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**Comment on "Bacterial bioerosion of bones is a post-skeletonisation phenomenon
and appears contingent on soil burial" [Quat. Int. 660 (2023) 75–83]**

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Histotaphonomic analysis, through thin section microscopy, SEM and micro-CT scanning, has become an increasingly popular approach for archaeologists in recent years. The method relies on assessing the character of degradation in bone microstructure, placing particular importance on the degree and nature of bacterial bioerosion. However, there remains considerable disagreement about the origins and timing of bacterial bioerosion and this has major ramifications for the interpretative potential of the approach. Turner-Walker et al. (2023) present a firm case for the origins of bacteria being exclusively exogenous (from the soil) with bioerosion occurring only after skeletonisation. This scenario means that information gained from analysis of histotaphonomy relates entirely to the nature of the burial environment and its suitability for collagenolytic bacteria to thrive and thus provides very little useful information about human behaviour and mortuary practice. This contrasts with the common position that the origins of bacteria can be enteric (from the gut) and can effect bioerosion during putrefaction in the early post-mortem phase, thus potentially informing on mortuary practice.

In this response, we present the alternative view to Turner-Walker et al. (2023) and demonstrate strong and wide-ranging evidence for bacteria from the gut microbiome to have the potential to cause bioerosion. A review of previous studies is used to evidence the impact of mortuary practice on variable microstructural preservation. We counter some of Turner-Walker et al.'s key lines of evidence and present alternative, evidence-based explanations. Importantly, we acknowledge that the origins of bacteria are not always enteric and that current interpretations that only consider bacteria as either enteric or exogenous cannot account for the variability seen in the archaeological record.

Keywords: *Bone diagenesis; Bacteria; Bioerosion; Taphonomy; Decomposition*

In their paper entitled 'Bacterial bioerosion of bones is a post-skeletonisation phenomenon and appears contingent on soil burial', Turner-Walker et al. (2023) use Scanning Electron Microscopy (SEM) to investigate the histological preservation of bones from varied experimental contexts and conclude that their results are inconsistent with an enteric (from within the decomposing organism) as opposed to exogenous (from the burial soil) model of osteolytic bacterial bioerosion of mineralised tissues. They argue that their results are generalisable and that it is not possible to conclude anything about early postmortem treatment based on bacterial attack in bone. Turner-Walker et al.'s (2023) study makes an invaluable contribution in providing more sorely-needed experimental data. Moreover, we agree that their study provides no support enteric bioerosion and some evidence for an exogenous model. However, we argue that the strength of evidence for their two main conclusions is exaggerated due to methodological aspects of the authors' experiments and an incomplete discussion of evidence relevant to associations between bioerosion and early taphonomy.

Turner-Walker et al.'s (2023) first case study involved the deposition of two pig carcasses in buried stone-built cavities. The carcasses decomposed underground for three years without interacting with soil. SEM analysis of a rib and humerus from each pig found no evidence for bacterial bioerosion. As both pigs had decomposed and were presumed to have undergone putrefaction, they argue that these results are inconsistent with enteric bacterial bioerosion. However, the authors acknowledge that one of the pigs (12.20) was given antibiotic medication shortly before it died, that this medication is likely to have affected the gut microbiome (Dash and Das 2020) and that there is evidence that this alteration of the gut microbiome can affect the progression of bodily decomposition (Hayman and Oxenham 2016). The authors argue that they have been unable to replicate the inhibitory effects of antibiotic medication on bodily decomposition in their own pig experiments but provide no relevant citations. Pig 12.20 had also been covered in hydrated lime (calcium hydroxide). The authors argue that lime was only in contact with the outside of carcasses and could not

85 have inhibited internal osteolytic bacterial activity. However experimental studies with lime
86 have shown that it can interfere with bodily decomposition even when simply covering a
87 body (Schotsmans et al. 2012; Schotsmans 2014; McIntyre et al. 2022). Moreover, a recent
88 histological study of two medieval cemeteries from Britain found that, while almost all bones
89 had been extensively bioeroded, bioerosion was absent from the only two sampled
90 skeletons which showed evidence for liming (Hemer et al. 2021).

91
92 It is clear from images of the pig in the second tomb structure (05-26; Figure 1b) that
93 substantial parts of the carcass had mummified/desiccated, contrasting with the total
94 skeletonisation of Pig 12.20 and providing evidence that depositional conditions had
95 interfered with decomposition. Histological studies of desiccated/mummified bodies all find
96 bones were subject to little bacterial bioerosion, suggesting processes leading to
97 mummification inhibit osteolytic bacteria (Booth et al. 2015). The potential impact of
98 antibiotics, liming and mummification/desiccation on bodily decomposition means the
99 absence of bioerosion from the bones of Turner-Walker et al.'s (2023) pigs would have been
100 anticipated even under an enteric model of bioerosion. These factors seriously confound the
101 authors' results and undermine the strength of their conclusions.

102
103 Turner-Walker et al.'s (2023) second study observes an absence of bioerosion from a rib of
104 a human body that had been exposed for ten years in a room with open windows.

105 Skeletonisation of the body suggested that it had undergone putrefaction, and therefore the
106 authors argue that, under an enteric model of bioerosion, bones should have been
107 extensively bioeroded. Among the most common and replicated observations in
108 experimental studies of decomposition is that bodies left to decompose on the ground
109 surface in temperate environments skeletonise much more rapidly (months) than bodies
110 buried in soil (years; Vass 2011; Iqbal et al. 2020), mainly because exposure allows a wider
111 range of scavengers and invertebrates to access the body. Rapid removal of soft tissue by
112 invertebrates will substantially reduce the bacterial soft tissue decomposition to which bones

are exposed and, consequently, bones from subaerially decomposed bodies would be expected to show little or no bacterial attack (Fernández-Jalvo et al. 2010; White and Booth 2014; Booth et al. 2015; Booth 2016; Booth and Madgwick 2016; Kontopoulos et al. 2016; Papakonstantinou et al. 2020; Bricking 2023).

In the human case discussed by Turner-Walker et al. (2023) the room's open window meant that the body was effectively subaerially exposed. The authors note that the remains were surrounded by fly pupae, suggesting substantial soft tissue loss due to insect activity. Turner-Walker et al. argue that staining on the bones of the abdomen indicates that the body underwent putrefaction but provide no evidence for staining as a reliable proxy of putrefaction. Again, an absence of bacterial bioerosion from these remains would be predicted under an enteric model of osteolytic bacteria. Moreover, the absence of references to an association between subaerial exposure and a lack of bioerosion, which is discussed in almost every study which explores the relationship between bioerosion and early taphonomy, represents an inexplicable omission (White and Booth 2014; Booth 2016; Booth and Madgwick 2016; Kontopoulos et al. 2016; Brönnimann et al. 2018; Papakonstantinou et al. 2020).

Turner-Walker et al. (2023)'s final case study examined two cattle bones buried in soil for one and ten years. In contrast to the human case and the experimental pig burials, the cattle bones show minor bacterial bioerosion. In addition to evidence in similar case studies (Turner-Walker 2012; Kendall et al. 2018; Turner-Walker 2019; Eriksen et al. 2020), this supports a scenario where at least some bioerosion is mediated by exogenous microorganisms. However, the authors use this to argue against an enteric origin, whereas it provides no evidence to this effect. It only evidences the potential for exogenous bioerosion, a point that has been consistently acknowledged in research that supports the potential for enteric bacteria to cause bioerosion (e.g. Madgwick and Bricking 2023; Booth et al. 2022). Turner-Walker et al. (2023: 81) concede their results cannot rule out the possibility that gut

bacteria may variably produce bioerosion in certain circumstances, but this statement is inconsistent with the broader tone of their paper. The confounding factors in their experiments prevent any unambiguous assessment of whether enteric gut bacteria invariably cause bone bioerosion.

Turner-Walker et al. (2023)'s characterisation of studies interpreting patterns of bacterial bioerosion in terms of early postmortem treatment, or indeed other factors which may have influenced enteric bacteria (e.g. stillbirth), is incomplete, with some key evidence entirely omitted. One of the authors' specific criticisms was (Turner-Walker et al., 2023: 81):

'...the enteric hypothesis builds upon assigning presence or absence of bacterial bioerosion criteria to individual cases of putative stillbirth, mummification, etc., rather than applying a statistical approach at the population level.'

In fact, studies which explore relationships between bioerosion and early taphonomy rely on previous investigations of dozens to hundreds of bone samples at a population level and which often detect statistically significant correlations between independent proxies of early taphonomy (e.g. butchery, primary burial) and bioerosion while observing little or no correlation with burial environment (Jans et al. 2004; Nielsen-Marsh et al. 2007; Booth and Madgwick 2016; Brönnimann et al. 2018; Hollund et al. 2018; Mandl et al. 2018; Papakonstantinou et al. 2020; Hemer et al. 2021; Haddow et al. 2023; Maurer et al. 2023). The suggestion that bacterial bioerosion could be used to identify stillborn infants in the archaeological record (cf. Jans et al. 2004) is not based on testing of 'individual cases of putative stillbirth, mummification, etc,' (Turner-Walker et al. 2023: 81) but is supported by a large-scale study of archaeological data (Booth 2020) the results of which have been replicated in successive studies of archaeological infant remains as well as one experimental study of pig carcasses (White and Booth 2014; Booth et al. 2016; Booth 2020).

In a more recent paper, Turner-Walker (2023) puts an emphasis on the strong association between bioerosion and burial environment, particularly in bones from skeletonised bodies that presumably underwent extensive putrefaction, arguing this both refutes an enteric origin for osteolytic bacteria and confounds attempts to reconstruct taphonomic processes in the early postmortem period. However, anoxic and waterlogged environments also inhibit bodily decomposition (Vass 2011) and, subsequently, histotaphonomic studies consistently acknowledge these environments as possible confounds which pre-empt robust statements about early decomposition or funerary treatment (Hollund et al. 2012; Booth 2016; Booth and Madgwick 2016; Brönnimann et al. 2018; Papakonstantinou et al. 2020). Only in cases where there is no evidence for waterlogging or anoxic burial are interpretations based on early taphonomy usually favoured. An absence of bacterial bioerosion from archaeological samples outside of anoxic or waterlogged environments is an unusual but not exceptional finding which Turner-Walker et al. (2023) do not address and which an exogenous model of bioerosion cannot easily account for. This is particularly true in cases where differentially bioeroded bones come from the same or similar burial contexts and thus similar patterns of bioerosion would be expected under an exogenous model (though more experimental work on microenvironmental variation is required). Moreover, histotaphonomic results are not interpreted in isolation but are usually integrated with other corroborating sources of taphonomic evidence (e.g. completeness, articulation, surface modifications, weathering, archaeoethanatology), a standard that Turner-Walker et al. (2023: 81) themselves approve of but fail to acknowledge is common practice.

Turner-Walker et al. (2023) do not discuss previous histotaphonomic studies which include human remains recovered from archaeological contexts such as cists, tombs and caves where bones were not covered by soil, even though these studies are directly relevant to their experimental explorations of bodily decomposition in underground cavities. Patterns of bacterial bioerosion in archaeological samples from cavities are variable but include remains that have been extensively bioeroded (Booth 2016; Hoole et al. 2018; Papakonstantinou et

al. 2020). The authors also do not mention histotaphonomic experiments featured in White and Booth (2014), Kontopoulos et al. (2016) and Fernandez-Jalvo et al. (2011) which observed bioerosion in bones from faunal cadavers that had never been buried or were protected from the soil by wrappings.

Turner-Walker et al. (2023) assert that the rejection of an enteric model of bacterial bone bioerosion also refutes an association with early taphonomy, but this is not necessarily the case, and does not consider recent attempts to reconcile contradictory signals from experimental and archaeological data. In part due to previous experimental research by Turner-Walker (2012; Kendall et al. 2018; Turner-Walker 2019) favouring an exogenous model of bioerosion, some researchers (ourselves included) who investigate taphonomy and early postmortem histories no longer assume an exclusive enteric origin for osteolytic bacteria. Rather, they consider that both exogenous and enteric microbiomes could be responsible for bioerosion. Increasingly, attempts are made to explore other archaeological, osteological and environmental variables that can aid in identifying bacterial origin (and thus interpretation) on a case-by-case basis (e.g. Papakonstantinou et al. 2020; Bricking 2023; Mavroudas et al. 2023).

Associations between bioerosion and early taphonomy in the archaeological record could be explained by a full or partial exogenous model of bacterial bioerosion and we acknowledge that bioerosion is not always informative in terms of early post-mortem treatment. In an earlier paper, Turner-Walker (2019) invoked early taphonomic processes to explain the lack of bioerosion in butchered faunal remains, arguing that cooking may block cortical bone porosities with hydrophobic fatty deposits. Another possibility is that osteolytic soil bacteria are attracted to bones surrounded by decomposing soft tissue (Booth et al. 2022), a scenario potentially supported by changes in the soil microbiome produced by the insertion of a decomposing body (Cobaugh et al. 2015; Singh et al. 2017). However, thus far, exogenous models of bacterial bone bioerosion cannot explain the wide range of variation

and correlates we see in the archaeological record, and attempts to account for these correlates via confounding variables have been unconvincing. For instance, the observation that isolated burials are often extensively bioeroded (Jans et al. 2004; Booth 2016; Hoole et al. 2018; Brönnimann et al. 2018) refutes the idea that associations between primary burial and bioerosion are explained by the accumulation of osteolytic bacteria in large cemeteries (Kendall et al. 2018). Without a plausible hypothesis for explaining variation in bioerosion in archaeological bone that is divorced from early taphonomy, it is difficult to see how the unambiguous conclusions presented by Turner-Walker et al. can be supported.

References

- Booth, T.J. 2016. An Investigation Into the Relationship Between Funerary Treatment and Bacterial Bioerosion in European Archaeological Human Bone: Funerary treatment and bacterial bioerosion in human bone. *Archaeometry* 58(3), 484–499.
- Booth, T.J. 2020. Using Bone Histology to Identify Stillborn Infants in the Archaeological Record. In: Gowland, R. and Halcrow, S. eds. *The Mother-Infant Nexus in Anthropology: Small Beginnings, Significant Outcomes*. Cham: Springer International Publishing, 193–209.
- Booth, T.J., Brönnimann, D. & Madgwick, R. (2022) The taphonomic and archaeoethanatomical potentials of diagenetic alterations of archaeological bone. In Knusel, C.J. and Schotsmans, E. M.J. (eds.) *The Routledge Handbook of Archaeoethanatology*. London: Routledge, 580-599.
- Booth, T.J., Chamberlain, A.T. & Pearson, M.P. (2015) Mummification in Bronze Age Britain. *Antiquity* 89 (347), 1155 - 1173.
- Booth, T.J. & Madgwick, R. (2016) New evidence for diverse secondary burial practices in Iron Age Britain: A histological case study. *Journal of Archaeological Science* 67, 14-24.
- Booth, T.J., Redfern, R.C. and Gowland, R.L. 2016. Immaculate conceptions: Micro-CT

249 analysis of diagenesis in Romano-British infant skeletons. *Journal of Archaeological Science*
250 74, 124–134.

251 Bricking, A. 2023. Mortuary Practices in the Iron Age of Southwest Britain. Unpublished PhD
252 thesis, Cardiff University.

253

254 Brönnimann, D., Portmann, C. & Pichler, S.L., Booth, T.J., Röder, B., Vach, W., Schibler, J.,
255 & Rentzel, P. (2018) Contextualising the dead—Combining geoarchaeology and osteo-
256 anthropology in a new multi-focus approach in bone histotaphonomy. *Journal of*
257 *Archaeological Science* 98, 45 - 58.

258 Cobaugh, K.L., Schaeffer, S.M. and DeBruyn, J.M. 2015. Functional and Structural
259 Succession of Soil Microbial Communities below Decomposing Human Cadavers. *PloS one*
260 10(6), e0130201.

261 Dash, H.R. and Das, S. 2020. Thanatomicrobiome and epinecrotic community signatures for
262 estimation of post-mortem time interval in human cadaver. *Applied Microbiology and*
263 *Biotechnology* 104(22), 9497–9512.

264 Eriksen, A.M.H. et al. 2020. Bone biodeterioration—The effect of marine and terrestrial
265 depositional environments on early diagenesis and bone bacterial community. *PloS one*
266 15(10), e0240512.

267 Fernández-Jalvo, Y., Andrews, P., Pesquero, D., Smith, C., Marín-Monfort, D., Sánchez, B.,
268 Geigl, E.-M. & Alonso, A. (2010) Early bone diagenesis in temperate environments: Part I:
269 Surface features and histology. *Palaeogeography, Palaeoclimatology, Palaeoecology*,
270 288(1), 62–81.

271 Haddow, S.D., Mazzucato, C., Mangaloğlu-Votruba, S., Yağcı, B., Booth, T., Schotsmans,
272 E.M. and Knüsel, C.J. 2023. Scratching the surface? A histotaphonomic study of human
273 remains at Neolithic Çatalhöyük. *Archaeological and Anthropological Sciences* 15(6), 1-18.

274 Hayman, J. and Oxenham, M. 2016. Peri-mortem disease treatment: a little known cause of
 275 error in the estimation of the time since death in decomposing human remains. *The*
 276 *Australian Journal of Forensic Sciences* 48(2), 171–185.

277 Hemer, K.A., Booth, T.J., Raffone, C., Mann, C., Corkhill, C.L. and Willmott, H. 2021.
 278 “Among his fellows cast”: A histotaphonomic investigation into the impact of the Black Death
 279 in England. *Journal of Archaeological Science: Reports* 39, 103161.

280 Hollund, H.I., Blank, M. and Sjögren, K.-G. 2018. Dead and buried? Variation in post-mortem
 281 histories revealed through histotaphonomic characterisation of human bone from megalithic
 282 graves in Sweden. *PloS one* 13(10), e0204662.

283 Hollund, H.I., Jans, M.M.E., Collins, M.J., Kars, H., Joosten, I. and Kars, S.M. 2012. What
 284 Happened Here? Bone Histology as a Tool in Decoding the Postmortem Histories of
 285 Archaeological Bone from Castricum, The Netherlands: Bone Histology as a Tool in
 286 Decoding the Postmortem History. *International Journal of Osteoarchaeology* 22(5), 537–
 287 548.

288 Hoole, M., Sheridan, J.A., Boyle, A. & Booth, T. (2018) “Ava”: a Beaker-associated woman
 289 from a cist at Achavanich, Highland, and the story of her (re-) discovery and subsequent
 290 study. *Proceedings of the Society of Antiquaries of Scotland* 147, 73-118.

291 Iqbal, M.A., Ueland, M. & Forbes, S.L. (2020) Recent advances in the estimation of post-
 292 mortem interval in forensic taphonomy. *The Australian Journal of Forensic Sciences*, 52(1),
 293 107–123.

294 Jans, M.M.E., Nielsen-Marsh, C.M., Smith, C.I., Collins, M.J. & Kars, H. (2004)
 295 Characterisation of microbial attack on archaeological bone. *Journal of Archaeological*
 296 *Science*, 31(1), 87–95.

297 Kendall, C., Eriksen, A.M.H., Kontopoulos, I., Collins, M.J. & Turner-Walker, G. (2018)
 298 Diagenesis of archaeological bone and tooth. *Palaeogeography, Palaeoclimatology,*

299 *Palaeoecology*, 491, 21–37.

300 Kontopoulos, I., Nystrom, P. & White, L. (2016) Experimental taphonomy: post-mortem
301 microstructural modifications in *Sus scrofa domesticus* bone. *Forensic Science International*,
302 266, 320–328.

303 Madgwick, R. and Bricking, A. 2023. Exploring mortuary practices: histotaphonomic analysis
304 of the human remains and associated fauna. In P. Guarino and A. Barclay (eds.) In the
305 Shadow of Segsbury: Archaeological Investigations on the H380 Childrey Warren Pipeline
306 2018-19. CA Monograph. Cirencester: Cotswold Archaeology. 96-102.

307 Mandl, K., Novotny, F., Teschler-Nicola, M., Weiss-Krejci, E. and Others. 2018. The corpse
308 in the early bronze age. Results of histotaphonomic and archaeothanatological
309 investigations of human remains from the cemetery of Franzhausen I, Lower Austria.
310 *Archaeologia Austriaca* 102, 135–168.

311 Maurer, A.-F., Zeitoun, V., Bardin, J., Millard, A.R., Ségalen, L., Guérin, F., Saliège, J.-F. &
312 Person, A. (2023) Multifactorial approach to describe early diagenesis of bones: The case
313 study of the Merovingian cemetery of Saint-Linaire (France). *Quaternary International* 660,
314 42–55.

315 Mavroudas, S.R., Alfsdotter, C., Bricking, A. & Madgwick, R. (2023) Experimental
316 investigation of histotaphonomic changes in human bone from whole-body donors
317 demonstrates limited effects of early post-mortem change in bone. *Journal of Archaeological*
318 *Science* 154, 105789.

319 McIntyre, D.B., Conlan, X. & Harvey, M.L. (2022) The effects of hydrated lime and bleach on
320 carrion decomposition and associated insect succession. *The Australian Journal of Forensic*
321 *Sciences*, 1–19.

322 Nielsen-Marsh, C.M., Smith, C.I., Jans, M.M.E., Nord, A., Kars, H. & Collins, M.J. (2007)
323 Bone diagenesis in the European Holocene II: taphonomic and environmental

324 considerations. *Journal of Archaeological Science*, 34(9), 1523–1531.

325 Papakonstantinou, N., Booth, T. & Triantaphyllou, S. (2020) Human remains under the
 326 microscope of funerary taphonomy: Investigating the histological biography of the decaying
 327 body in the prehistoric Aegean. *Journal of Archaeological Science: Reports* 34, 102654.

328 Schotsmans, E.M.J., Fletcher, J.N., Denton, J., Janaway, R.C. & Wilson A.N. (2014) Long-
 329 term effects of hydrated lime and quicklime on the decay of human remains using pig
 330 cadavers as human body analogues: Field experiments. *Forensic Science International* 238,
 331 141.e1-141.e13.

332 Schotsmans, E.M.J., Denton, J., Dekeirsschieter, J., Ivaneanu, T., Leentjes, S., Janaway,
 333 R.C. & Wilson, A.S. (2012) Effects of hydrated lime and quicklime on the decay of buried
 334 human remains using pig cadavers as human body analogues. *Forensic Science*
 335 *International*, 217(1-3), 50–59.

336 Singh, B., Minick, K.J., Strickland, M.S., Wickings, K.G., Crippen, T.L., Tarone, A.M.,
 337 Benbow, M.E., Sufrin, N., Tomberlin, J.K. & Pechal, J.L. (2017) Temporal and Spatial Impact
 338 of Human Cadaver Decomposition on Soil Bacterial and Arthropod Community Structure and
 339 Function. *Frontiers in Microbiology* 8, 2616.

340 Turner-Walker, G. 2012. Early bioerosion in skeletal tissues: persistence through deep time.
 341 *Neues Jahrbuch fur Geologie und Palaontologie. Abhandlungen* 265(2), 165–183.

342 Turner-Walker, G. (2019) Light at the end of the tunnels? The origins of microbial bioerosion
 343 in mineralised collagen. *Palaeogeography, Palaeoclimatology, Palaeoecology* 529, 24–38.

344 Turner-Walker, G. (2023). Diagenetic Alterations to Vertebrate Mineralized Tissues – A
 345 Critical Review. In A.M. Pollard, R. Armitage, C. Makarewicz (eds.) *Handbook of*
 346 *Archaeological Sciences*. Hoboken: Wiley, 1117-1175.

347 Turner-Walker, G., Galiacho, A.G., Armentano, N. & Hsu, C.-Q. (2023) Bacterial bioerosion

348 of bones is a post-skeletonisation phenomenon and appears contingent on soil burial.

349 *Quaternary International* 660, 75-83

350 Vass, A.A. (2011) The elusive universal post-mortem interval formula. *Forensic Science*

351 *International*, 204(1-3), 34–40.

352 White, L. & Booth, T.J. (2014) The origin of bacteria responsible for bioerosion to the internal

353 bone microstructure: Results from experimentally-deposited pig carcasses. *Forensic Science*

354 *International*, 239, 92–102.

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356

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358

359