

Human Digestive Effects on a Micromammalian Skeleton

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This study describes the results of an experiment involving the consumption of a skinned, eviscerated, and segmented insectivore by an adult human male. Bone remains from recovered faecal contents are examined for skeletal element representation, breakage and digestive damage. Detailed examination of each category suggests severe skeletal attrition which is comparable to, and at times in excess of, the damage exhibited in microvertebrate skeletal accumulations originating from the scats of small mammalian carnivores.

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Introduction

Even when the buried remains of small mammals are purposely recovered and analysed, most archaeologists approach their interpretation with some trepidation. The significance of micromammalian bone assemblages for palaeocological and human subsistence reconstructions is often obscured by factors stemming from the natural abundance, ubiquity, habitat, and diminutive sizes of representative taxa. Small mammal skeletons may accumulate in buried sediments through varied mechanisms, from accidental death to selective predation and deposition by a wide host of predators. Subsequently, their small and fragile remains are easily exposed to rapid and complete loss of spatial and structural integrity by a wide range of agents.

The obscurity surrounding assemblage accumulation and modification is a particularly vexing problem for identifying purposive human predation and deposition of small mammal remains. In archaeological contexts, any substantiation of dietary significance approaches its greatest confidence with the identification of micromammalian bone and hair fragments in coprolitic materials (e.g. Watson, 1969: 55; Heizer & Napton, 1969: 567; Bryant, 1974: 413; Bryant & Williams-Dean, 1975: 102–103; Reinhard, 1988: 357–358; Reinhard & Bryant, 1992: 255; Sobolik, 1993). However, these unique archaeological remains are only rarely preserved in particular geographical settings. More commonly, the buried bones of small mammals are rejected as dietary inclusions for reasons associated with obscured identification of accumulating agent, difficulty in recovery and study, or outright dismissal as probable food sources [see the various discussions in

Stahl (1982, 1992), Andrews (1990), Szuter (1991), Semken & Falk (1991), Shaffer (1992), Schmitt & Juell (1994)].

Recent advances in methodology have provided great strides towards unravelling the fascinating complexity of micromammalian taphonomy. In addition to the use of supporting ethnographic and historic documentation, various criteria have been offered for establishing human agency in the accumulation and modification of small mammal assemblages. Arguing the need for multiple lines of evidence, these studies have focused on relevant signatures in bone modification, skeletal representation, comparisons between assemblages with known or imputed accumulation histories, habitat and ecology of represented taxa, and archaeological contextual distributions (e.g. Thomas, 1971; Mengoni, 1983; Payne, 1983; Vigne & Marinval-Vigne, 1983; Jones, 1984: 103–107; Hesse, 1985, 1986; Whyte, 1988: 79–83; 1991; Falk & Semken, 1990; Grayson, 1991; Hockett, 1991; Szuter, 1991: 155–167; Semken & Falk, 1991; Simonetti & Cornejo, 1991; Shaffer, 1992; White, 1992: 334).

Comparable studies have focused attention on signatures of non-human accumulation and deposition. These studies principally document biases in skeletal representation and bone modifications involving patterned breakage and digestive corrosion (e.g. Mellett, 1974; Mayhew, 1977; Korth, 1979; Dodson & Wexler, 1979; Fisher, 1981; Levinson, 1982; Andrews & Evans, 1983; Maas, 1985; Emslie, 1988; Hoffman, 1988; Pratt, 1989; Andrews, 1990; Kusmer, 1990; Fernandez-Jaluo & Andrews, 1992; Schmitt & Juell, 1994). Human digestive effects on fish bones and otoliths have been described (Jones, 1986, 1990; Wheeler & Jones, 1989: 69–76); however, we are in need of comparative data which document the biases induced through human

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digestion of micromammalian materials (Jones, 1984: 148; Szuter, 1991: 165). This paper offers a preliminary study of human digestive effects on a small insectivore skeleton. The materials and procedures used in the study are described below, followed by a brief discussion of the results and their archaeological implications. A short summary concludes.

Materials and Procedures

Our study involved the consumption of a skinned, eviscerated and segmented insectivore by an adult human male, followed by the recovery and examination of related faecal contents. Northern short-tailed shrews (*Blarina brevicauda*) were procured via snap trapping in Broome Co., New York during the early summer of 1991. *B. brevicauda* is a relatively large and robust member of its genus, with subspecific forms ranging throughout the north-central and northeastern United States and contiguous areas in Canada. This semifossorial mammal tends to reside in areas with herbaceous cover, frequenting runways in the upper soil horizons where it feeds on a highly catholic diet of animal and plant materials (George, Choate & Genoway, 1986).

Standard zoological measurements were determined for an adult male specimen (head-and-body=90 mm; tail=24 mm; hind foot=13 mm; weight=18.92 g), after which it was skinned and eviscerated (skin=2.85 g; gut=6.02 g). The carcass was lightly boiled for approximately 2 min and swallowed without mastication in hind and forelimb, head, and body and tail portions. The rapid period of gentle boiling did not promote any further loss or dissociation of tissues. However, it should be cautioned that carcass segmentation may have led to increased exposure of certain bone surfaces more likely to have been protected by soft tissue, had the carcass been swallowed whole. Marker foods of corn and sesame seeds were ingested several hours before and after the experimental meal in an attempt to establish control parameters for faecal collection.

Faecal matter was collected for the following 3 days. Each faeces was stirred in a pan of warm water until completely disintegrated. This solution was then decanted through a quadruple-layered cheesecloth mesh. Sieved contents were rinsed with a dilute detergent solution and examined with a hand lens for bone remains. All specimens were cleaned and fixed by immersion in alcohol. Selected specimens were subsequently coated with gold, mounted on Cambridge studs and secured with carbon cement for viewing under scanning electron microscopy at magnifications ranging from 10 × to 1000 ×.

Results and Discussion

The majority of recovered bone specimens appeared in the first faecal collection. Very little material, including

Table 1. Frequency and relative abundance of recovered elements. One cervical vertebra was recovered, and is compared here to an averaged number (range: 29–33) of non-caudal vertebrae (Gilbert 1990: 111)

Element	Number recovered	Number in skeleton	Relative abundance (%)
Maxillae	2	2	100
Cranial fragment	1	—	—
Mandible	1	2	50
Molar	4	12	33
Humerus	2	2	100
Ulna	2	2	100
Tibio-fibula	1	2	50
Calcaneum	1	2	50
Metapodium	5	20	25
Phalange	8	56	14
Vertebra (non-caudal)	1	31 (avg.)	0.03

a molar and one humerus, were present in the second collection. No bone specimens were recovered in faeces from the third day, when food remains from subsequent meals became obvious. An accounting of the recovered elements is summarized in Table 1. In the interest of promoting comparison, the data are presented in a manner consistent with Andrews (1990). This source provides detailed comparative data for skeletal element proportions, bone breakage, and digestive damage from 19 species of owl, diurnal raptor, and mammalian carnivore predators. Our analysis is primarily focused on skeletal representation and digestive damage, although some mention of breakage is also provided below.

Skeletal Element Proportions

Due to the controlled nature of this study, we have exact information on both the predatory consumer and the prey species consumed, the number and nature of skeletal elements involved in consumption and the manner in which they were introduced to the consumer. Obviously, in studies that examine faecal remains, many of these dates can only be approximated; therefore, some of the statistical measures introduced by Andrews (1990) for estimating the original death assemblage from the coprolitic assemblage, may be inappropriate for our study. Nevertheless, broader comparisons can be undertaken, keeping in mind the small size of our sample.

The data in Table 1 indicate significant skeletal attrition, as only 28 bone elements and fragments appear to have survived the digestive process. Considering the total number of elements in the entire shrew skeleton, this represents a proportionately low survivorship. The computation of a comparable index for relative abundance of skeletal proportions (Andrews, 1990: 45) is complicated by differences in analysis. Whereas the exact attributes of our death assemblage are known, Andrew's calculations of dietary prey are necessarily underestimations. Nevertheless, for

purposes of comparison, the average relative abundance of skeletal elements (20.6% excluding the cranial fragment), is uniformly much lower than all the predators surveyed by Andrews (1990: tables 2.3–2.5), with the exception of one Kestrel subsample. This would certainly merit placement at least among Category 5 predators in Andrew's classificatory scheme (Andrews, 1990: Table 3.16). As expected, the relative abundance of individual prey skeletal elements is most similar to surveyed mammalian predators, including white-tailed mongoose, small-spotted genet, bat-eared, red, and Arctic foxes, coyote and pine marten (Andrews, 1990: figure 3.4, appendix table 13; Andrews & Evans, 1983).

It is interesting to consider the relatively high survivorship of forelimb elements, particularly as the short-tailed shrew, in addition to being a competent climber, is the most fossorial of the North American soricines (Churchfield, 1990: 11). Although no differential skeletal density values exist for shrews, it is possible that fossorial habitat is reflected in the differential survivorship of the stout, robust humerus and the relatively well-developed ulna. The radius, often a columnar weight-supporting element within the mammalian plan, is both smaller and more gracile in the forelimb of *Blarina*. On the basis of detailed density measures for a large fossorial rodent, Lyman, Houghton and Chambers (1992: 565) have suggested that limb, particularly distal limb, elements tend to be denser than comparable elements in cursorial animals. In this regard, the differential survivorship of metapodial and phalangeal elements, may be related to increased density associated with fossorial adaptations. However, it should be cautioned that the distal podial elements were not skinned, but swallowed with covering hair and pads intact. Certain metapodial and phalangeal elements were actually articulated upon recovery, tentatively suggesting that the added protective cover may have mitigated digestive destruction (Andrews & Evans, 1983: 303); however, this of course remains unclear.

None of these factors explains the complete absence of both hip and femoral elements within the faecal sample. We are confident that these major elements were not missed in collection. Establishing whether or not this is simply a capricious result, or perhaps due to the manner in which the prey item was consumed, would of course depend upon comparison with similarly controlled experiments. Although tooth-bearing bones also indicate high survivorship, the relatively high percentage of loose teeth and total destruction of the characteristically prominent, procumbent incisors and all premolars, are indicative of the overall heavy degree of digestive damage.

Detailed analytical indices used by Andrews, include a comparison of postcranial–cranial proportions. Using his computations, our limited human sample lies within the range of Category 2 modification, associated with kestrels, tawny owls and genets (Andrews, 1990:

table 3.2, figure 3.5). These values are also low for other mammalian predators. Andrews (1990: 49) logically suggests that the preferential destruction of postcranial elements may be a factor of increased chewing. This is not supported by our data as the shrew was ingested without chewing; any damage occurred as the remains were processed internally. Mastication undoubtedly damages bone, but the effects of this process are perhaps repeated in the acidic, churning environment of the stomach; therefore, chewing should be considered as only one necessary variable for increased destruction of small, fragile bone elements.

A computation of distal element loss, comparing survivorship of the tibia and radius with that of the femur and humerus, places the human sample within the range of Category 4 predators, especially red fox, hen harrier, and spotted eagle owl (Andrews, 1990: table 3.2, figure 3.6). This, of course, reflects the total absence of radii in the sample. However, substituting the ulna for the radius in this index produces drastically different results, with an extreme bias against proximal elements. The sturdier ulna of *Blarina* might be expected to survive unless there was some patterned bias against distal elements. This latter bias against distal elements could be the product of mastication, a point certainly born out by the remains of certain owl assemblages.

Breakage

It is suggested that a detailed analysis of element breakage in digested assemblages can help to differentiate between various predators, since prey species are variably ingested in a continuum from intact to heavily masticated (Andrews, 1990: 50). Our results can not be systematically compared, as the shrew was swallowed without mastication. As such, our experiment does not replicate the potential range of consumptive patterns by which such an animal might have been ingested by humans; however, some interesting comparisons can still be drawn.

With the exception of one tibio–fibula, the few surviving major limb bones were relatively complete. Andrews (1990: 49) has suggested that a low proportion of cranial elements within certain mammalian carnivore assemblages might be attributable to prey decapitation prior to ingestion. The shrew skull was not only ingested in our experiment, but swallowed intact. Nonetheless, damage to the skull is extreme. In addition to one isolated cranial fragment, both palatal portions of the maxillae are all that survived digestion. As shrews lack zygomatic processes, differential survivorship of this structure can not be compared with Andrews' data; nevertheless, maxillary survivorship is generally comparable to the pattern produced by mammalian carnivores. This is certainly supported by the complete loss of maxillary teeth (Figure 1) and heavy damage to the alveolar borders (Figure 2).

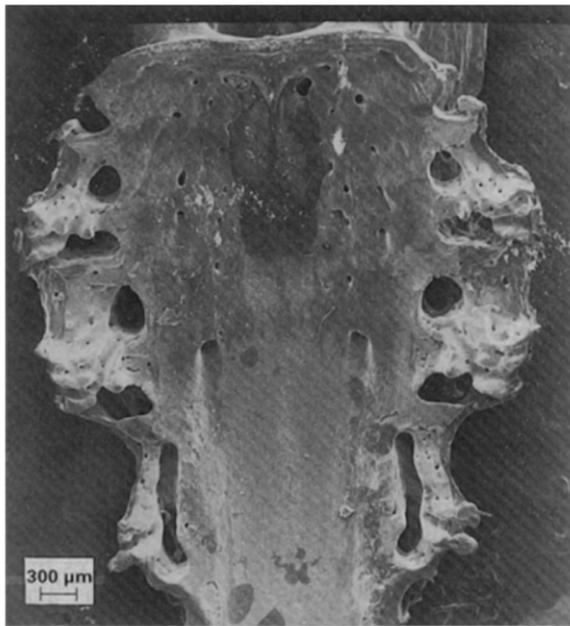


Figure 1. SEM micrograph of the digested shrew maxillae (basal view with nuchal orientation at top).

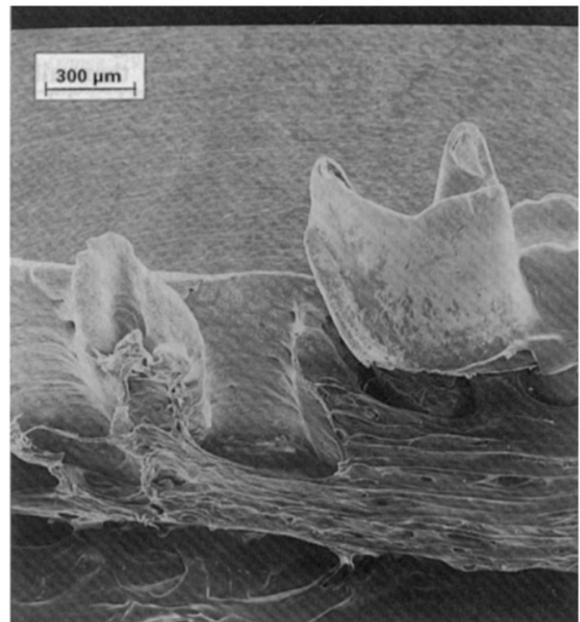


Figure 3. SEM micrograph detailing *in situ* teeth in the surviving mandibular portion (buccal orientation).

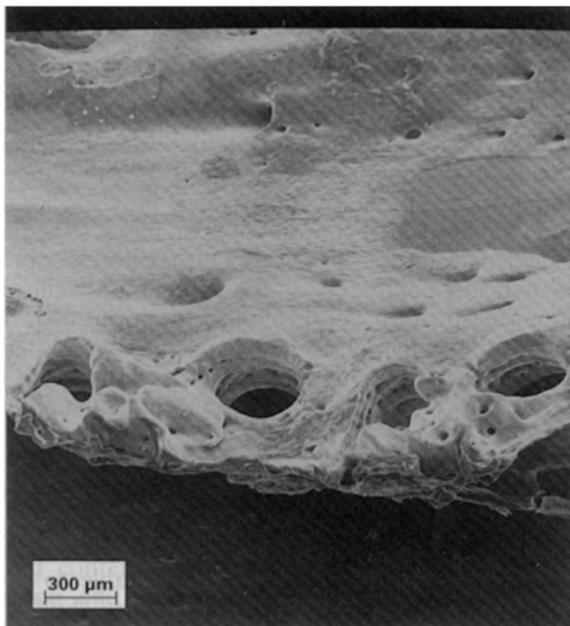


Figure 2. SEM micrograph detailing digestive damage on the alveolar border of the shrew maxilla (basal view with nuchal orientation to the right).

A similar pattern of heavy damage to the single surviving mandibular element is also apparent. The ascending mandibular ramus with its characteristic double articulating surface (Churchfield, 1990: 1) is absent, as is the inferior border. With the exception of one molar and a fragmented portion of another

(Figure 3), the surviving mandibular portion was otherwise devoid of teeth. Only a small fraction of isolated molars, and no incisors or premolars were recovered. As we are certain of the number of prey species consumed, and confident of the collection results, this corroborates the significance of digestion to notable tooth loss in certain assemblages (Andrews, 1990: 61). As discussed below, surviving teeth do indicate some cracking, but no major breakage. Whether or not the missing teeth were first broken and then dissolved along exposed lines of weakness (Andrews, 1990: 64) might be suggested by the *in situ* tooth fragment (Figure 3). This remains inconclusive. However, our data strongly supports the observation that extreme tooth loss is associated with digestion. Where applicable or comparable, especially with respect to skull and mandible breakage, our experimental data suggest that human digestion generally results in extreme breakage, at the far end of Andrews' predator modification categories.

Digestion

Due to potential equifinality amongst different breakage processes, Andrews (1990: 64) suggests that digestion, determined by both the degree of damage and proportion of elements affected, may be the most reliable indicator of specific predator accumulations. Again, we must caution that our sample is limited in both size and scope. Certainly the varying morphology of different prey items can strongly influence digestive outcomes. For example, Andrews' data might suggest that insectivore teeth are relatively durable elements.

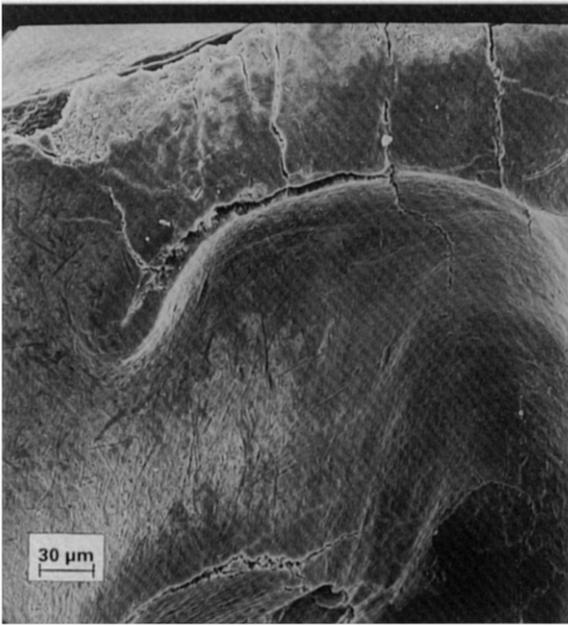


Figure 4. SEM micrograph detailing a closer view of the surviving mandibular tooth (buccal orientation). Note the enamel cracking in the lower portion, and the enamel digestion along the dentine-enamel junction in the lower right corner.

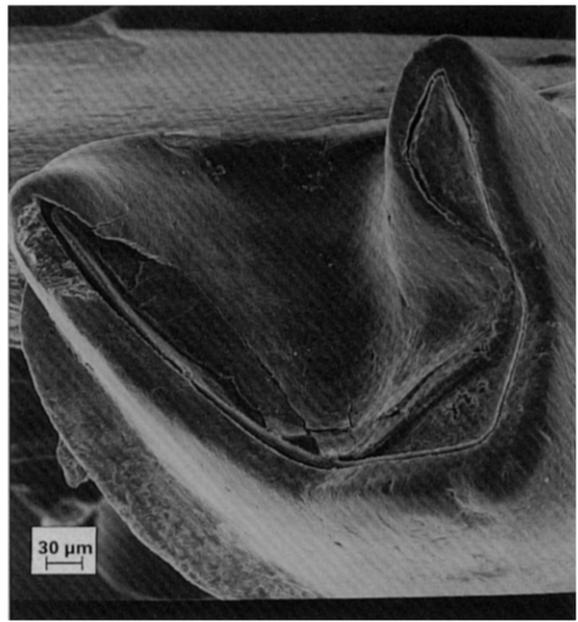


Figure 5. SEM micrograph detailing the occlusal surface of the surviving mandibular tooth. Note the cracking of enamel as the underlying dentine is eroded.

Furthermore, his data suggest that effects of mammalian digestion are variable, ranging from intermediate to extreme, depending upon the predator.

Of the few surviving molars in our sample, all show a certain degree of enamel damage. This includes both cracking and limited removal of enamel, particularly along the dentine-enamel junction at the base of the teeth (Figures 3 and 4). Gastric juices also appear to have penetrated the crown along the occlusal surfaces, thus weakening the enamel from underneath (Figures 5 and 6). Higher magnification of the enamel surface (Figure 7) details the extensive pitting associated with intermediate category digestion (compare with Andrews, 1990: figure 3·18 i·1). The *in situ* mandibular molar was the least digested amongst the surviving teeth. Of the remaining teeth in the sample, one has no root structure and two have only vestigial remnants. This might suggest that the initial stages of tooth digestion may be slowed by alveolar protection and accelerated once the tooth is freed from its socket. When we take into account that all other dental material is missing, we may be observing a continuum of digestive states including total digestion of early liberated teeth, through severely degraded dental structures, to relatively well-preserved teeth still remaining in their sockets. Andrews (1990: 67) notes that mammalian predators produce a range of molar digestion from intermediate to extremely severe. Our human data tentatively suggest a similar range of digestion categories within one sample. None of the anterior dentition of incisors and premolars was recovered. It is possible, although unlikely, that these teeth and the



Figure 6. Close-up of Figure 5, detailing cracking of the enamel surface.

missing molars were overlooked in recovery. As great care was taken to recover all elements, it is more likely that these teeth were either totally disintegrated or reduced to entirely unrecognizable fragments.

Some of the postcranial damage produced by human digestion is illustrated by one of the relatively intact humeri. All of the epiphyseal tissue of the more fragile proximal portion had been removed, along with some

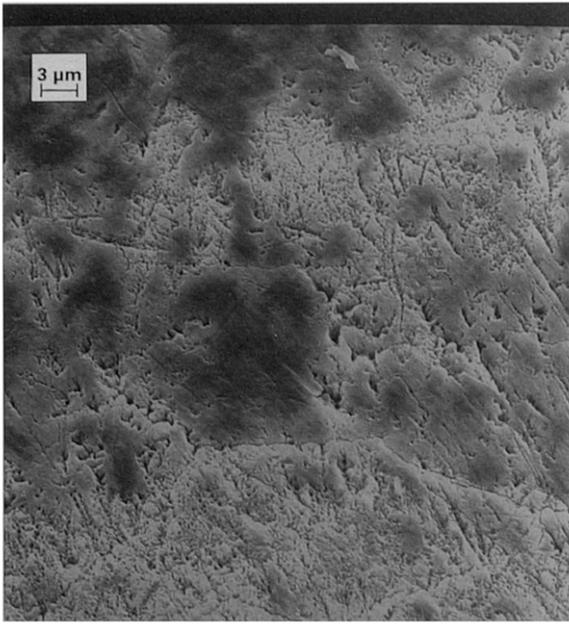


Figure 7. Higher magnification of the surviving mandibular tooth in Figure 5, detailing pitting of the enamel surface.

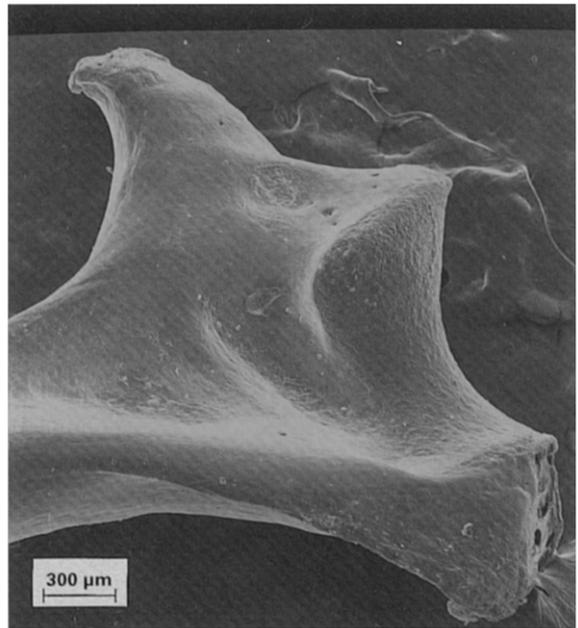


Figure 9. SEM micrograph detailing digestive damage to the accompanying distal portion of the surviving shrew humerus in Figure 8.

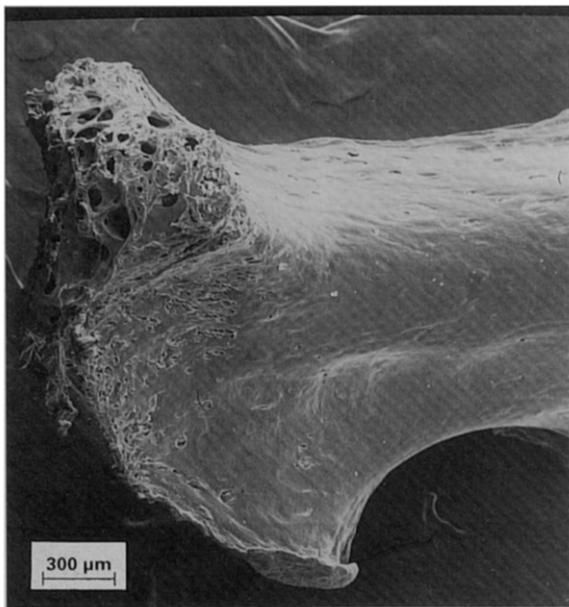


Figure 8. SEM micrograph detailing digestive damage to the proximal portion of a surviving shrew humerus.

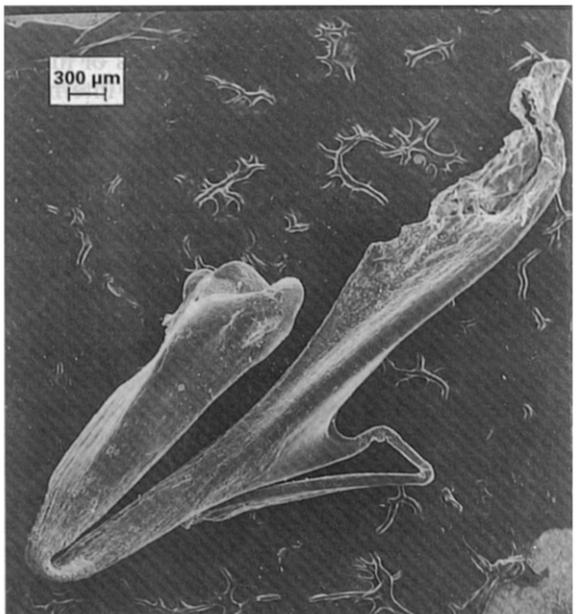


Figure 10. SEM micrograph detailing digestive damage to the surviving shrew tibio-fibula.

pitting of the shaft (Figure 8). This can be compared to the accompanying distal end which shows some rounding, but remains relatively less damaged (Figure 9). This differential destruction of the proximal humerus is consistent with the density data published by Lyman *et al.* [1992: 564, see also Schmitt and Juell (1994: 256)] for fossorial marmots. The proximal portion is relatively low in density both when compared to its distal counterpart, and other elements in the

skeleton. It is interesting to contrast this modification with the surviving tibio-fibula. The entire proximal end is destroyed, with the shaft bent over upon itself (Figure 10).

Postcranial damage may therefore suggest a potential range of digestive categories, which appear in a continuum. The articulated metapodials and phalanges (compare with Andrews and Evans 1983: 300), show

none of the discolouration characteristics of the entire assemblage, and were neither etched nor pitted. Whether or not the adhering heavy pads and hair afforded protection to these elements (Andrews & Evans, 1983: 303), remains uncertain. Most of the recovered postcranial elements, as illustrated by the humerus, seem to match Andrews' (1990: 88) Category 2 digestion with extensive damage to articular ends and etching on the shaft areas. However, differential damage may appear on the same bone, most likely relating to the structural density of respective portions. Toward the more extreme end of the continuum, certain bones like the illustrated tibio-fibula show extensive damage and even warping. At the most extreme, it should be remembered that many postcranial elements were completely absent and in all likelihood totally digested.

Summary and Conclusion

This study was undertaken as a contribution toward unravelling the many ambiguities that can surround the interpretation of microvertebrate accumulations in archaeology. Small animals are perfectly adequate human dietary inclusions. Often, their role in palaeoecological analysis is crucial. Nonetheless, the profuse ways in which their remains can be introduced and subsequently altered in buried contexts, often produce significant interpretative ambivalence. In the absence of relatively unique coprolitic evidence, the identification of microvertebrate assemblages which had been purposely accumulated by humans, is obscure at best. This paper offers a preliminary assessment of human signatures on microvertebrate remains resulting from the controlled digestion of a small insectivore.

The surviving skeletal remains of a northern short-tailed shrew were recovered within 2 days after it was swallowed in segments without mastication. Where applicable, a detailed comparison of skeletal element proportions, breakage and digestion was undertaken following Andrews' (1990) comprehensive study of micromammalian predators. The human assemblage predictably indicated extreme skeletal attrition which was minimally comparable to Category 5 predator modification (for summaries, see Andrews (1990: table 3-16). The likely possibility of density-mediated digestive attrition (Andrews & Evans, 1983: 303; Schmitt & Juell, 1994: 256) is tentatively suggested by the significant survivorship of denser forelimb elements associated with this semi-fossorial animal. Analyses of crania/postcrania and distal element loss were more ambiguous, probably due to the lack of mastication in our experiment. Our data suggest Category 2 and Category 4 predator modification respectively; however, had we substituted the ulna for the radius in the latter category, human modification would clearly have indicated a preferential loss of proximal limb portions. Perhaps the increasing loss of distal element portions amongst diurnal raptors and mammalian carnivores is

an attribute of significant tearing or mastication. Breakage was less comparable due to the lack of mastication in our experiment. Nevertheless, skull breakage, maxillary tooth loss, mandibular breakage, and the high proportion of isolated teeth in the assemblage all compare at least minimally with small mammalian carnivores and Category 5 modification. Molar digestion is similar to mammalian carnivores in that a range of digestive states from intermediate to extreme damage were apparent. Post-cranial digestion may also tentatively indicate density-mediated survivorship as variable degrees of damage appear on different portions of the same element.

Whereas the experimental human data often indicated a range of modifications, this preliminary assessment minimally conformed, and in many cases surpassed, the severe modifications produced by mammalian carnivores. The severity of human digestive modification presented in this experiment was underscored by the extreme damage to cranial and mandibular elements. Despite being swallowed relatively intact and without mastication (e.g. compare with Andrews & Evans 1983: 291; 294), these elements were severely modified by human digestion. Certainly, our small experiment did not in any way replicate the range of human consumptive patterns which can involve extreme destruction from pounding, crushing, differential burning, and chewing. It did indicate, however, the extensive damage produced after ingestion. The majority of this damage undoubtedly began only after the bolus had quickly passed through a neutral esophageal environment into the prepyloric and pyloric regions. Here, the resultant chyme was produced through maceration and exposure to a reduced acid (approximately pH 2.5 in humans) gastric fluid (Miller & Leavell, 1972: 448; and compare with Duke *et al.*, 1975). Bone digestion conceivably proceeded within the stomach, particularly upon contact with hydrochloric acid and activated pepsin. Also, gritty particles of accompanying food, along with stomach turbulence, could further damage small, fragile bone. Further digestion probably took place in the high pH intestinal environment via peristalsis and continued protein hydrolysis (Miller & Leavell, 1972).

Many factors can control the degree of digestion and transit time within the entire gastrointestinal tract. These can vary from individual stomach shape, to the kind of food ingested, the amount of exercise undertaken after eating, and food particle size (e.g. Miller & Leavell, 1972; Stahl, 1989). It remains unclear as to whether the degree of digestion or the maximum transit time of 2 days in our experimental conditions is in any way representative. Nevertheless, the results of our small preliminary study certainly tend to support Andrews and Evans' (1983: 306) original disagreement with Mellett's (1974) coprocoenotic hypothesis. The digestive systems of mammalian predators, in this particular case humans, appear to severely destroy and weaken the bones of small prey items, even when

swallowed relatively intact. Except in cases of fortuitous preservation, post-depositional forces would certainly exacerbate the survival of any human coprolitic microvertebrate assemblage after liberation from its protective enclosure.

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