Configurational approach to identifying the earliest hominin butchers

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The announcement of two approximately 3.4-million-y-old purportedly butchered fossil bones from the Dikika paleoanthropological research area (Lower Awash Valley, Ethiopia) could profoundly alter our understanding of human evolution. Butchering damage on the Dikika bones would imply that tool-assisted meat-eating began approximately 800,000 y before previously thought, based on butchered bones from 2.6- to 2.5-million-y-old sites at the Ethiopian Gona and Bouri localities. Further, the only hominin currently known from Dikika at approximately 3.4 Ma is *Australopithecus afarensis*, a temporally and geographically widespread species unassociated previously with any archaeological evidence of butchering. Our taphonomic configurational approach to assess the claims of *A. afarensis* butchery at Dikika suggests the claims of unexpectedly early butchering at the site are not warranted. The Dikika research group focused its analysis on the morphology of the marks in question but failed to demonstrate, through recovery of similarly marked in situ fossils, the exact provenience of the published fossils, and failed to note occurrences of random striae on the cortices of the published fossils (incurred through incidental movement of the defleshed specimens across and/or within their abrasive encasing sediments). The occurrence of such random striae (sometimes called collectively "trampling" damage) on the two fossils provide the configurational context for rejection of the claimed butchery marks. The earliest best evidence for hominin butchery thus remains at 2.6 to 2.5 Ma, presumably associated with more derived species than *A. afarensis*.

taphonomy | cut marks | hammerstone percussion | abrasion | equifinality

The claims that early hominin tool-assisted butchery of large animal carcasses produced surficial modifications on two approximately 3.4-million-y-old fossil bone specimens (specimens DIK-55–2 and DIK-55-3) from the DK-55 locality (Dikika, Ethiopia) (1) are surprising, considering that (*i*) intentionally made stone tools in isolation or associated with faunal remains are unknown before 2.6 Ma (2–4) and (*ii*) the only known hominin species associated (broadly) temporally with the marked fossils is *Australopithecus afarensis* (5). *Australopithecus afarensis* is a well known species that is documented between 3.6 and 2.9 Ma at sites in Ethiopia, Kenya, and Tanzania (6). Since its discovery in the mid-1970s at Laetoli (Tanzania) and Hadar (Ethiopia), and until the claims from the Dikika Research Project (DRP), *A. afarensis* has never been associated with evidence of the butchery and consumption of large animals. Thus, if the claims for *A. afarensis* tool-assisted butchery withstood scientific scrutiny, paleoanthropologists would be forced to revise a widely accepted view of hominin behavioral evolution. We argue, however, that the DRP claims do not withstand such scrutiny, and thus the earliest best evidence for early hominin, tool-assisted butchery remains that from 2.6- to 2.5-Ma archaeological sites at the Ethiopian localities of Gona and Bouri (2–4).

The DRP's claims of authentic butchered fossils from approximately 3.4 Ma rests on their detailed documentation of the morphology of surficial damage marks on DIK-55–2 and DIK-55–3. The DRP's presentation of those data are state-of-the-art, but their report still lacks in failing to provide—and assess—thoroughly the stratigraphic, depositional, and assemblage contexts of DIK-55–2 and DIK-55–3. Such a holistic assessment of bone surface modifications in zooarchaeology is sometimes referred to as a configurational approach (7–9), explained as such: "First, we must be able to resolve the dilemma posed by the fact that different taphonomic processes can produce similar effects on bones [i.e., equifinality]. This can be accomplished through the use of multiple lines of evidence and comprehensive analytical methods. For example, butchering with stone tools, trampling by large animals in coarse substrates, and gnawing by animals can all produce linear grooves with microscopic, internal, longitudinal striations. . . Thus, although the microscopic, internal striations were initially heralded as the panacea for identifying cut marks made by stone tools. . . it would be risky now to rely solely on them to identify the cause of particular linear grooves. A more appropriate methodology for identifying whether linear grooves are cut marks, gnaw marks, trampling marks, or something else (e.g., excavation-tool marks) employs several diagnostic attributes, including the size, cross-sectional shape, anatomical location, and other macroscopic and microscopic characteristics of a particular linear groove, as well as the depositional and temporal context of the specimen. . . At the assemblage level there are several testable hypotheses for distinguishing the potential misidentification of trample marks as cut marks, including the grain size and angularity of the sedimentary substrate, comparability in the frequency of the alleged cut marks among different skeletal elements of similar shape, and anatomical location of the alleged cut marks. . . It is unfortunate that some researchers continue to make claims for cut marks, especially ones of great antiquity, without meeting any of the accepted criteria for their identification. . ." (ref. 8, p. 453).

Results

The first problem recognized by a configurational appraisal of the DIK-55–2 and DIK-55–3 modifications is that both fossils are surface finds. Their provenience(s) is/are thus unknown and the basis of their attribution to a thick sand bed has been inferred by their purported lack of adhering sediment. We note, however, that adhering matrix is visible in published images of DIK-55–2 and DIK-55–3 and is even mentioned in the descriptions of the fossils in the supplemental materials associated with reference (1). Such adhering matrix is typical of fossils recovered at Dikika from the Sidi Hakoma Member of the Hadar Formation. Because the claims of the DRP are so extraordinary, and because they could also induce a major paradigm shift in paleoanthropology, team members should have sought to link DIK-55–2 and DIK-55–3 to a secure geological context(s) by seeking, through test excavation, similarly preserved fossils in situ. Such was the

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standard procedure to securely link surface finds of butchered fossils to in situ samples at Gona and Bouri (2–4). It is a simple undertaking and it is thus unfortunate that it was not carried out by the DRP in a situation in which the human evolutionary implications are so important.

However, if we accept that DIK-55–2 and DIK-55–3 do indeed come from the massive, poorly sorted sandstone unit below the Sidi Hakoma-1m marker, the configurational approach to their assessment raises a second problem with their interpretation as butchered. The sandstone unit is composed of sand and gravel particles ranging in size from −3φ to 3φ; in other words, it is a sedimentary system bearing particles up to 8 mm in diameter. There are lag deposits at the base of erosional contacts within the sands, which contain rounded gravel clasts. Fossils deposited in such a sedimentary regime are expected to show abrasional modifications [i.e., random striae (9) or "trampling" damage (10)]

on their surfaces, but the DRP did not diagnose any trampling damage on either DIK-55–2 or DIK-55–3 (1). In fact, the DRP explicitly rejected attribution of any of the linear surficial features on DIK-55–2 and DIK-55–3 to trampling or other incidental movement on/in their sedimentary substrate(s) because the DRP did not diagnose two common trampling modifications—microabrasion, in the form of very shallow, randomly distributed striations, and shallower striations that intersect deeper trampling grooves (oblique intersecting striations) (11)—on the two fossils. Although it is true that these two types of shallow trampling damage do occur on most specimens in a large sample of modern, experimentally trampled bones (11), their expression requires excellently preserved bone surfaces.

DIK-55–3 is the fossil of a subadult bone (1). Published images of the specimen reveal, on better-preserved portions of the fossil, a vascularized periosteal histology, typical of subadult mamma-
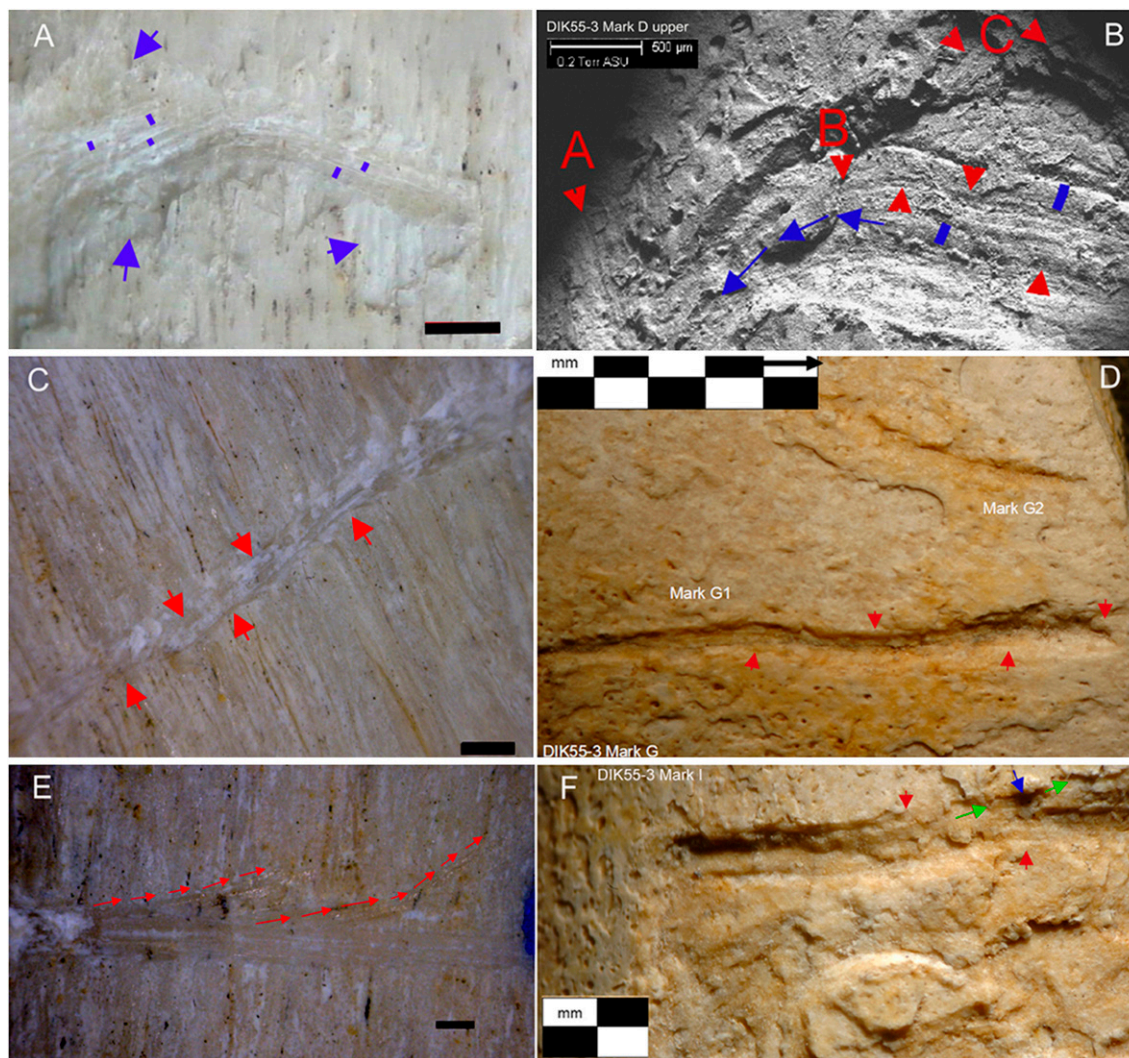

Fig. 1. Experimentally produced trampling mark showing two divergent trajectories; the mark also has heterogeneously spaced microstriations (blue bars) and shallow pseudopits resulting from lamellar flaking (blue arrows) (*A*). This modern trampling mark compares favorably in morphology to mark D, a purported butchery mark on the DIK-55–3 fossil (details in *Results*) (*B*). Experimentally produced trampling groove showing a winding trajectory and internal microstriations (red arrows indicate the groove's inflection points) (*C*) and a remarkable morphological similarity (in size, shape, and trajectory) to mark G1, a purported butchery mark on the DIK-55–3 fossil (*D*). Broad, experimentally produced trampling mark showing two sets of ancillary grooves (red arrows) abandoning the mark's main groove and creating a curved trajectory on to the shoulder of the main groove; we infer that each of these ancillary grooves was created by a single sedimentary particle (*E*). Mark I on the DIK-55–3 fossil shows an identical ancillary effect of a single abrasive particle leaving the mark's main groove (details in *Results*) (*F*). The image in *A* is courtesy of R. Blasco and J. Rosell. The images in *B*, *D*, and *F* are modified from McPherron et al. (1). (Scale bars: 1 mm in *A*, *C*, and *E*.)

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lian long limb bones. Based on their experimental observations, Domínguez-Rodrigo et al. (11) eliminated such subadult bone specimens from their comprehensive study of trampling damage because such bones' surfaces are insufficient to securely infer the causal actions that produced linear modifications on them. The published images of DIK-55–2 suggest its cortex is relatively well preserved, but that the original periosteal surface may not be intact at the submillimeter level. For instance, the cortex of DIK-55–2 shows seemingly moderate weathering in the form of a reticulated pattern of cracking that is associated with breaks that are perpendicular and parallel to the specimen's long axis. Judging from the image of DIK-55–2, this pattern of surface degradation might be attributed to dehydration and dry breakage of the specimen (12, 13). In addition, the edges of some of the major fracture lines on DIK-55–2 appear rounded off in some images. This rounding might indicate subsequent weathering of DIK-55–2 by the action of water and/or soil chemicals. A final point regarding trampling microabrasion is that its occurrence is much lower on specimens that have been simply stepped upon, rather than abraded in sediments for a number of seconds up to a number of hours (10, 11, 14).

Within this actualistic framework, given that the inferred sedimentary matrix of DIK-55–2 and DIK-55–3 is probably highly abrasive—meaning that trampling damage and/or other types of abrasive linear damage is likely on its encased fossils—the repor-

ted absence of shallow microabrasion and oblique intersecting striations cannot guarantee that the marks identified as butchery damage on those fossils were not, instead, caused by trampling or some other incidental movement of specimens within their matrix. More than that, and contrary to the claims of the DRP, some of the shallow, isolated striations on DIK-55–3 compare very favorably to the morphology and configuration of microabrasion (see marks A and C, indicated by red arrows, in Fig. 1B).

To address the Dikika butchery hypothesis most persuasively we must, however, deal directly with the purported butchery marks themselves. The first of two types of supposed butchery marks on DIK-55–2 and DIK-55–3 are long grooves that are purportedly V-shaped in cross-section (1). Close examination of the images of such marks on DIK-55–3 reveals, however, that most of them are not actually V-shaped. If they were, each would show a single thin line at its base that separates two steeply intersecting walls. Instead, most of the DIK-55–3 marks actually appear in cross-section with a base that is commonly broader than the heights of the walls of the groove (i.e., __/). Further, in most cases on DIK-55–3, the groove trajectories of the marks are curved or sinuous. Ninety-six percent of experimental trampling grooves display a broad-based, open cross-section with the aforementioned shape, versus just 4% of experimental grooves inflicted by simple (i.e., unmodified) stone flakes used to cut meat from bones (11). In addition, curvy and sinuous groove trajecto-
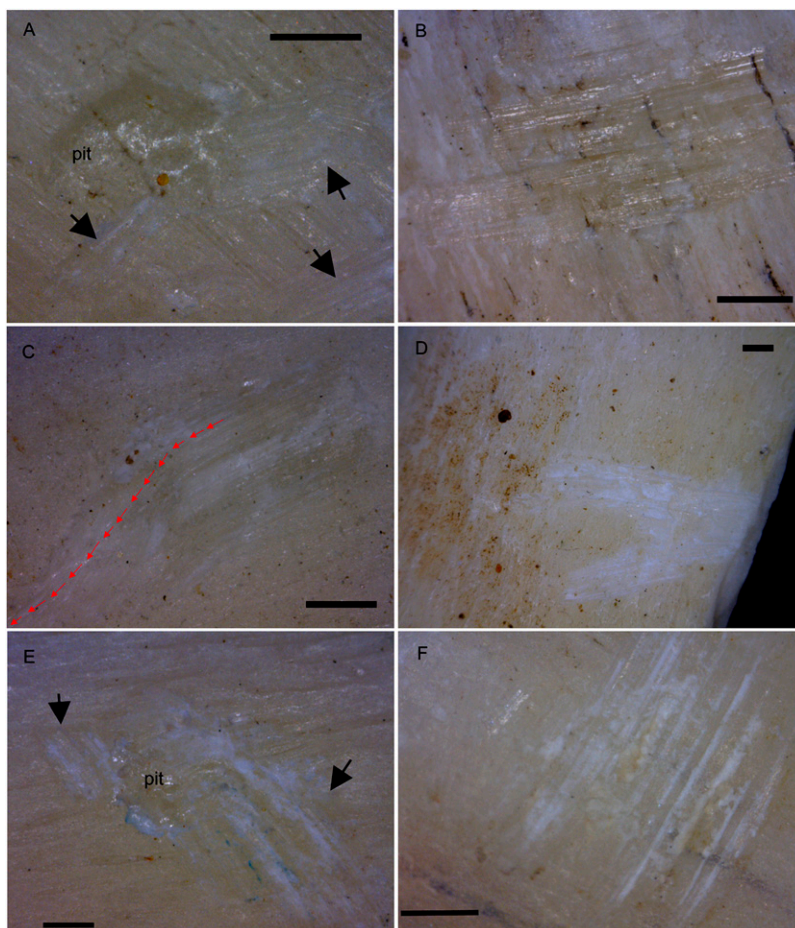

Fig. 2. Examples of striae fields created by experimental trampling (see also ref. 17): pit associated with microstriations (*A*); isolated striae field with straight trajectory (*B*); isolate striae field with winding trajectory (*C*); and microstriations emanating from the green fracture edge of a bone specimen (*D*). The striae fields illustrated in *B* and *C* are morphologically indistinguishable from bone surface marks B and C on the DIK-55–2 fossil and mark D on the DIK-55–3 fossil posited to be stone tool scraping and percussion damage. Compare these incidences of bone surface damage to the pit and associated sets of microstriations (arrows) (*E*) and isolated striae field (*F*) created by experimental hammerstone. (Scale bars: 1 mm.)

ries characterize nearly 70% of experimental trampling marks, compared with just 10% of experimental cutmarks created with simple flakes (11). Together, these experimental results provide a robust actualistic context to evaluate illustrated marks F, G, H2, and I on DK-55–3 as high-probability trampling damage and not stone tool cut or percussion marks, as asserted by the DRP (Figs. 1 and 2).

The red arrows in Fig. 1*B* (near the letter B) and Fig. 1 *D* and *F* map the sinuous outlines of shallow, broad-based grooves with the aforementioned shape, with microstriations (for marks G1 and I in Fig. 1 *D* and *F*, respectively) and microstriation field with adjacent flaking (for the upper part of mark D in Fig. 1*B*); these marks also have irregular and sometimes discontinuous trajectories, further features that are more commonly observed in trampling marks rather than in butchery marks of experimental (known) origins (11). Likewise, mark H2 (Fig. 3*B*), with its broad, shallow section and sinuous microstriations, and subparallel trace to the long axis of DIK-55–3, is classic example of a trampling mark (compare the morphologies of mark H2 in Fig. 3*B* vs. a modern trampling mark in Fig. 3*D*). In addition, mark H2's proximity to mark H1 (Fig. 3*B*) reinforces our inference that the latter mark also resulted from trampling, as it consists of concentric lamellar flaking near DIK-55–3's distal breakage plane and is associated with small notches along that breakage plane—damage features documented on experimentally trampled bones (15) (Fig. 3*A*). Another ancillary effect of trampling is

observed in mark I (Fig. 1*F*), where sinuous damage from a single sediment particle leaves the mark's main groove (left, green arrow, Fig. 1*F*) is punctuated by a distinct pit (blue arrow) and then continues as a striation on the shoulder of the mark's main groove (right, green arrow) (Fig. 1 *E* and *F*).

Mark D (Fig. 1*B*) is particularly complex and informative; it also illustrates striae fields, the second supposed butchery mark documented on DIK-55–2 and DIK-55–3 by the DRP. The lower part of mark D (Fig. 1*B*; with reference to its illustration in fig. 3 of ref. 1) shows multiple striations, some straight and some curved, with an intersecting striation and even an isolated area of shallow microabrasion. The origin of these occurrences is ambiguous, but the upper part of mark D (Fig. 1*B*) manifests features more securely diagnostic of trampling than of butchery, including a flaked area with a clear striae field that shows a sinuous trajectory of its microstriations (compare red arrows by B in Fig. 1*B* versus similar features in a trampling mark in Fig. 1*A*). Further, these microstriations are occasionally interrupted, are widely separated (Fig. 1*B*, blue bars), and are of varying depths. As opposed to hammerstone-imparted striae fields, which usually show more tightly packed, less-separated microstriations (16, 17), the mark D striae field (Fig. 1*B*) was likely caused by incidental movement across a substrate or within a sedimentary matrix in which separate particles of various sizes abraded the surface of DIK-55–3 simultaneously and on the same trajectory (compare with Fig. 1*A*). At the edge of mark D's flaked area (Fig. 1*B*, B), the striae field
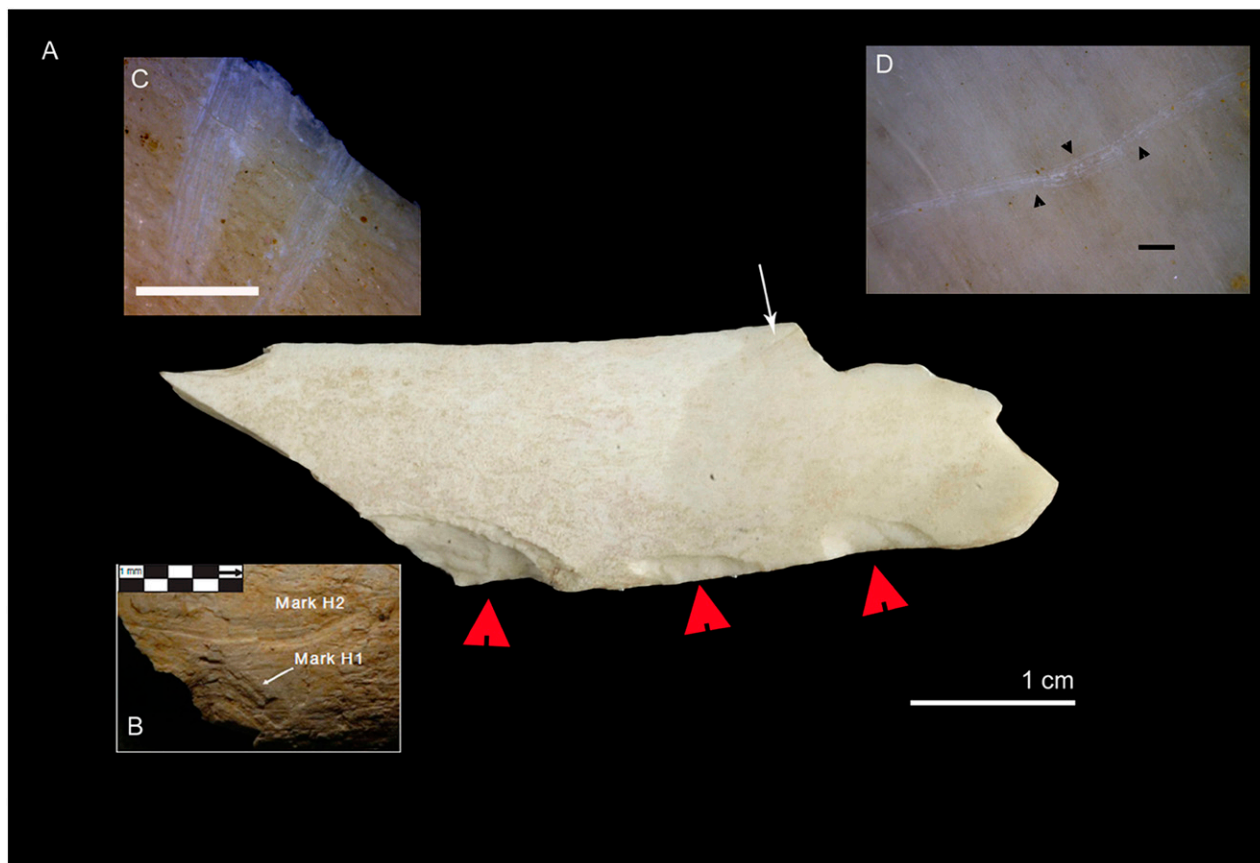

Fig. 3. Modern ungulate long limb bone shaft fragment that was experimentally trampled, showing damage typical of that action, including small fracture edge notches and micronotches and conchoidal flaking of its cortical surface (red arrows) and linear trampling marks (white arrow) (*A*). Marks H1 and H2 on the fossil DIK-55–3, which show, respectively, small notching and conchoidal flaking (H1) and a winding trajectory (H2) (*B*) that are similar to the modern bone surface trampling damage illustrated in *A*, *C*, and *D*. The winding shallow groove of mark H2 emanates from the fossil's breakage plane, as is common in trampled bones, including that illustrated in *C*. Note also the shallowness, winding trajectory, and internal microstriations of the experimentally produced trampling mark in *D*. The image in *A* is courtesy of R. Blasco and J. Rosell. The image in *B* is modified from McPherron et al. (1). (Scale bars: 1 mm in *C* and *D*.)

curves left and downward (blue arrows), leading to perpendicular striations caused by the intersection of mark G1 (Fig. 1B, A). The presence of isolated shallow striations (Fig. 1B, C, red arrows) away from the striae field also suggests microabrasion.

We note further that there is an even more general reason for caution in diagnosing striae fields as evidence of ancient hominin tool behavior; studies not cited by the DRP have demonstrated that some striae fields caused by animal trampling can mimic exactly those created by hammerstone percussion (17, 18) (Fig. 2). Mark B on DIK-55–2 is a prime example of an ambiguous isolated striae field. The mark, with its broad and shallow form and curved trajectory, is certainly not a cut mark, and the narrow separation of its two sets of microstriations would seem to eliminate its assignment as either a scraping mark or a percussion mark, and instead support the interpretation that it is a trampling mark, which commonly manifest adjacent striae fields (11).

These alternative interpretations of the DIK-55–2 and DIK-55–3 mark morphologies, and an appreciation of the high abrasiveness of their probable geological context, provide a maximally conservative perspective for evaluating the claims of the morphologically strongest evidence of possible cut marks in the DIK-55–2/DIK-55–3 mark sample. Marks A1 and A2 on DIK-55–2 are morphologically compelling in their similarity to verified cut marks created by stone tools used in experimental butcheries: the marks show deep, V-shaped cross-sections and contain microstriations. In a less contentious context, the marks would likely be accepted as genuine cutmarks. However, the prominence of high-probability trampling damage (described earlier) on both DIK-55–2 and DIK-55–3 casts doubt on that diagnosis in this case—a geologically coarse-grain context older than the earliest known stone tools. Skepticism should be the guiding principle in such a context, and we are, indeed, skeptical about the purported butchery origins of marks A1 and A2. Beyond our contextually provoked doubt, we also note the high degree of similarity in morphology between marks A1 and A2 to some of those created by experimental trampling, illustrating once again the pervasive and confounding insertion of equifinality into bone surface modification analyses in zooarchaeology (Fig. 4).

Discussion

Theoretically, there is no reason to deny, a priori, the hypothesis of a well developed degree of carnivory in *A. afarensis* and/or other pre-stone tool/non-stone-tool-using hominins (19, 20). The Dikika "butchery mark" evidence does not, however, withstand peer scrutiny undertaken from an actualistic perspective and with a configurational approach. Our approach in assessing the Dikika claims was intentionally conservative: the claims are extraordinary because of their singularity and because of the inferred age of the fossils. Thus, natural processes of bone modification need to be eliminated before precluding nonanthropogenic origin(s) for the surficial marks on DIK-55–2 and DIK-55–3. High probability trampling damage on both specimens does not allow for this elimination and, again, taking our contextualized, maximally conservative position, forces us to reject even marks A1 and A2, the two morphologically strongest claims of cutmarks on DIK-55–2.

McPherron et al. (1) suggest that the Dikika bone surface marks might have been created by hominins using unmodified, naturally occurring stones (as an aside, if this was the case, one wonders why no such stones were found at the DIK-55 locality). It could be argued that this is the reason that the forms of most of the Dikika bone surface marks generally fall outside the observed morphologies of butchery marks created experimentally using intentionally flaked stones. However, this explanation fails for marks A1 and A2 as their deep V-shaped cross-sections can be produced only by exceptionally sharp effectors, such as an intentionally created flake or an angular gravel clast, and they are the unlikely results of the irregular, natural edges of a rock.
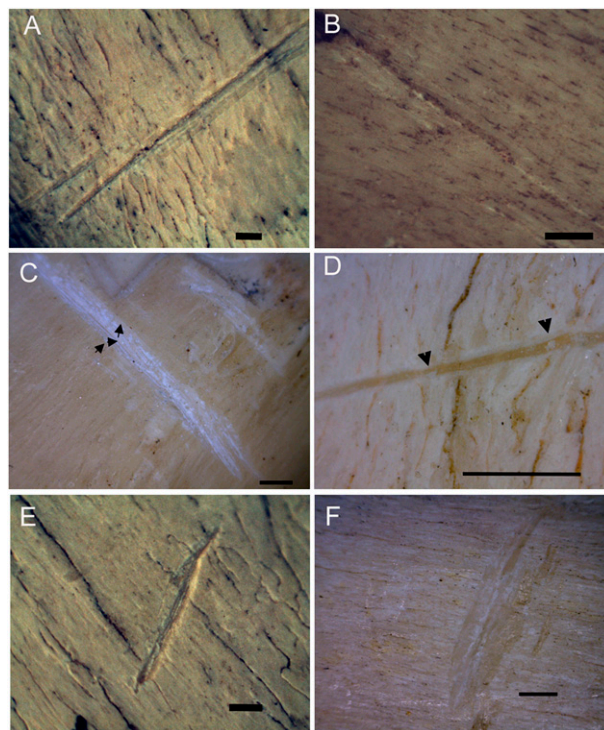

Fig. 4. Examples of modern bone surface marks that are V-shaped in cross-section and were created by trampling in gravel sediment. They range in morphology from broad grooves like marks A1 and A2 on the DIK-55–2 fossil (A, F) to much narrower grooves (D). All of the modern trampling marks have internal microstriations. Modern marks illustrated in A–C are longer than fossil marks A1 and A2. The V-shaped trampling mark illustrated in D preserves sedimentary particles in its main groove, just as does mark A2 on DIK-55–2. The trampling damage illustrated in E shows the overlap of a short mark at the top and longer one with a different trajectory, similar to the damage on the DIK-55–3 fossil. The trampling mark illustrated in F is short and wide, morphologically very similar to marks A1 and A2 on the DIK-55–2 fossil. (Scale bar: 1 mm.)

There are gaps in our actualistic dataset. To our knowledge, no one has yet published results of butchery experiments using unmodified, naturally occurring stones, but the onus to fill that gap falls on anyone who contends such a possibility to explain the anthropogenic origins of the Dikika marks. Until then, we can only apply the results of published experiments that used more conventional lithological effectors, e.g., intentionally produced stone artifacts and sedimentary particles. We might predict that, because of their irregularity, the naturally sharp edges of unmodified stones will produce cut marks more similar in morphology to those created by retouched flakes (*Methods*) and trampling marks than do cut marks created by simple, unmodified flakes. This remains to be tested, but we doubt any range of marks produced in the as-yet hypothetical experiments will negate our diagnosis of the significant occurrence of random striae on DIK-55–2 and DIK-55–3.

Thus, until and if stronger causal links are demonstrated between the DK-55 bone surface marks and hominin taphonomic agents, the 2.6- to 2.5-million-y-old butchery marked fossil from Gona and Bouri stand as the earliest, best evidence of the tool-assisted reduction of large animal carcasses by hominins (2–4). The surficial damage on the Gona and Bouri specimens not only matches the morphology of known cut and percussion marks, but the fossils bearing those marks are also from secure in situ geological contexts and at Gona are associated spatially with flaked stone tools. It is therefore premature to posit the existence

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of an archaeologically invisible pre-Oldowan Industrial Complex based on the evidence from Dikika.

Methods

There are well accepted mark morphology criteria to differentiate bone surface damage imparted by hominins by using stone tools from that inflicted by nonhominin biotic agents, such as carnivorous mammals and reptiles (e.g., tooth marks), rodents (e.g., gnawing), and plants and fungi (e.g., biochemical erosion; e.g., refs. 7–9, 21–24). In contrast, distinguishing between stone tool-assisted butchery marks and random striae (including trampling damage) is less clear-cut because both types of damage are induced by abrasive lithological effectors. However, a recent multivariate statistical analysis of experimentally produced stone tool cut marks and trampling marks demonstrated that the marks can be successfully discriminated in greater than 90% of cases (11). Most of the trampling marks produced in some experiments were caused by gravel particles ranging between 2.6 mm and 10.3 mm (mean ± SD, 5.9 ± 1.7 mm) in diameter (these statistics were arrived at by removing the sand component from the sand–gravel mix in which the experiments were conducted and then measuring the largest remaining gravel particle; 49 more gravel particles were also selected randomly and measured).

We used the following criteria, based on the results of Domínguez-Rodrigo et al. (11), in our critical assessment and falsification of the Dikika butchery mark hypothesis. Cut marks made with simple, unmodified stone flakes are usually V-shaped in cross-section, with steeply intersecting walls at their bases. Overwhelmingly, their trajectories are straight and their main grooves contain continuous, straight microstriations. These unmodified flake cut mark characteristics contrast significantly with typical trampling marks, which differ from a V-shaped in cross-section and have instead a flat, broad base (*Results*), are often sinuous in trajectory and have discontinuous, irregularly trending microstriations. Occasionally, trampling marks can show a V-shaped cross-section; 4% of experimental produced trampling marks are V-shaped, roughly equivalent to the percentage of V-shaped cut marks created with retouched flakes (11).

Because retouched stone flakes have irregular cutting edges, they tend, unlike unmodified flakes, to produce bone surface marks that more closely approximate those inflicted by the multiple, variously sized sedimentary particles that scar a bone when it is trampled. Both types of damage converge morphologically in tending to show the flat-bottomed shape in cross-section. Because of this convergence, inferring the origins of stone-inflicted grooves with the flat-bottomed shape on bone surfaces when retouched flakes are potential mark effectors becomes a probabilistic process. In these cases, experimental data show that if the groove in question displays shoulder effects and has a straight rather than sinuous trajectory, it is much more likely to be a cut mark rather than a trampling mark (74% of experimentally created cut marks display shoulder effects, vs. only 6% of experimentally created trampling marks; 97% of experimentally created cutmarks have a straight trajectory, vs. only 30% of experimentally created trampling marks) (11). As a final caveat, taphonomic processes can, of course, alter the expression of these traits and thus the analyst should be mindful of assemblage context at all levels of organization.

1. McPherron SP, et al. (2010) Evidence for stone-tool-assisted consumption of animal tissues before 3.39 million years ago at Dikika, Ethiopia. *Nature* 466:857–860.
2. de Heinzelin J, et al. (1999) Environment and behavior of 2.5-million-year-old Bouri hominids. *Science* 284:625–629.
3. Semaw S, et al. (2003) 2.6-Million-year-old stone tools and associated bones from OGS-6 and OGS-7, Gona, Afar, Ethiopia. *J Hum Evol* 45:169–177.
4. Domínguez-Rodrigo M, Pickering TR, Semaw S, Rogers MJ (2005) Cutmarked bones from Pliocene archaeological sites at Gona, Afar, Ethiopia: implications for the function of the world's oldest stone tools. *J Hum Evol* 48:109–121.
5. Alemseged Z, et al. (2006) A juvenile early hominin skeleton from Dikika, Ethiopia. *Nature* 443:296–301.
6. White TD (2002) Earliest hominids. *The Primate Fossil Record*, ed Hartwig WC (Cambridge Univ Press, Cambridge, UK), pp 407–417.
7. Binford LR (1981) *Bones: Ancient Men and Modern Myths* (Academic Press, New York).
8. Bunn HT (1991) A taphonomic perspective on the archaeology of human origins. *Annu Rev Anthropol* 20:433–467.
9. White TD (1992) *Prehistoric Cannibalism at Mancos 5MTUMR-2346* (Princeton Univ Press, Princeton, NJ).
10. Behrensmeyer AK, Gordon KD, Yanagi GT (1986) Trampling as a cause of bone surface damage and pseudo-cutmarks. *Nature* 319:768–771.
11. Domínguez-Rodrigo M, de Juana S, Galán A, Rodríguez M (2009) A new protocol to differentiate trampling marks from butchery cut marks. *J Archaeol Sci* 36:2643–2654.
12. Behrensmeyer AK (1978) Taphonomic and ecologic information from bone weathering. *Paleobiology* 4:150–162.
13. Villa P, Mahieu E (1991) Breakage patterns of human long bones. *J Hum Evol* 21:27–48.
14. Olsen SL, Shipman P (1988) Surface modification on bone: trampling versus butchery. *J Archaeol Sci* 15:535–553.
15. Blasco R, Rosell J, Fernández-Peris J, Cáceres I, Vergés JM (2008) A new element of trampling: Experimental application on the Level XII faunal record of Bolomor Cave (Valencia, Spain). *J Archaeol Sci* 35:1605–1618.
16. Pickering TR, Egeland CP (2006) Experimental patterns of hammerstone percussion damage on bones: Implications for inferences of carcass processing by humans. *J Archaeol Sci* 33:459–469.
17. Prendergast M, Domínguez-Rodrigo M (2008) Taphonomic analyses of a hyena den and a natural-death assemblage near Lake Eyasi (Tanzania). *J Taphonomy* 6:301–335.
18. Domínguez-Rodrigo M, Barba R, Egeland CP (2007) *Deconstructing Olduvai* (Springer, New York).
19. Pickering TR, Domínguez-Rodrigo M (2010) Chimpanzee referents and the emergence of human hunting. *Open Anthropol J* 3:107–113.
20. Pickering TR (2010) Invited comment on Shipman "The animal connection and human evolution." *Curr Anthropol* 51:529–530.
21. Brain CK (1981) *The Hunters or the Hunted? An Introduction to African Cave Taphonomy* (Univ of Chicago Press, Chicago).
22. Blumenschine RJ, Marean CW, Capaldo SD (1996) Blind tests of inter-analyst correspondence and accuracy in the identification of cut marks, percussion marks, and carnivore tooth marks on bone surfaces. *J Archaeol Sci* 23:493–507.
23. Domínguez-Rodrigo M, Barba R (2006) New estimates of tooth marks and percussion marks from FLK Zinj, Olduvai Gorge (Tanzania): The carnivore-hominid-carnivore hypothesis falsified. *J Hum Evol* 50:170–194.
24. Njau JK, Blumenschine RJ (2006) A diagnosis of crocodile feeding traces on larger mammal bone, with fossil examples from the Plio-Pleistocene Olduvai Basin, Tanzania. *J Hum Evol* 50:142–162.

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