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An experimental investigation of cut mark production and stone tool attrition

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Abstract

In discussions of Paleolithic hominin behavior it is often assumed that cut marks are an unwanted byproduct of butchery activities, and that their production causes the dulling of stone tool edges. It is also presumed that Paleolithic butchers would have refrained from making cut marks to extend the use life of their tools. We conducted a series of butchery experiments designed to test the hypothesis that cut marks affect the use life of tools. Results suggest cut marks are not associated with edge attrition of simple flake tools, and therefore it is unlikely that Paleolithic butchers would have avoided contact between bone surfaces and tool edges. Edge attrition is, however, significantly greater during skinning and disarticulation than during defleshing. This suggests that skinning and disarticulation activities would require more tool edges relative to butchery events focused purely on defleshing. Differences between the number of cut-marked bones relative to the number of stone artifacts deposited at taphonomically comparable archaeological localities may be explicable in terms of different types of butchery activities conducted there, rather than strictly the timing of carcass access by hominins. Archaeological localities with higher artifact discard rates relative to raw material availability may represent an emphasis on activities associated with higher edge attrition (e.g. skinning or disarticulation).

Keywords: Cut marks; Use life; Butchery; Stone tools; Actualistic study

1. Introduction

In many Paleolithic butchery studies there is an implicit assumption that prehistoric butchers would have avoided creating cut marks with their stone tools. This assumption is based on the notion that the production of cut marks causes edge attrition, or dulling, of the sharp edges of these tools. Identifying such links between butchery activities and stone tool use life is potentially invaluable for understanding stone artifact discard decisions by Paleolithic tool users, the role of these decisions in formation processes at Stone Age archaeological sites, and the relationship between the abundances of stone tools and hominin-modified fossil bone. However, this particular assumption has never been explicitly tested and the relationship between cut mark production and stone tool edge attrition has never been quantified.

Despite this assumption remaining untested, it has influenced a variety of other types of analyses in Paleolithic studies including analyses of cut mark frequency, and raw material procurement, use, and conservation. Bunn (2001) is perhaps most explicit, stating that "…butchers with any interest in preserving the sharpness of their knife blades are not going to repeatedly hack into the visible bone surfaces when the adhering meat can be shaved free without hitting the bone directly enough to produce cut marks. Cutmarks are mistakes; they are accidental miscalculations of the precise location of the

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bone surface when muscle masses obscure it. As soon as the butcher can see the bone surface, few if any cut marks will be inflicted thereafter in that area'' (Bunn, 2001: 207).

Bunn (2001: 208) further asserts that ''[E]ven partial defleshing by carnivores reveals where the surface of the bone is, which enables the butcher to avoid hitting it with the knife (which would only be dulled by contacting the bone and producing a cutmark).'' Bunn has therefore used the assumption that stone tools are dulled by the creation of cut marks to build a scenario in which Paleolithic butchers are unlikely to make marks on bones that have been previously defleshed by carnivores. From this he has made the behavioral inference that at archaeological sites with cut-marked fossils, the bones must have been accessed by hominins while they retained substantial muscle masses.

The assumed relationship between cut mark production and tool edge attrition (dulling) also has obvious implications for the use life of tools found in archaeological assemblages (Shott and Sillitoe, 2005). Understanding the factors that influence use life of simple flake tools during butchery activities is important for understanding the functional significance of stone artifacts at Early Stone Age sites (Tactikos, 2005; Toth, 1982, 1987). Although new studies suggest that many Early Stone Age sites may represent the use of stone artifacts to procure non-mammal tissue resources (Mora and de la Torre, 2005), there remains extensive evidence that sharp edge flakes were associated with extracting resources from large mammal carcasses during this time period (Bunn et al., 1980; Bunn, 1981, 1986; de Heinzelin et al., 1999; Dominguez-Rodrigo and Pickering, 2003; Dominguez-Rodrigo et al., 2005; Potts and Shipman, 1981). Therefore, exploration of the association between stone artifact use life and various butchery activities will assist in the development of hypotheses about tool discard behaviors in the past (Schick, 1987).

Two things are required before such analyses may proceed. First, the assumption that cut mark production dulls stone tools must be tested and quantified. Second, the relationship between various butchery activities and stone tool edge attrition must be more precisely investigated. This study reports a series of butchery experiments designed to address these requirements. We first quantify the degree of association between cut mark number and three different measurements of edge attrition, thereby examining the basis of Bunn's (2001) inference that hominins took measures to reduce the likelihood of tool-bone contact. We then evaluate the relationship between stone tool edge attrition and three specific butchery tasks, not all of which would consistently leave archaeological traces that would be preserved in the form of cut-marked fossils: skinning, disarticulation, and defleshing.

2. Methods

This study is based on two separate types of butchery experiments designed to test specific hypotheses. The first set of experiments is aimed at determining the association between cut mark number and edge attrition. This set of experiments included the systematic butchery of 18 individual hindlimbs of various sized animals (6 sheep; 6 juvenile cows; 6 zebras) acquired from a local commercial butcher. In these 18 experiments (Cut Mark Experiment 1–18, henceforth CME 1–18) skinning was carefully conducted with a metal knife in a manner that precluded contact between the knife edge and any bone surfaces. Subsequent defleshing was done with a single whole flake (detached piece with a complete platform and completely intact distal edge: *sensu* Isaac, 1981) so that all cut marks could be associated with edge attrition of a single flake. These limbs were not disarticulated. The second set of experiments was conducted to measure edge attrition in three separate butchery tasks (defleshing, disarticulation and skinning). This set of experiments included the systematic butchery of two sheep (Cut Mark Experiment A and Cut Mark Experiment B, henceforth CME A and CME B). All of the stone tools used for the butcheries were made from fine-grained tholeitic basalts from the Gombe Group of basalts in the Turkana Basin in northern Kenya. This raw material was used by the majority of hominins that produced the archaeological record in the Koobi Fora Formation (Braun, 2006).

2.1. Butchery

The butcheries were conducted by two Turkana men who were skilled butchers (Dominguez-Rodrigo, 1999). These men were aware that the butcheries were being conducted for research purposes. For CME 1–18 butchers were presented with the skinned hindlimbs and told to completely deflesh each limb. A total of 18 flakes were used for these experiments. The CME A and B experiments were conducted following the pattern described by Jones (1980). An initial vertical incision was made with a metal knife from throat to tail to remove the viscera. The head was then removed with a metal knife. No cut marks were made on the limbs during these two operations. The carcass was then hung upside down from a tree, by a rope tied around one leg, to facilitate butchery.

In CME A and B, a single whole flake was used for each butchery task (skinning, disarticulation, defleshing) on each limb (4 forelimbs, 4 hindlimbs). A total of 24 flakes were used for these two experiments (8 skinning flakes, 8 disarticulation flakes, and 8 defleshing flakes). Periosteum was not removed. The sequence of butchery on each limb was as follows:

1) skinning, which began at the carpals or tarsals and removed enough skin to disarticulate the limb from the axial skeleton;
2) initial disarticulation, or removing the limb from the axial skeleton;
3) defleshing, which involved the scapula/humerus/radio-ulna in the forelimbs and femur/tibia in the hindlimbs (metapodials were not processed, as they have very little flesh and the butchers said they would not normally process them for flesh);
4) secondary disarticulation, or removing each of the aforementioned limb bones from each other.

Only one whole flake was used for each of these butchery activities during CME A and B, regardless of the difficulty associated with butchering with dulled tools. For consistency, initial disarticulation and secondary disarticulation were performed with the same "disarticulation" flake. Each activity was timed to the nearest minute. Defleshing activities were limited to limbs.

After butchery was complete, flakes and bones were washed with hot water and a mild detergent to remove adhering grease and bits of tissue.

2.2. Stone tool measurements

We assumed that dulling of the sharp edge on a flake is related to the loss of small amounts of material on/around the edge. We measured the potential loss from each flake using three different methods:

1) MASS: We weighed each flake before and after butchery with a digital scale. We recorded mass to the nearest 0.1 gram.
2) AREA: We measured the area of each flake using a digital imaging technique. Digital photographs of each flake were taken before and after butchery. The area was calculated by tracing the outline of the ventral surface of each flake using digital imaging software. Measurements were taken to ensure accuracy and consistency of measurements following the methods outlined in Braun and Harris (2003), Braun (2005) and McPherron and Dibble (1999).
3) EDGE ANGLE: We measured the edge angle of each flake before and after butchery using a modified caliper edge angle measurement developed by Dibble and Bernard (1980). This technique was selected because Dibble and Bernard showed that it was subject to minimal measurement error. The measurement was taken at intervals of 2 cm along the edge of each flake. Edge angle measures were averaged from the multiple measures along the edge to create a composite edge angle measure (Eren et al., 2005). Each flake had between three and six measurements. The location where these measurements were taken was marked with a permanent marker so that the measurement could be repeated after the butchery experiments.

2.3. Cut mark counts

We counted cut marks for CME 1–18 on the long bones and innominates only (Table 1). Cut marks were examined with a 10× hand lens under a bright high incident light (Blumenschine, 1986; Blumenschine et al., 1996). Although some single butchery actions (=strokes) can simultaneously leave multiple incisions, for our purposes here in quantifying the damage this might cause to a stone tool, any single incision was counted as a separate cut mark.

2.4. Statistical analysis

We tested three null hypotheses using three different variables to identify any correlation between the number of cut marks produced and stone tool edge attrition:

Table 1
Numbers of cut marks on hindlimbs from experimental butcheries

Experiment	Cut mark count
CME 1 (*Bos taurus*)	30
CME 2 (*Bos taurus*)	45
CME 3 (*Bos taurus*)	82
CME 4 (*Bos taurus*)	47
CME 5 (*Bos taurus*)	66
CME 6 (*Bos taurus*)	94
CME 7 (*Ovis aries*)	49
CME 8 (*Ovis aries*)	33
CME 9 (*Ovis aries*)	18
CME 10 (*Ovis aries*)	51
CME 11 (*Ovis aries*)	76
CME 12 (*Ovis aries*)	22
CME 13 (*Equus burchelli*)	133
CME 14 (*Equus burchelli*)	295
CME 15 (*Equus burchelli*)	163
CME 16 (*Equus burchelli*)	232
CME 17 (*Equus burchelli*)	236
CME 18 (*Equus burchelli*)	183

1) H_0: The total number of cut marks in the experimental assemblage will have no significant correlation with proportional flake area lost.
2) H_0: The total number of cut marks in the experimental assemblage will have no significant correlation with proportional edge angle change.
3) H_0: The total number of cut marks in the experimental assemblage will have no significant correlation with proportional flake mass lost.

Because these samples do not meet the assumptions of the least squares regression we used the non-parametric correlation coefficient (Kendall's Tau) to describe the goodness of fit between cut mark count and the three measures of flake edge attrition. To account for differences in initial flake size and shape prior to the different butchery tasks we normalized each value as a proportion of the original value. The following formulae describe the values expressed in the figures and analyses:

1) Proportional mass lost is calculated as

$$\left(M_{\text{Before}} - M_{\text{After}}\right) / M_{\text{Before}} * 100$$

where M_{Before} is the mass of the flake prior to butchery and M_{After} is the mass of the flake after the butchery task was complete.

2) Proportional area lost refers to the change in the area as measured with digital imaging software, and is calculated as

$$\left(A_{\text{Before}} - A_{\text{After}}\right) / A_{\text{After}} * 100$$

where A_{before} represents the area of the flake prior to each butchery task and A_{after} represents the area after the butchery task was complete. As the change in flake area is small we digitized each flake three times prior to butchery and three times after butchery. The values in this analysis represent the differences between the mean of these three separate calculations of flake area.

3) Proportional change in angle refers to the change in the proportional edge angle measurement, and is calculated as

$$\left(V_{\mathrm{Before}} - V_{\mathrm{After}}\right) / V_{\mathrm{Before}} * 100.$$

where V_{Before} represents the composite angle measure prior to butchery and V_{After} represents the composite angle measure after the butchery task was complete. Several of these edge angle measurements were taken on each flake, therefore the measurements in this analysis are a composite measurement for each tool that represents the average proportional angle change.

We examined the relationship between stone tool edge dulling (as quantified in the three measures of tool attrition described above) and three butchery activities (skinning, disarticulation, and defleshing) to identify any significant differences in these variables during various butchery tasks. We chose the Mann–Whitney U-test for independent samples to compare these different butchery activities to one another because small sample sizes precluded the use of parametric tests.

Table 2
Correlation coefficients (Kendall's $\mathrm{Tau_b}$) and associated significance values for correlations between measures of edge attrition and cut mark count

Measure of edge attrition	Kendall's $\mathrm{Tau_b}$	Significance
Proportional flake area lost	0.072	0.67
Proportional edge angle change	−0.098	0.57
Proportional flake mass lost	−0.270	0.12

3. Results

Our tests of the association between cut marks and edge attrition found that the variation in the number of cut marks produced during a specific defleshing event cannot explain the variation in edge attrition in three separate measures of attrition (Table 2). None of the correlation coefficients are significant to the $p = 0.05$ or even $p = 0.1$ level of significance (Fig. 1a–c). We therefore cannot reject any of the null hypotheses stated above, and have found no statistical support for the

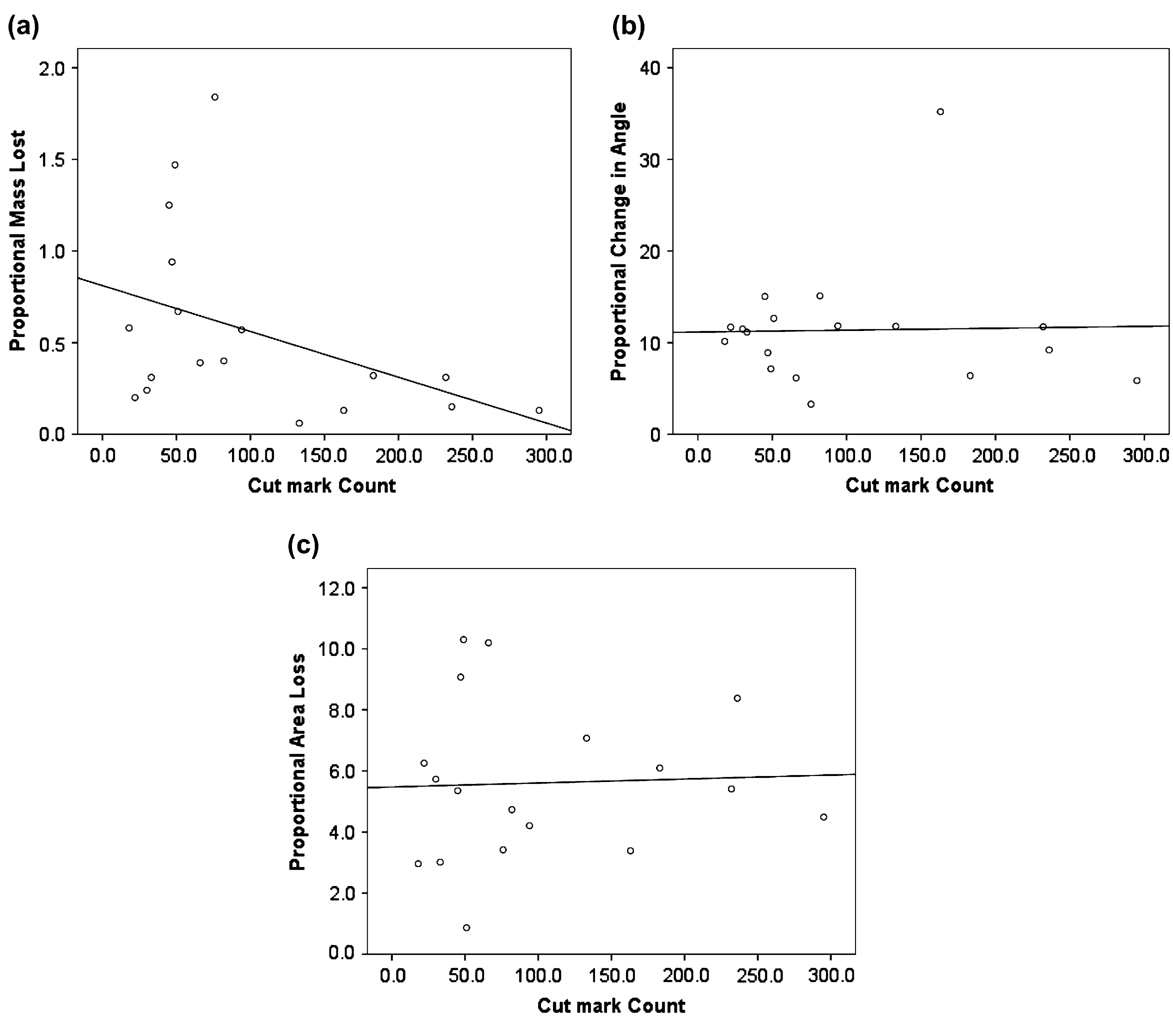

Fig. 1. Three separate measures of edge attrition correlated with the number of cut marks associated with that experiment showing a lack of significant correlation between measures of edge attrition and cut mark count. (a) Proportional mass loss; (b) proportional change in edge angle; and (c) proportional flake area loss. These values are normalized to account for differences in flake shape and size. Regression lines are based on least squares regression. Evaluation of the statistical strength of the relationship between each set of variables can be found in Table 2.

assumption that infliction of cut marks causes significant dulling of stone tool edges.

However, investigation of different butchery activities did show significant differences in edge attrition. Fig. 2a–c display the median and interquartile ranges of all three of the measurements of stone tool attrition, and Table 3 summarizes the results of the Mann–Whitney U-test. Proportional area loss and proportional change in angle both show significant differences between defleshing and skinning and disarticulation samples respectively at below the $p = 0.01$ level of significance. However, proportional mass loss does not show significant differences between the different butchery tasks. Given that two of the three measures of edge attrition show highly significant differences between certain butchery activities, we conclude that there are much higher attrition rates in flakes used for skinning and disarticulation than those used for defleshing only.

4. Discussion

The results of our experiments provide no statistical support for Bunn's (2001) inference that hominins took measures to reduce the likelihood of tool-bone contact because of potential edge dulling caused by cut mark production. Our results also lead to the expectation that tool discard behavior should not necessarily be associated with high frequencies of cut-marked bone, and this expectation can be tested at a variety of archaeological localities. A brief investigation of stone artifact discard patterns at Early Stone Age sites suggest that hominins are discarding artifacts at very high rates even at sites when there is very little evidence of butchery activity (Table 4). However, we still expect that stone tool discard rates may be associated with the degree of edge attrition. Given the differences in tool edge attrition described in this study, the frequency of different types of tasks may have had a substantial effect on rates of tool discard at different archaeological localities. This raises the possibility that stone tool discard was linked to butchery activities that did not always result in high numbers of cut marks.

Our experiments show that two specific butchery activities (skinning and disarticulation) cause significantly more edge attrition than regular defleshing activities. When hominins were engaged in these activities, their tools are likely to have had shorter use lives. Ethnographic data suggest that the nature of flake edges was a major factor in tool selection and use (Hayden, 1979). Further, edge abrasion of utilized flakes is suggested to be very high during skinning activities (Hayden, 1979). Shott and Sillitoe (2005) have reviewed

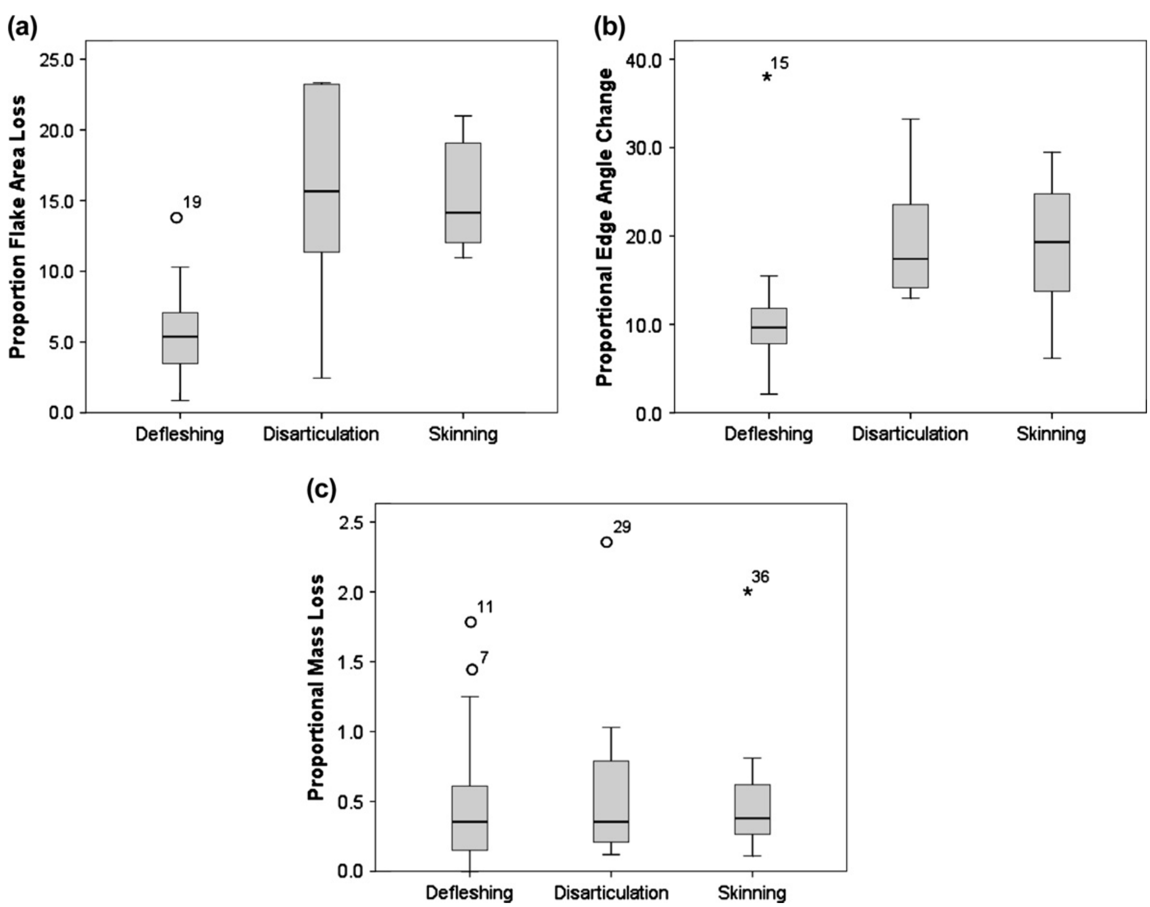

Fig. 2. Edge attrition measured by three separate measures (a: proportional flake area lost during butchery; b: proportional mass lost during butchery; c: proportional change in edge angle during butchery) in whole flakes used for different butchery activities. Samples of whole flakes varied for different butchery activities (Defleshing: $n = 26$ [18 from CME 1–18 and 8 from CME A and B]; Skinning $n = 8$ [CME A and B]; Disarticulation $n = 8$ [CME A and B]).

Table 3
Results of Mann–Whitney *U*-test for independent samples showing significant differences in two measures of edge attrition between defleshing and disarticulation samples as well as defleshing and skinning samples

Mann–Whiney *U*-test						
	Proportional area loss		Proportional change in angle		Proportional mass loss	
Defleshing vs. disarticulation						
	U	27	*U*	16	*U*	95
	Z	−3.126	Z	−3.573	Z	−0.345
	signif.	0.001	*signif.*	0.0001	*signif.*	0.735
Defleshing vs. skinning						
	U	4.00	*U*	40	*U*	95
	Z	−4.060	Z	−2.598	Z	−.366
	signif.	0.0001	*signif.*	0.008	*signif.*	0.715

ethnographic evidence of stone tool butchery and suggested that the use life of butchery tools is often very short (in matters of hours to days). Sillitoe (1982) reports use-life values of up to weeks at a time for simple flake tools, although completion of a task is the most frequent reason for discard. As Early Stone Age toolkits are primarily simple flake and core industries, the use life of stone tools in Oldowan assemblages was probably associated with the relative sharpness of their edges.

Discard rates of stone tools are clearly associated with raw material availability (Marks, 1988; Potts, 1994), and comparisons of numbers of artifacts across localities is little more than anecdotal without raw material availability information. Furthermore, if the degree of tool edge damage affected tool discard rates then it is likely that physical properties of different raw materials would also affect the use life of artifacts (Greenfield, 2006; Lerner et al., 2007). Rates of edge attrition are likely much higher for tools made from less durable materials (e.g. obsidian; Cotterell and Kamminga, 1990) and subsequently discard rates may be much higher for these materials. In contexts where raw material sources for stone are scarce it is likely that conservation of stone raw material will prompt hominins to extend the use life of their tools (Brantingham et al., 2000; Dibble, 1995; Dibble and Rolland, 1992; Roth and Dibble, 1998). Because the simple production of cut marks are not demonstrated to dull stone tool edges, the abundance of cut marks in an assemblage is not likely to be linked to the amount of effort that was directed at conservation of raw material sources (Odell, 1996). However, the sheer volume of lithic material deposited at many archaeological sites suggests that activities that drastically reduce the use life of flake tools are being carried out at these archaeological localities and providing the impetus for stone tool discard.

Presently, the best evidence for stone artifact use in the Plio-Pleistocene is the presence of striae made by tool edges on the surfaces of bones (Bunn, 1981; Potts and Shipman, 1981). Although hominins were certainly using stone tools for other activities such as plant processing (Dominguez-Rodrigo et al., 2001), cut-marked bones show that hominins were definitely using stone tools to butcher carcasses. However, there are also high frequencies of stone artifacts found at sites that have relatively little evidence of hominin butchery. Extensive evidence of transport of flakes suggests that even simple elements of the hominin toolkit may have been used for several tasks (Bunn et al., 1980; Schick, 1987; Toth, 1985). If defleshing activities have less effect on the edges of tools, as our experiments suggest, an alternative explanation for why so many artifacts are discarded at Early Stone Age archaeological sites may be that the tools were used for activities that are not producing evidence in the form of modification on bone surfaces of bone portions that are commonly preserved, such as skinning, disarticulation, and possibly processing plant matter.

A recent review of Plio-Pleistocene sites that preserve evidence of hominin butchery activities advocates the view that hominins may have had earlier access to carcasses than previously suggested (Dominguez-Rodrigo and Pickering, 2003). Early access to carcasses may have necessitated a greater variety of butchery activities that would have included skinning and disarticulation as well as flesh removal, and our experiments have shown that the high rate of stone tool discard at many Plio-Pleistocene sites may therefore offer supporting evidence for a pattern of early access. Our experiments further introduce an explanation for why some sites with high frequencies of discarded stone tools do not consistently also have high frequencies of cut-marked bones. Butchery activities may have varied across the landscape, depending on the

Table 4
Early Stone Age archaeological localities and the number of artifacts and associated cut-marked bones

Site/level	Number of excavated lithics	Number of excavated cut-marked bones	Source
FLK 22 (*Zinj*)	2647	252	Potts (1988), Bunn and Kroll (1986)
FLKN6	130	5	Potts (1988), Bunn (1982)
FLKNN1-2	1205	1	Bunn (1982), Leakey (1971)
HWKE1-2	467	5	Leakey (1971), Monahan (1996)
BK	6801	46	Leakey (1971), Monahan (1996)
MNK Main	4399	13	Leakey (1971), Monahan (1996)
Sterkfontein Member 5	3245	1	Pickering (1999)
Peninj	354	17	Dominguez-Rodrigo et al. (2002)
EG 13 (Gona)	179	1	Dominguez-Rodrigo et al. (2005), Stout et al. (2005)
FLKN5	151	3	Potts (1988)
DK1,2,3	1198	9	Potts (1988)
Swartkrans Member 3	72	60	Pickering (2004), Brain et al. (1988)

circumstances surrounding each carcass or prey encounter opportunity. These different activities would have resulted in variability in the length of tool use-life, therefore also affecting the number of cut-marked bone fragments, the number of cut marks on these fragments, and the number of discarded stone tools.

An obvious caveat in comparisons between archaeological localities is that they may not be taphonomically equivalent, and simple cut mark counts or cut-marked fragment counts relative to stone tool counts on assemblages with poorly-understood taphonomic histories are only useful in the broadest sense. However, some generally applicable patterns have been established in the zooarchaeological literature with regards to the relationship between butchery activity, cut-marked fragment count, and bone portion survivability. By using these general observations to inform the results of this study, we can make predictions about the archaeological record that can then be more specifically examined on a site-by-site basis.

Different butchery activities will often produce cut marks that are location-specific (Abe et al., 2002; Nilssen, 2000). Many of the traces of disarticulation are focused on or near long bone ends, while traces of defleshing can occur anywhere along the length of the shaft or on other elements such as the ribs and vertebrae. Depending on the method used, skinning can result in cut marks around the carpals, tarsals, and distal metapodia – or none at all. However, taphonomic processes that commonly operate at archaeological sites (carnivore ravaging, sediment compaction, and a variety of other biotic and abiotic processes) result in differential survivorship of elements within a single skeleton – along with the activity-specific cut marks they bear.

Several studies have shown that bone density is a very strong predictor of bone survivability, and that long bone shaft fragments are among the most dense bone portions in the skeleton (Lam et al., 1998, 2003; Lam and Pearson, 2005; Lyman, 1984). We therefore expect that under the majority of taphonomic circumstances, long bone shafts will have higher representation per individual than long bone ends or elements comprised entirely of spongy bone (such as the vertebrae, pelvis, or the small compact bones of the wrist and ankle). The archaeological implication is that although skinning and disarticulation have been shown to increase the degree of edge attrition on simple flake tools relative to defleshing, yet defleshing marks may be preserved relatively more often – even in association with stone tools that may have been discarded as a result of skinning and disarticulation damage to their edges.

5. Conclusion

Our experiments provide no support for the assumption that there is a direct relationship between the production of cut marks and the dulling of a stone tool edge. Bunn's (2001) assertion that Paleolithic butchers actively reduce the likelihood of producing cut marks during butchery activities is therefore also not supported by this experiment. Furthermore, tool edge attrition is much higher in butchery activities that are not usually associated with cut mark production. Butchers that were skinning or disarticulating carcasses would reduce the use life of their artifacts relative to butchers that were defleshing only. Thus, it is possible that as the frequency of skinning and disarticulation increased at archaeological localities, discard rates of stone tools would have also increased – but without leaving a corresponding archaeological signature on the fossils.

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References

Abe, Y., Marean, C.W., Nilssen, P.J., Assefa, Z., Stone, E.C., 2002. The analysis of cutmarks on archaeofauna: a review and critique of quantification procedures, and a new image-analysis GIS approach. American Antiquity 67, 643–663.

Blumenschine, R.J., 1986. Carcass consumption sequences and the archaeological distinction of scavenging and hunting. Journal of Human Evolution 15, 639–659.

Blumenschine, R.J., Marean, C.W., Capaldo, S.D., 1996. Blind tests of interanalyst correspondence and accuracy in the identification of cut marks, percussion marks, and carnivore tooth marks on bone surfaces. Journal of Archaeological Science 23, 493–507.

Brain, C.K., Churcher, C.S., Clark, J.D., Grine, F.E., Shipman, P., Susman, R.L., Turner, A., Watson, V., 1988. New evidence of early hominids, their culture and environment from the Swartkrans cave, South Africa. South African Journal of Science 84, 828–835.

Brantingham, P.J., Olsen, J.W., Rech, J.A., Krivoshapkin, A.I., 2000. Raw material quality and prepared core technologies in northeast Asia. Journal of Archaeological Science 27, 255–271.

Braun, D.R., 2005. Examining flake production strategies: examples from the middle Paleolithic of Southwest Asia. Lithic Technology 30, 107–125.

Braun, D.R., 2006. Ecology of Oldowan Technology: Koobi Fora and Kanjera South, Anthropology. Rutgers University, New Brunswick.

Braun, D.R., Harris, J.W.K., 2003. Oldowan: Rather More Than Smashing Stones. In: Moreno, J.M., Torcal, R.M., Sainz, I.T. (Eds.), Technological developments in the Oldowan of Koobi Fora: innovative techniques of artifact analysis. University of Barcelona Press, Barcelona, pp. 117–144.

Bunn, H.T., 1981. Archaeological evidence for meat-eating by Plio-Pleistocene hominids from Koobi Fora and Olduvai Gorge. Nature 291, 574–577.

Bunn, H.T., 1982. Meat-eating and Human Evolution: Studies on the Diet and Subsistence Patterns of Plio-Pleistocene Hominids in East Africa, Anthropology. University of California, Berkeley.

Bunn, H.T., 1986. Patterns of skeletal representation and hominid subsistence activities at Olduvai Gorge, Tanzania, and Koobi Fora, Kenya. Journal of Human Evolution 15, 673–690.

Bunn, H., 2001. Hunting, Power-Scavening, and Butchering by Hadza Foragers and by Plio-Pleistocene Homo, Meat-Eating and Human Evolution. Oxford University Press, Oxford. 199–218.

Bunn, H.T., Kroll, E.M., 1986. Systematic butchery by Plio-Pleistocene hominids at Olduvai Gorge, Tanzania. Current Anthropology 27, 431–452.

Bunn, H., Harris, J.W.K., Isaac, G., Kaufulu, Z., Kroll, E., Schick, K., Toth, N., Behrensmeyer, A.K., 1980. FxJj50: an early pleistocene site in northern Kenya. World archaeology 12, 109–136.

Cotterell, B., Kamminga, J., 1990. Mechanics of Pre-industrial Technology. Cambridge University Press, Cambridge.

de Heinzelin, J., Clark, J.D., White, T., Hart, W., Renne, P., WoldeGabriel, G., Beyene, Y., Vrba, E., 1999. Environment and behavior of 2.5-million-year-old Bouri hominids. Science 284, 625–629.

Dibble, H.L., 1995. Middle Paleolithic scraper reduction: background, clarification, and review of the evidence to date. Journal of Archaeological Method and Theory 2, 299–368.

Dibble, H.L., Bernard, M.C., 1980. A comparative study of basic edge angle measurement techniques. American Antiquity 45, 857–865.

Dibble, H.L., Rolland, N., 1992. On assemblage variability in the Middle Palaeolithic of Western Europe: history, perspectives, and a new synthesis. In: Dibble, H.L., Mellars, P.A. (Eds.), The Middle Paleolithic: Adaptation, Behavior, and Variability. University of Pennsylvania, Philadelphia, pp. 1–28.

Dominguez-Rodrigo, M., 1999. Distinguishing between apples and oranges: the application of modern cut-mark studies to the Plio-Pleistocene (a reply to Monahan). Journal of Human Evolution 37, 793–800.

Dominguez-Rodrigo, M., Pickering, T.R., 2003. Early hominid hunting and scavenging: a zooarcheological review. Evolutionary Anthropology 12, 275–282.

Dominguez-Rodrigo, M., Serrallonga, J., Juan-Tresserras, J., Alcala, L., Luque, L., 2001. Woodworking activities by early humans: a plant residue analysis on Acheulian stone tools from Peninj (Tanzania). Journal of Human Evolution 40, 289–299.

Dominguez-Rodrigo, M., de la Torre, I., de Luque, L., Alcala, L., Mora, R., 2002. ST Site complex at Peninj, west Lake Natron, Tanzania: implications for early hominid behavioral models. Journal of Archaeological Science 29, 639–665.

Dominguez-Rodrigo, M., Pickering, T.R., Semaw, S., Rogers, M.J., 2005. Cutmarked bones from Pliocene archaeological sites, at Gona, Afar, Ethiopia: implications for the function of the world's oldest stone tools. Journal of Human Evolution 48, 109–121.

Eren, M., Dominguez-Rodrigo, M., Kuhn, S., Adler, D.S., Le, I., Bar-Yosef, O., 2005. Defining and measuring reduction in unifacial stone tools. Journal of Archeological Science 32, 1190–1201.

Greenfield, H.J., 2006. Slicing cut marks on animal bones: diagnostics for identifying stone tool type and raw material. Journal of Field Archaeology 31, 147–163.

Hayden, B., 1979. Palaeolithic Reflections: Lithic Technology and Ethnographic Excavations Among Australian Aborigines. Australian Institute of Aboriginal Studies, Canberra.

Isaac, G.L., 1981. Stone Age Visiting Cards; approaches to the study of early land use patterns. In: Hodder, I., Isaac, G.L., Hammond, N.D.C. (Eds.), Patterns of the Past: Studies in Honour of David Clarke. Cambridge University Press, Cambridge, pp. 131–155.

Jones, P.R., 1980. Experimental butchery with modern stone tools and its relevance for Paleolithic archaeology. World Archaeology 12, 153–165.

Lam, Y.M., Pearson, O.M., 2005. Bone density studies and the interpretation of the faunal record. Evolutionary Anthropology 14, 99–108.

Lam, Y.M., Chen, X., Marean, C.W., Frey, C.J., 1998. Bone density and long bone representation in archaeological faunas: comparing results from CT and photon densitometry. Journal of Archaeological Science 25, 559–570.

Lam, Y.M., Pearson, O.M., Marean, C.W., Chen, X., 2003. Bone density studies in zooarchaeology. Journal of Archeological Science 30, 1701–1708.

Leakey, M.D., 1971. Olduvai Gorge: Excavations in Beds I and II, 1960–1963. Cambridge University Press, Cambridge.

Lerner, H., Du, X., Costopoulos, A., Ostoja-Starzewski, M., 2007. Lithic raw material physical properties and use-wear accrual. Journal of Archaeological Science 34, 711–722.

Lyman, R.L., 1984. Bone density and differential survivorship of fossil classes. Journal of Anthropological Archaeology 3, 259–299.

Marks, A.E., 1988. The curation of stone tools during the Upper Pleistocene: a view from the Central Negev. In: Dibble, H.L., Monet-White, A. (Eds.), Upper Pleistocene Prehistory of Western Eurasia. University of Pennsylvania Museum, Philadelphia, pp. 275–286.

McPherron, S.P., Dibble, H.L., 1999. Stone tool analysis using digitized images: lower and middle Paleolithic. Lithic Technology 24, 38–52.

Monahan, C.M., 1996. New zooarchaeological data from Bed II, Olduvai Gorge, Tanzania: implications for hominid behavior in the Early Pleistocene. Journal of Human Evolution 31, 93–128.

Mora, R., de la Torre, I., 2005. Percussion tools in Olduvai Beds I and II (Tanzania): implications for early human activities. Journal of Anthropological Archaeology 24, 179–192.

Nilssen, P.J., 2000. An Actualistic Butchery Study in South Africa and its Implications for Reconstructing Hominid Strategies of Carcass Acquisition and Butchery in the Upper Pleistocene and Plio-Pleistocene, Archaeology. University of Cape Town, Cape Town.

Odell, G.H., 1996. Economizing Behavior and the concept of "Curation". In: Odell, G.H. (Ed.), Stone Tools: Theoretical Insights into Human Prehistory. Plenum Press, New York, pp. 51–80.

Pickering, T.R., 1999. Taphonomic Interpretations of the Sterkfontein Early Hominid Site (Gauteng, South Africa) Reconsidered in Light of Recent Evidence. University of Wisconsin, Madison.

Pickering, T.R., 2004. New data and ideas on the foraging behaviour of Early Stone Age hominids at Swartkrans Cave, South Africa. South African Journal of Science 100, 215–219.

Potts, R., 1988. Early Hominid Activities at Olduvai Gorge. Aldine de Gruyter, Hawthorne, NY.

Potts, R., 1994. Variables versus models of early Pleistocene hominid land-use. Journal of Human Evolution 27, 7–24.

Potts, R., Shipman, P., 1981. Cutmarks made by stone tools on bones from Olduvai Gorge, Tanzania. Nature 291, 577–580.

Roth, B.J., Dibble, H.L., 1998. Production and transport of blanks and tools at the French Middle Paleolithic site of Combe-Capelle bas. American Antiquity 63, 47–62.

Schick, K.D., 1987. Modeling the formation of early stone age artifact concentrations. Journal of Human Evolution 16, 789–807.

Shott, M.J., Sillitoe, P., 2005. Use life and curation in New Guinea experimental used flakes. Journal of Archaeological Science 32, 653–663.

Sillitoe, P., 1982. The lithic technology of a Papua New Guinea highland people. Artefact 7, 19–38.

Stout, D., Quade, J., Semaw, S., Rogers, M.J., Levin, N.E., 2005. Raw material selectivity of the earliest stone toolmakers at Gona, Afar, Ethiopia. Journal of Human Evolution 48, 365–380.

Tactikos, J.C., 2005. A Landscape Perspective on the Oldowan from Olduvai Gorge, Tanzania. Anthropology, Rutgers, the State University of New Jersey, New Brunswick.

Toth, N., 1982. The Stone Age Technology of Early Hominids at Koobi Fora. Kenya: an experimental approach, Anthropology. University of California, Berkeley.

Toth, N., 1985. Oldowan reassessed: a close look at early stone artifacts. Journal of Archaeological Science 12, 101–120.

Toth, N., 1987. Behavioral inferences from Early Stone artifact assemblages: an experimental model. Journal of Human Evolution 16, 763–787.