samples of specimens. On the other hand, TEM and SEM are relatively common and accessible technologies, should one wish to explore whether boiling was a means of processing vertebrates in a sample. With regard to boiling and heating, readers are also referred to the work of Karr and Outram reported in Chap. 11.

Stiner et al. (1995) experimentally assessed the effects of bone specimens placed directly into fires and buried in sediments below fires. They monitored visible color shifts and shifts in bioapatite crystallinity, using FTIR spectroscopy, as well as exploring the fragility of burned specimens, compared to fresh bone specimens. Properties of heat-stressed and unburned specimens were also compared to those of experimentally monitored weathered elements (Chap. 15) and diagenetically altered archaeological specimens. They established that experimental specimens buried up to 5 cm below fires were partly or entirely blackened but that color shifts proceeded no further toward calcination. This is a significant finding because traces of thermal alteration into the carbonized range are common in many archaeofaunas, whereas actualistic research indicates that black, gray, or white bone colors are seldom produced during cooking itself.

Stiner et al. (1995) reported that Hayonim Cave archaeofaunal specimens categorized as burned by their color were depleted of organic material, whereas specimens lacking such color shifts retained fair amounts of collagen or its by-products, even millennia after burial. They also reported that carbonized (burned black) experimental specimens broke into smaller fragments when trampled in sediments or agitated in a box than did unburned or less heat-stressed specimens. The near-complete consumption of collagen in carbonized bones would reduce their resilience. As the Shipman and Taylor research teams, Stiner et al. encountered equifinality between products of heating, weathering, and diagenesis. Burned bone showed higher crystallinity, reflecting rapid bioapatite shifts into larger crystals under heat stress. However, similar recrystallization effects were produced by 1–2 years' exposure of *unburned* bones to weathering in hot, arid environments, as well as being seen unburned archaeofaunal specimens from Hayonim.

Bennett (1999) extended experimental research on effects of fires burning above buried bones, burying bones at varying depths in both clay and sand matrices with thermal sensing units. Fires above each unit were maintained for 48 h, with hourly temperature monitoring during 40 h of the firing, five checks during the 12 h immediately after the firing ended. While both units followed roughly similar heating and cool-down curves, the clay unit heated to a higher temperature than the sand unit. Temperatures did not exceed 500 °C (932 °C) in the substrate. Bones as deep as 10 cm below the surface turned black. Bennett (1999:7) notes that those at shallower depths were in the process of calcination, and that this kind of alteration may be confused with diagenetic alteration.

15.6.3 Thermal Alteration: Bone Surface Changes

Buikstra and Swegle (1989) experimentally cremated human bone to elucidate how deposits of cremated bones in some U.S. Midwestern archaeological sites were created, and their findings are relevant to zooarchaeologists. Heating human cadavers and bone with and without flesh in open fires and in a high-temperature oven, Buikstra and Swegle found differences in the extent of bone color shifts, surface cracking, and flaking, depending upon whether the bone was covered with flesh. Some bones that never developed color shifts through the experiment nonetheless developed hairline cracking and flaking on their outer surfaces as a result of thermal stress.

White (1992) noted similar patterns of bone surface modification on archaeological human bones, and I noted hairline cracks and shallow exfoliation on some parts of ethnoarchaeological ungulate long bone specimens that displayed brown color shifts on other portions (Gifford-Gonzalez 1989). If one were unfamiliar with bone weathering, these changes might be mistaken for Behrensmeyer Weathering Stages One or Two (Chap. 16). Careful comparison revealed that thermal cracking was developed without alignment with an element's osteonal structure.

15.6.4 Thermal Alteration: Bone Fracture Patterns

Chapter 11 noted that fracture patterns on previously heated bone differ from those on fresh bone. Oliver's (1993) ethnoarchaeological study among the Hadza of Tanzania documented transverse fractures of large ungulate long bones after marrow cooking. As illustrated in Chap. 11, I noted relatively high frequencies of transverse breaks with stepped break surfaces on ethnoarchaeological long bones with evidence for heating and a sample time frame that excluded the possibility of weathering (Gifford-Gonzalez 1989). Outram (2002) undertook experiments assess the prediction that long bones exposed to thermal stress would transmit force and fracture differently than do fresh bones. His results indicated that the highest sustained temperatures affected how experimental bones broke. Outram illustrates two cattle radii, one boiled (≥100 °C, 212 °F) for 10 min and then fractured, and one heated in an oven at 100 °C (212 °F) for 5 h before breakage. The first radius fractured in helical fashion, but more transversely than would be expected with fresh bone, and fresh bone break surface features were absent. The baked bone broke transversely, with rough and jagged break surface, much like those reported for heated ethnoarchaeological specimens by Oliver (1993) and myself (Gifford-Gonzalez 1989). Other studies indicate similar effects of heating on mammal long-bone breakage. Bonnichsen (1973) noted that Calling Lake Cree informants heated defleshed long bones to prepare them for breakage, and that informants said heating made breakage easier.

Shortening of collagen fibers is probably responsible for the divergences in fracture properties of fresh versus heated bone. Richter's (1986) experimental observations showed collagen strands in fish bone began to unravel and denature when baked at temperatures between 60 °C (140 °F) and 100 °C (212 °F) for 30 min. Collagen in fish bones boiled (≥100 °C, 212 °F) for 30 min was completely denatured. She suggested that collagen in mammal bone may be somewhat more protected from heating effects than it is in thinner fish elements.

However, some cautions should be noted. Although it is true that heating may alter bone's ability to resist stress, it is not true that jagged, transverse breaks can only be produced after thermal stress. Taylor et al. (1995) demonstrated that diagenetic transformations of bone collagen replicate those of thermal stress. Thus, neither break shape nor collagen alteration cannot definitively reflect exposure to fire, and all possible lines of evidence should be used for such inferences. Boiling and pit roasting in earth ovens may leave no color shifts or flaking and cracking from thermal stress on bones. Analysts working in situations where contextual evidence indicates that these culinary techniques may have been employed should consider whether bone breakage patterns within a given taxon reflect different stages or types of culinary techniques.

15.6.5 Bone as Fuel

The use of fatty bone as fuel has been an item of zooarchaeological folklore for some time, but it only recently came under systematic study. Costamagno, Théry-Parisot, and coworkers (Costamagno et al. 2005; Théry-Parisot 2002) undertook experiments to elucidate the extreme burning in archaeofaunas from the French Upper Palaeolithic Aurignacian industry. Among the most interesting findings of their detailed experimentation is that fatty bone produces high flames for up to an hour after initial combustion but does not maintain heat from embers after those flames have died down, as does wood (Costamagno et al. 2005). The authors suggest that fat-rich bones are useful in combination with wood for a longer burn, as well as for drying via convection heating in wood-poor environments. Costamagno et al. (2005) list taphonomic evidence of fuel use of bones, including evidence for entire long bones, as these burn longer than fragments, and calcination of cancellous tissues. Use of bone as fuel or fire starters may have continued in later times, as suggested by accumulations of sheep horn cores in the metalworking sector of the medieval Moroccan city of al-Basra (Benco et al. 2002). Horn cores produce dense, waxy secretions that in life maintain the integrity of the horn sheath; these readily ignite and burn.

15.6.6 Evidence of Pot Boiling: Pot Sizing

In the absence of a clear signal of boiling from bone color, chemistry, or ultrastructure, the modal size of bone fragments may indirectly reflect this form of cooking. Bones boiled in stone, ceramic, or metal vessels may be chopped or percussion fractured to fit into pots, as Yellen (1991) reported for large animal elements chopped to fit into pots by !Kung foragers.

Exploring the higher fragmentation rates among domestic cattle, as opposed to sheep and goat specimens from the Neolithic archaeofauna at Ngamuriak, Kenya, Marshall (1990) noted that fragments' maximum dimensions were smaller than or overlapping with rim diameters of ceramic vessels from the site. Marshall therefore interpreted the taxon-specific fragmentation as pot sizing. I observed sagittal and transverse chopping of cattle and zebra vertebrae with bush-knives into roughly equal-sized sections in an ethnoarchaeological pastoralist sample, probably reflecting pot sizing to aluminum cook pots used for cooking meat (Fig. 15.4b). Analysts who suspect archaeofaunal specimens might have been boiled in vessels may wish to assess pot sizing by checking the bone specimens' modal maximum dimensions against modal pot mouth dimensions.

15.6.7 Evidence of Pot Boiling: Pot Polish

Some ceramic pots have coarse inner surfaces, replicating an abrasive sedimentary matrix, and stirring bone fragments in such vessels can develop abrasion on bone tissue. The most detailed treatment of pot polish is White's (1992) analysis of traces of Late Ancestral Pueblo cannibalism in the Mancos region. He noted polishing and beveling on human and deer diaphyseal fragments from several sites. To clarify modification processes, White experimentally fractured deer metapodia and boiled them in a Pueblo plainware ceramic pot for 3 h to mimic stewing. Of 69 specimens processed, 41 showed either rounding by abrasion on broken and projecting diaphyseal ends or rounding with beveling on similar breaks. No rounding was noted on

Fig. 15.5 Pot-polish on diaphyses: center: purported pot-polish on a human femoral fragment from a Mancos Canyon pueblo, 5MTUMR-2346, Colorado, flanked by SEM micrographs of experimentally produced analogue in deer metapodial fragments. White bar = 1 cm. (From White (1992:128, Fig. 6.8), used with permission of T. D. White and Princeton University Press)

epiphyseal surfaces. White infers that beveling is the result of directional stirring during cooking. White's illustrations (Fig. 15.5) of experimentally modified diaphyses and prehistoric human and deer bone show striae running longitudinally from the polished, rounded, and beveled edges. If an archaeofauna derives from a site with stone or ceramic cooking vessels, zooarchaeologists may wish to inspect diaphysis break surfaces for polish and beveling as an aid in defining culinary processing included boiling.

15.6.8 Bone Grease Extraction

The signature of bone grease extraction comprises dense concentrations of small, minimally identifiable bone scraps, commonly 1–5 cm in maximum dimension (Outram 2001). Leechman (1951), Bonnichsen and Will (1980), and Binford (1978) reported on grease rendering from bone fragments, and Outram (2001) offered further details on the process and its by-products. Brink (1997) and Church and Lyman (2003) present comprehensive bibliographic overviews.

Based on experiments with deer long bones broken into different sizes, Church and Lyman (2003) concluded that efficient grease extraction does not require the degree of fragmentation typical of ethnographic assemblages. Because no statistically significant difference in the amounts of bone grease rendered from fragments from 4 down to 1 cm in dimension, they speculated that nutrients other than lipids may have been the main motivator for expending they energy to break bones into very small fragments. Janzen et al. (2014) explored an alternate explanation for this extreme fragmentation, implicating the thermal inertia of water and fuel economy.[1] In a series trials with cattle femora of the same sizes as in the Church and Lyman experiment, Janzen et al. (2014) measured grease extraction and fuel consumption in relation to water volume. Their results supported Church and Lyman's finding that grease yield does not significantly increase in fragments <4 cm. Their trials demonstrated that smaller fragment sizes required less water, and hence fuel, to achieve a grease-extracting simmer. Janzen et al. (2014) suggested that ethnographic cases might represent a tradeoff between the effort required to produce very small fragments and broader energy budgets than those involved in grease rendering. For example, if fuel were scarce or energetically expensive to obtain, bone fragmentation tactics might lead to broader efficiencies in overall household activities.

15.7 Can Household Culinary Refuse Be Discerned Archaeologically?

Can culinary and preservational activities be discerned in archaeofaunal samples? Under certain circumstances, culinary refuse deposits can be distinguished. This section begins with an example from my ethnoarchaeological research, then cites three archaeological cases where secondary culinary refuse was discerned. It then sketches a method for identifying such deposits.

[1] While an undergraduate in my department, archaeologist Benjamin Broyles made a small-scale study that produced similar grease yield results to those of Church and Lyman. He proposed that extreme bone fragmentation could be intended to optimize fuel efficiency, as the thermal inertia of water requires considerable fuel to heat water to a simmer (Broyles, personal communication 1998). The Janzen et al. experiments explored this hypothesis.

Fig. 15.6 Aerial view of an abandoned Dassanetch defensive settlement (foreground) and an occupied one (background) showing overlapping animal pens around a central area for portable houses, near Ileret, Marsabit District, Kenya (Photograph by the author, over-flight courtesy Richard E. F. Leakey, 1974)

15.7.1 An Ethnoarchaeological Case

In the 1970s and the 1980s, the Dassanetch people of northeastern Lake Turkana were self-supporting for food, having access neither to markets nor to humanitarian food aid because of Kenyan and Sudanese government policies. The land away from the lake was semiarid bush and steppe (Carr 1977), with variable rainfall averaging less than 400 mm annually. Although viewing themselves as pastoralists, they grew sorghum and legumes via flood recession cultivation. Livestock sustained households during dry years, and poorer Dassanetch took fish and lake reptiles. The Dassanetch then had hostile relations with two other regional ethnic groups. Raiders took cattle and also killed as many people as possible, including women and children. Dassanetch residential settlements had a defensive layout, with portable houses inside a ring of livestock pens fenced with thorn tree boughs (Fig. 15.6).

Only livestock giving milk could be sustained on the sparse forage around the settlements. Other cattle and small stock were sent to stock camps tended by armed youths and younger boys. If environs of residential settlements became grazed out, families' milking stock could lose condition and fail as a crucial food source. Moving stock and homes to better grazing had to be balanced against risks of losing animals and family members in raids. One tactic was for 10–20 households with sufficient armed men to repel raiders to set up a large-scale temporary camps in better grazing areas. These resembled defensive residential settlements in their size and layout but were occupied a shorter time. Site 105 was such an encampment, occupied for 6 weeks in July–August 1973 by about 34 Dassanetch pastoralist households. I mapped the site in October 1973, collecting bones from animal pens, house interiors, and the "house area," the spaces between the houses.

Beginning with what I knew of Dassanetch butchery practices, space use, and refuse disposal, I explored whether specimens from these sectors reflected different steps in the chain of processing and discard. I selected parameters of faunal samples

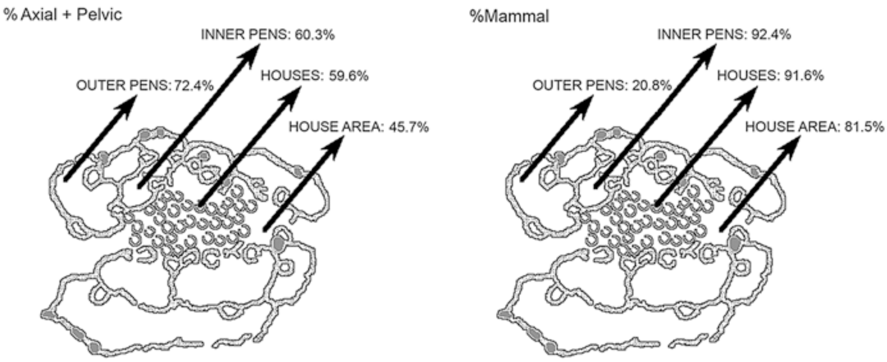

Fig. 15.7 Site 105: results of spatial content analysis for body segments and for taxonomic composition for *left*: frequencies, as %NISP, of axial+pelvic specimens in four zones of the site. Frequencies of the sample from inside all houses and that from the inner pens are virtually identical, while those of other zones diverge; *right* %NISP of mammalian specimens (vs. reptile and fish) in the same sampling zones. Frequencies are also virtually identical from the two respective sample areas, while those of other zones diverge. (Figure by author)

that could be transferred to archaeofaunal cases lacking such contextual information. Dassanetch butchers separated caprine appendicular segments from the axial skeleton distinctively: the scapula was removed with the foreleg, while pelvic bones remained articulated to the axial skeleton, the hindleg being detached at the femoral head. Separated units of a single animal could be cooked in disparate ways (Fig. 15.4a–c). Dassanetch women cleaned hearths in their houses by gathering up ash and food debris and throwing these into or over the fences of the innermost, sheep and goat pens surrounding the house area. I reasoned that secondary refuse from culinary processing would resemble the samples recovered from within the houses, which held abandonment debris of inhabitants' last few meals.

I compared proportions of appendicular (including scapula) elements to axial (including pelvis) elements across four aggregated samples: houses, house area, inner pens, and outer pens, also comparing proportions of mammals to non-mammals in the same subsamples. I hypothesized that the proportions of body segments and taxa within the houses should be similar to deposits in the inner pens, the end-points of processing I had observed in occupied localities. I expected that proportions of mammal to non-mammal specimens might vary among households, according on their owners' wealth, but that aggregate pattern of all houses would be paralleled by the aggregate of secondary refuse.

Actual proportions of axial to appendicular elements in the houses (locale of culinary processing) and the innermost pens (locale of culinary refuse disposal) were disconcertingly convergent (Fig. 15.7). Proportions in these two zones contrasted with those in the house area. Taxonomic proportions of the assemblages from the houses and pens were also extremely similar (Fig. 15.7) and contrasted with proportions of taxa from the house area sample. I infer that the house area aggregate reflects from different point in the processing and discard chain than the samples from inside the houses and from the inner pens. These also differed from the sample the outer pens, probably reflecting yet another processing stage. Thus, a simple comparison of intrasite subsamples, using uniform properties of animal bodies and taxonomic abundances, with knowledge of the location of culinary facilities, established with strong probability the locations of household secondary refuse.

15.7.2 Does It Work Archaeologically?

Is this just an ethnoarchaeological parlor trick or a potentially productive method for studying culinary and preservational processing archaeologically? Grantham (1995) explored variations in culinary processing and osteological outcomes among Druze people in the Golan Heights on the border of Israel and Lebanon and analyzed archaeofauna from Tel Hazor, a Late Bronze–Early Iron Age site in ancient Canaan. Druze handling of sheep for feasting produced an osteological residue distinct in its composition and locations from that of everyday meal debris that included sheep. Grantham (1995) reported that similarly differentiated types of bone debris were perceptible in spatially distinct Tel Hazor archaeofaunal sub-samples. In the Andean Moche Valley, Pozorski (1979) found similar correspondences between faunal debris associated with loci of culinary processing and the secondary refuse deposit outside the house compound studied. Russell and Martin (2005) distinguished household culinary debris from that of communal feasts in the Çatalhöyük archaeofauna, again using sub-sample composition and spatial contextual data.

These archaeological cases suggest that such an approach can be productive in relatively large-scale sites representing considerable depositional time, so long as some intrasite spatial structure is documented. If animal processing and disposal were constrained by permanent architecture – and, one imagines, by cultural practices – this could produce redundancies in the composition of deposits that endure over time. Such an analysis requires definition of cooking features and primary refuse in these zones of food preparation. Microdebris analysis (e.g. Stahl and Zeidler 1990; Bogaard et al. 2009) is particularly useful for this, as it can reflect not only the locales but also the types of culinary processing. Secondary refuse deposits may be discerned empirically through comparative sampling and compositional analyses in areas away from such functional zones or in features containing animal remains. Other lines of evidence, such as ash and broken culinary artifacts, might help define such deposits. I believe that such analyses are facilitated by a *chaîne opératoire* approach that identifies sequential stages of processing and discard and offers a functional framework for analyzing bone modifications (Fig. 15.1). This kind of analysis is not the first thing one does with an archaeofauna, but rather something one can explore once one has a grasp of "forensic reconstructions" of taxon-specific handling. Of course, such explorations are only workable with sites occupied long enough for refuse from meals to have been secondarily deposited.

Precedents for intrasite compositional analysis exist in zooarchaeological analyses of food sharing. Enloe and David (1992; Enloe et al. 1994) studied carcass subdivision in the Magdalenian sites of Pincevint and Verberie, France, as did Pozorski (1979) with Andean Moche archaeofaunal samples (Chap. 25). They did so by comparative analysis of the osteological *composition* of spatially discrete bone clusters, combined with refitting of individual reindeer carcasses. Enloe and David addressed subdivision of reindeer carcasses among households and did not explicitly address culinary processing, while Pozorski did, but compositional analysis appears to be a good strategy for analyzing culinary practices. Such approaches ultimately depend on a knowledge of the sequence of carcass dismemberment, also pioneered by Frison et al. (1976). Although they put the data produced from compositional analysis to a very different use, Muir and Driver (2002) defined spatially distinct deposits within Pueblo III phase sites, including household refuse, and analyzed their composition to explore differences in animal use, sites of varied sizes and architectural features in the northern San Juan region.

If we take a product-focused approach to zooarchaeological materials, we must include culinary processing. Human meals are products of tool-mediated, pre-consumption manipulation where the benefits of the food quest are realized. Its output comprises most of what we recover from archaeological sites, whether debris of a marrow snack at a butchery locale or heaps of household trash in a city. The nutritional and time benefits conferred by culinary processing incur added energetic costs in producing facilities and implements and fuel acquisition. Work allocation and mobility strategies must accommodate these activities. Zooarchaeologists cannot fully contribute their skills to addressing the feedbacks of food processing technology, anatomical form, and social relations over human evolutionary time, nor the roles animal foods played in emergent social relations and cultural systems, until we better grasp the distinctive aspects of materials that have undergone culinary processing.

References

Andrefsky, W. J. (2005). *Lithics: macroscopic approaches to analysis* (2nd ed.). Cambridge: Cambridge University Press.

Attwell, L., Kovarovic, K., & Kendal, J. R. (2015). Fire in the Plio-Pleistocene: The functions of hominin fire use, and the mechanistic, developmental and evolutionary consequences. *Journal of Anthropological Sciences, 93*, 1–20.

Bartram, L. E., Kroll, E. M., & Bunn, H. T. (1991). Variability in camp structure and bone food refuse patterning at Kua San hunter-gatherer camps. In E. M. Kroll, & T. D. Price (Eds.), *The interpretation of archaeological spatial patterning* (pp. 77–148, Interdisciplinary contributions to archaeology). New York: Plenum.

Benco, N. L., Ettahiri, A., & Loyet, M. (2002). Worked bone tools: Linking metal artisans and animal processors in medieval Islamic Morocco. *Antiquity, 76*(292), 447–457.

Bennett, J. L. (1999). Thermal alteration of buried bone. *Journal of Archaeological Science, 26*(1), 1–8.

Binford, L. R. (1977). *For theory building in archaeology: Essays on faunal remains, aquatic resources, spatial analysis, and systemic modeling*. New York: Academic Press.

Binford, L. R. (1978). *Nunamiut ethnoarchaeology*. New York: Academic Press.

Binford, L. R. (1980). Willow smoke and dogs' tails: Hunter-gatherer settlement systems and archaeology. *American Antiquity, 45*(1), 4–20.

Binford, L. R. (1981). *Bones: Ancient men and modern myths*. New York: Academic Press.

Blumenschine, R. J. (1988). An experimental model of the timing of hominid and carnivore influence on archaeological bone assemblages. *Journal of Archaeological Science, 15*(5), 483–502.

Bogaard, A., Charles, M., Twiss, K. C., Fairbairn, A., Yalman, N., Filipović, D., et al. (2009). Private pantries and celebrated surplus: Storing and sharing food at Neolithic Çatalhöyük, central Anatolia. *Antiquity, 83*(321), 649–668.

Bonnichsen, R. (1973). Some operational aspects of human and animal bone alteration. In B. M. Gilbert (Ed.), *Mammalian osteoarchaeology: North America* (pp. 9–24). Columbia: Missouri Archaeological Society.

Bonnichsen, R., & Will, R. T. (1980). Cultural modification of bone: The experimental approach in faunal analysis. In B. M. Gilbert (Ed.), *Mammalian osteology* (pp. 7–30). Laramie: B.M. Gilbert.

Bosch, P., Alemán, I., Moreno-Castilla, C., & Botella, M. (2011). Boiled versus unboiled: A study on Neolithic and contemporary human bones. *Journal of Archaeological Science, 38*(10), 2561–2570. https://doi.org/10.1016/j.jas.2011.04.019.

Bowen, J. (1988). Seasonality: An agricultural construct. In M. C. Beaudry (Ed.), *Documentary archaeology in the New World* (pp. 161–171). Cambridge: Cambridge University Press.

Brink, J. W. (1997). Fat content in leg bones of *Bison bison*, and applications to archaeology. *Journal of Archaeological Science, 24*(3), 259–274.

Buikstra, J. E., & Swegle, M. (1989). Bone modification due to burning: Experimental evidence. In R. Bonnichsen & M. Sorg (Eds.), *Bone modification* (pp. 247–258). Orono: Center for the Study of the First Americans/Institute for Quaternary Studies/University of Maine.

Bunn, H. T. (1993). Bone assemblages at base camps: A further consideration of carcass transport and bone destruction by the Hadza. In J. Hudson (Ed.), *From bones to behavior: Ethnoarchaeological and experimental contributions to the interpretation of faunal remains* (pp. 156–168, Occasional paper, Vol. 21). Carbondale: Center for Archaeological Investigations/ Southern Illinois University.

Carmody, R. N., Weintraub, G. S., & Wrangham, R. W. (2011). Energetic consequences of thermal and nonthermal food processing. *Proceedings of National Academy of Sciences, 108*(48), 19199–19203.

Carr, C. J. (1977). *Pastoralism in crisis. The Dasanetch and their Ethiopian lands, Research Paper, University of Chicago. Department of Geography*, (Vol. 180). Chicago: University of Chicago Press.

Church, R. R., & Lyman, R. L. (2003). Small fragments make small differences in efficiency when rendering grease from fractured artiodactyl bones by boiling. *Journal of Archaeological Science, 30*(8), 1077–1084.

Copley, M. S., Berstan, R., Dudd, S. N., Straker, V., Payne, S., & Evershed, R. P. (2005a). Dairying in antiquity. I. Evidence from absorbed lipid residues dating to the British Iron Age. *Journal of Archaeological Science, 32*(4), 485–503.

Copley, M. S., Berstan, R., Mukherjee, A. J., Dudd, S. N., Straker, V., Payne, S., et al. (2005b). Dairying in antiquity, III: Evidence from absorbed lipid residues dating to the British Neolithic. *Journal of Archaeological Science, 32*(4), 523–546.

Copley, M. S., Berstan, R., Straker, V., Payne, S., & Evershed, R. P. (2005c). Dairying in antiquity, II: Evidence from absorbed lipid residues dating to the British Bronze Age. *Journal of Archaeological Science, 32*(4), 505–521.

Costamagno, S., Théry-Parisot, I., Brugal, J.-P., & Guibert, R. (2005). Taphonomic consequences of the use of bones as fuel. Experimental data and archaeological consequences. In T. O'Connor (Ed.), *Biosphere to lithosphere. New studies in vertebrate taphonomy* (pp. 51–62). Oxford: Oxbow Books.

Crader, D. C. (1984). The zooarchaeology of the Storehouse and the Dry Well at Monticello. *American Antiquity, 49*(3), 542–558.

de Heinzelin, J., Clark, J. D., White, T. W., Hart, W., Renne, P., WoldeGabriel, G., et al. (1999). Environment and behavior of 2.5-million-year-old Bouri hominids. *Science, 284*(5414), 625–629.

Deetz, J. F. (1996). *In small things forgotten: An archaeology of early American life*. New York: Anchor Books.

Egeland, C. P., Rayne Pickering, T., Dominguez-Rodrigo, M., & Brain, C. K. (2004). Disentangling Early Stone Age palimpsests: Determining the functional independence of hominid- and carnivore-derived portions of archaeofaunas. *Journal of Human Evolution, 47*(5), 343–357.

Emerson, A. M. (1993). The role of body part utility in small-scale hunting under two strategies of carcass recovery. In J. Hudson (Ed.), *From bones to behavior: Ethnoarchaeological and experimental contributions to the interpretation of faunal remains* (pp. 138–155, Occasional paper, Vol. 21). Carbondale: Center for Archaeological Investigations/Southern Illinois University.

Enloe, J. G. (1993). Ethnoarchaeology of marrow cracking: Implications for the recognition of prehistoric subsistence organization. In J. Hudson (Ed.), *From bones to behavior: Ethnoarchaeological contributions to the interpretation of faunal remains* (pp. 82–97, Occasional paper, Vol. 21). Carbondale: Center for Archaeological Investigations/Southern Illinois University.

Enloe, J. G., & David, F. (1992). In L. Hofman & J. G. Enloe (Eds.), *Food sharing in the palaeolithic: Carcass refitting at Pincevent* (Vol. 578, pp. 296–315). Oxford: British Archaeological Reports, International Series.

Enloe, J. G., David, F., & Hare, T. S. (1994). Patterns of faunal processing at Section 27 of Pincevent: The use of spatial analysis and ethnoarchaeological data in the interpretation of archaeological site structure. *Journal of Anthropological Archaeology, 13*(2), 105–124.

Fairgrieve, S. I. (2008). *Forensic cremation: Recovery and analysis*. Boca Raton: CRC Press.

Frison, G. C. (Ed.). (1974). *The Casper site: A Hell Gap bison kill on the High Plains*. New York: Academic Press.

Frison, G. C., & Reher, C. A. (1970). The Glenrock Buffalo Jump, 48CO304: Late prehistoric period buffalo procurement and butchering. *Plains Anthropologist, 15*(50), 1–45.

Frison, G. C., & Todd, L. (Eds.). (1987). *The Horner site: The type site of the Cody Cultural Complex*. Orlando: Academic Press.

Frison, G. C., Wilson, M., & Wilson, D. J. (1976). Fossil bison and artifacts from an early Altithermal period arroyo trap in Wyoming. *American Antiquity, 41*(1), 28–57.

Gifford-Gonzalez, D. (1989). Ethnographic analogues for interpreting modified bones: Some cases from East Africa. In R. Bonnichsen & M. Sorg (Eds.), *Bone modification* (pp. 179–246). Orono: Center for the Study of the First Americans/Institute for Quaternary Studies/University of Maine.

Gifford-Gonzalez, D. (1993). Gaps in zooarchaeological analyses of butchery: Is gender an issue? In J. Hudson (Ed.), *From bones to behavior: Ethnoarchaeological and experimental contributions to the interpretation of faunal remains* (pp. 181–199, Occasional paper, Vol. 21). Carbondale: Center for Archaeological Investigations/Southern Illinois University Press.

Gejvall, N.-G. (1969). Cremations. In D. R. Brothwell, & E. S. Higgs (Eds.), *Science and archaeology. A survey of progress and research* (pp. 468–479). London: Thames and Hudson.

Gifford-Gonzalez, D. (2008). Thoughts on a method for zooarchaeological study of daily life. In S. Montón Subias, & M. Sánchez Romero (Eds.), *Engendering social dynamics: The archaeology of maintenance activities* (pp. 15–23, BAR international series, Vol. 1862). Oxford, UK: Archaeopress.

Graff, S. R., & Rodríguez-Alegría, E. (Eds.). (2012). *The menial art of cooking: Archaeological studies of cooking and food preparation*. Boulder: University Press of Colorado.

Grantham, B. (1995). Dinner in Buqata: The symbolic nature of food animals and meal sharing in a Druze village. In P. J. Crabtree, & K. Ryan (Eds.), *The symbolic role of animals in archaeology, MASCA Research Papers in Science and Archaeology* (Vol. 12, pp. 73–78). Philadelphia: University of Pennsylvania Museum of Archaeology and Anthropology.

Habicht-Mauche, J. A. (2006). The social history of the Southwestern Glaze Wares. In J. Habicht-Mauche, S. L. Eckert, & D. L. Huntley (Eds.), *The social life of pots: Glaze wares and cultural dynamics in the Southwest, AD 1250–1680* (pp. 3–16). Tucson: University of Arizona Press.

Guilday, J. E., Parmalee, P., & Tanner, D. P. (1962). Aboriginal butchering techniques at the Eschelman Site (36LA12), Lancaster County, Pennsylvania. *Pennsylvania Archaeologist, 32,* 59–83.

Hoberg, E. P., Alkire, N. L., Queiroz, A. D., & Jones, A. (2001). Out of Africa: Origins of the *Taenia* tapeworms in humans. *Proceedings of the Royal Society of London: Biological Sciences, 268*(1469), 781–787.

Holden, J. L., Phakey, P. P., & Clement, J. G. (1995a). Scanning electron microscope observations of heat-treated human bone. *Forensic Science International, 74*(1–2), 29–45.

Holden, J. L., Phakey, P. P., & Clement, J. G. (1995b). Scanning electron microscope observations of incinerated human femoral bone: A case study. *Forensic Science International, 74*(1–2), 17–28.

Janzen, A., Reid, R. E. B., Vasquez, A., & Gifford-Gonzalez, D. (2014). Smaller fragment size facilitates energy-efficient bone grease production. *Journal Archaeological Science, 49*, 518–523.

Koon, H. E. C., Nicholson, R. A., & Collins, M. J. (2003). A practical approach to the identification of low temperature heated bone using TEM. *Journal of Archaeological Science, 30*(11), 1393–1399.

Koon, H. E. C., O'Connor, T. P., & Collins, M. J. (2010). Sorting the butchered from the boiled. *Journal of Archaeological Science, 37*(1), 62–69. https://doi.org/10.1016/j.jas.2009.08.015.

Leechman, D. (1951). Bone grease. *American Antiquity, 16*(4), 355–356.

Lemonnier, P. (1986). The study of material culture today: Toward an anthropology of technical systems. *Journal of Anthropological Archaeology, 5*(2), 147–186.

Leonard, W. R., Snodgrass, J. J., & Robertson, M. L. (2007). Effects of brain evolution on human nutrition and metabolism. *Annual Review of Nutrition, 27*, 311–327.

Lupo, K. D. (2006). What explains the carcass field processing and transport decisions of contemporary hunter-gatherers? Measures of economic anatomy and zooarchaeological skeletal part representation. *Journal of Archaeological Method and Theory, 13*(1), 19–66.

Lupo, K. D., & Schmitt, D. N. (1997). Experiments in bone boiling: Nutritional returns and archaeological reflections. *Anthropozoologica, 25–26*, 137–144.

Lyman, R. L. (1987). Archaeofaunas and butchery studies: A taphonomic perspective. *Advances in Archaeological Method and Theory, 10,* 249–337.

Lyman, R. L. (1995). A study of variation in the prehistoric butchery of large artiodactyls. In E. M. Johnson (Ed.), *Ancient peoples and landscapes* (pp. 233–253). Lubbock: Museum of Texas Tech University.

Marean, C. W. (1998). A critique of the evidence for scavenging by Neandertals and early modern humans: New data from Kobeh Cave (Zagros Mountains, Iran) and Die Kelders Cave 1 Layer 10 (South Africa). *Journal of Human Evolution, 35*(2), 111–136.

Marshall, F. B. (1990). Cattle herds and caprine flocks. In P. T. Robertshaw (Ed.), *Early pastoralists of south-western Kenya* (pp. 205–260). Nairobi: British Institute in Eastern Africa.

Miracle, P. T. (2002). Mesolithic meals from Mesolithic middens. In P. T. Miracle & N. Milner (Eds.), *Consuming passions and patterns of consumption* (pp. 65–88). Cambridge, UK: McDonald Institute for Archaeological Research.

Montón Subías, S. (2002). Cooking in zooarchaeology: is this issue still raw? In P. Miracle, & N. Milner (Eds.), *Consuming passions and patterns of consumption* (pp. 7-15). Cambridge: McDonald Institute for Archaeological Research.

Muir, R. J., & Driver, J. C. (2002). Scale of analysis and zooarchaeological interpretation: Pueblo III faunal varation in the northern San Juan region. *Journal of Anthropological Archaeology, 21*(2), 165–199.

Nicholson, R. A. (1992). Bone survival: The effects of sedimentary abrasion and trampling on fresh and cooked bone. *International Journal of Osteoarchaeology, 2*(1), 79–90.

Nicholson, R. A. (1993). A morphological investigation of burnt animal bone and an evaluation of its utility in archaeology. *Journal of Archaeological Science, 20*(4), 411–428.

O'Connell, J. F., & Marshall, B. (1989). Analysis of kangaroo body part transport among the Alyawara of central Australia. *Journal of Archaeological Science, 16*(4), 393–405.

O'Connell, J. F., Hawkes, K., & Blurton-Jones, N. (1988). Hadza hunting, butchering, and bone transport and their archaeological implications. *Journal of Anthropological Research, 44*(2), 113–161.

O'Connell, J. F., Hawkes, K., & Blurton-Jones, N. (1990). Reanalysis of large mammal body part transport among the Hadza. *Journal of Archaeological Science, 17*(3), 301–316.

O'Connor, T. P. (1993). Process and terminology in mammal carcass reduction. *International Journal of Osteoarchaeology, 3*(2), 63–67.

Oliver, J. S. (1993). Carcass processing by the Hadza: Bone breakage from butchery to consumption. In J. Hudson (Ed.), *From bones to behavior: Ethnoarchaeological and experimental contributions to the interpretation of faunal remains* (pp. 200–227, Occasional paper, Vol. 21). Carbondale: Center for Archaeological Investigations/Southern Illinois University Press.

Outram, A. K. (2001). A new approach to identifying bone marrow and grease exploitation: Why the "Indeterminate" fragments should not be ignored. *Journal of Archaeological Science, 28*(4), 401–410.

Outram, A. K. (2002). Bone fracture and within-bone nutrients: An experimentally based method for investigating levels of marrow extraction. In P. T. Miracle & N. Milner (Eds.), *Consuming passions and patterns of consumption* (pp. 51–64). Cambridge: McDonald Institute for Archaeological Research.

Pelegrin, J., Karlin, C., & Bodu, P. (1988). Chaînes opératoires: un outil pour le préhistorien. In J. Tixier (Ed.), *Journée d'Études Technologiques en Préhistoire* (pp. 55–62, Notes et Monographies Techniques, Vol. 25). Paris: Centre National de la Recherche Scientifique.

USDA Agricultural Research Service. (2008). *Nutrient Data*. http://www.ars.usda.gov/main/site_main.htm?modecode=12354500. Accessed 10.18.2008.

Pozorski, S. (1979). Late prehistoric llama remains from the Moche Valley, Peru. *Annals of the Carnegie Museum, 48*, 139–170.

Richter, J. (1986). Experimental study of heat induced morphological changes in fish bone collagen. *Journal of Archaeological Science, 13*(5), 477–481.

Russell, N., & Martin, L. (2005). Çatalhöyük Mammal Remains. In I. Hodder (Ed.), *Inhabiting Çatalhöyük: Reports from the 1995–1999 Seasons* (pp. 33–98, Çatalhöyük Research Project Volume 4, BIAA Monograph No. 38). Cambridge: McDonald Institute for Archaeological Research and the British Institute of Archaeology at Ankara.

Schiffer, M. B. (1987). *Formation processes of the archaeological record*. Albuquerque: University of New Mexico Press.

Seetah, K. (2008). Modern analogy, cultural theory and experimental replication: A merging point at the cutting edge of archaeology. *World Archaeology, 40*(1), 135–150.

Semaw, S. (2000). The world's oldest stone artefacts from Gona, Ethiopia: Their implications for understanding stone technology and patterns of human evolution between 2·6–1·5 million years ago. *Journal of Archaeological Science, 27*(12), 1197–1214.

Shahack-Gross, R., Bar-Yosef, O., & Wiener, S. (1997). Black-coloured bones in Hayonim Cave, Israel: Differentiating between burning and oxide staining. *Journal of Archaeological Science, 24*(5), 439–446.

Shipman, P., Foster, G., & Schoeninger, M. (1984). Burnt bones and teeth: An experimental study of color, morphology, crystal structure and shrinkage. *Journal of Archaeological Science, 11*(4), 307–325.

Speth, J. D., & Spielmann, K. A. (1983). Energy source, protein metabolism, and hunter-gatherer subsistence strategies. *Journal of Anthropological Archaeology, 2*(1), 1–31.

Stahl, P. W., & Zeidler, J. A. (1990). Differential bone-refuse accumulation in food-preparation and traffic areas on an early Ecuadorian house floor. *Latin American Antiquity, 1*(2), 150–169.

Stiner, M. C., Kuhn, S. L., Weiner, S., & Bar-Yosef, O. (1995). Differential burning, recrystallization, and fragmentation of archaeological bone. *Journal of Archaeological Science, 22*(2), 223–237.

Stopp, M. P. (2002). Ethnohistoric analogues for storage as an adaptive strategy in northeastern subarctic prehistory. *Journal of Anthropological Archaeology, 21*(3), 301–328.

Taylor, R. E., Hare, P. E., & White, T. D. (1995). Geochemical criteria for thermal alteration of bone. *Journal of Archaeological Science, 22*(1), 115–119.

Théry-Parisot, I. (2002). Fuel management (bone and wood) during the Lower Aurignacian in the Pataud Rock Shelter (Lower Palaeolithic, Les Éyzies de Tayac, Dordogne, France). Contribution of experimentation. *Journal of Archaeological Science, 29*(12), 1415–1421.

Thoms, A. V. (2008). The fire stones carry: Ethnographic records and archaeological expectations for hot-rock cookery in western North America. *Journal of Anthropological Archaeology, 27*(4), 443–460.

Thoms, A. V. (2009). Rocks of ages: Propagation of hot-rock cookery in western North America. *Journal of Archaeological Science, 36*(3), 573–591.

Ungar, P. S., Grine, F. E., & Teaford, M. F. (2006). Diet in early *Homo*: A review of the evidence and a new model of adaptive versatility. *Annual Review of Anthropology, 35*, 209–228.

Vitelli, K. D. (2007). *The Neolithic pottery from Lerna*. Athens: American School of Classical Studies at Athens.

Wandsnider, L. (1997). The roasted and the boiled: Food composition and heat treatment with special emphasis on pit-hearth cooking. *Journal of Anthropological Archaeology, 16*(1), 1–48.

Wheat, J. B. (1972). The Olsen-Chubbuck site: A Paleo-Indian bison kill. *Memoirs of the Society for American Archaeology, 26*(i-ix), 1–180.

White, T. D. (1992). *Prehistoric cannibalism at Mancos 5MTUMR-2346*. Princeton: Princeton University Press.

Wrangham, R. W. (2009). *Catching fire: how cooking made us human*. New York: Basic Books.

Wrangham, R. W. (2017). Control of fire in the paleolithic: Evaluating the cooking hypothesis. *Current Anthropology*, *58*(Supplement 16), S000 not available. https://doi.org/10.1086/692113.

Yellen, J. E. (1977). *Archaeological approaches to the present: Models for reconstructing the past*. New York: Academic Press.

Yellen, J. E. (1991). Small mammals: !Kung San utilization and the production of faunal assemblages. *Journal of Anthropological Archaeology, 10*(1), 1–26.

Zink, K. D., & Lieberman, D. E. (2016). Impact of meat and Lower Palaeolithic food processing techniques on chewing in humans. [Letter]. *Nature, 531*(7595), 500–503.