With Cane In Hand: Going Deeper Into A Bioarchaeology of Innovative Disability

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by

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TABLE OF CONTENTS

ABSTRACT

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Impairment and disability are understudied and under-explored dimensions in bioarchaeological reconstruction of past lives. As methodology improves and bioarchaeologists continue to embrace new branches of social theory, in tandem with greater embrasure and application of evolutionary theory, the characteristic difficulties of studying the lives of impaired and disabled people in the past are not the barriers they once were. New approaches to the problematic paucity of information available at the surface level of archaeological remains have begun to allow deeper molecular and proteomic investigation of formerly invisible processes. Because of this opening of new avenues, traditional resistance to expanding research into disability in the past is no longer a tenable stance. Furthermore, as bioarchaeology engages with extended theories of evolution in human history and deep time, it is pertinent to address the great antiquity of impairment and disability survivorship as participant of the evolutionary history of the

human lineage, rather than a static byproduct or an artifact of modernity. In accordance with an inclusive view of disabled lives as integrated in the processes and systems of human evolution, it is here proposed that disability itself represents a signature feature of the evolved plasticity characteristic of human beings at the embodied, communal, and cultural levels.

A HISTORY OF A PREHISTORY OF BODILY OTHERS

Early scholarship addressing the archaeology of impaired individuals or their caregiving in past societies is sparse and rarely if ever elaborated upon. This occurs in tandem with the way the confluence of the concepts of disability and prehistory are often couched within topics of evolutionary salience, where the remnants of social Darwinism haunt questions about what variation in form and function could persist in the past. Impairment and disability become relegated to the list of characteristics that a narrow selectionism deems impossible under contexts predating modernity--and so the effort of exploring these facets of the human condition in prehistory, through archaeology, has often been given the silent treatment. Immediately outwith archaeology proper, however, some early social theorizing about the construction of disability in "foreign" societies inadvertently created the groundwork for the way archaeologists would frame impairment and care in future work. A paper entitled *The Physically-Handicapped in Certain Non-Occidental Societies* addressed the manifold nature of communal responses to the presence and sometime-constraints of a community member presenting with an impairment, suggesting a heuristic of five broad types of such responses (Hanks and Hanks, 1948). Attention to disability as a true feature of human experience—its myriad cultural contexts, its role as an example of human variation, for instance—slowly

increased as disability studies launched forward in the social sciences (Scheer and Groce, 1988; Scotch and Schriner, 1997).

Care and treatment of disabled persons as an epistemological focus in archaeology overlaps and perhaps emerges from the study of "deviant" burials. Signified by breakages of typical funerary patterning, including mortuary arrangement, location, and provision or withholding of grave goods, "deviance" in mortuary archaeology came to also include the presence of markedly pathological remains. In the attentions of mortuary archaeologists, simply the signatures of significantly different or more advanced pathological conditions of the skeleton evidenced in an individual, with respective contrast to the broader assemblage, were qualified as their own form of deviance. Preoccupation with "deviance" in mortuary archaeology did have one unintentional result that preceded an attention and interest in disability: isolated attention on a single "deviant" individual or subset of individuals produced a necessarily case-by-case approach in the assessment thereof. "Deviance" as an archaeological concept might best be called an offshoot of processual archaeology and its predilection for the survey of social grouping and ranking, while simultaneously representing the shift toward postprocessual expansions of the social dimensions of past societies available for reconstruction. Characterization under processual methodology concerned the particulars of the material and biological components of a given burial; postural, spatial, and artifactual decisions on the part of the mourners were believed to reflect the occupational or political prestige of the individual. Under such a framework, "deviance" was identifiable first and most obviously in the factors of space and provision of grave goods;

in many cases, “deviant” individuals are isolates of a roughly contemporaneous assemblage where the overarching pattern is spatially intimate, ‘marked ’by a lack of goods where the overwhelming majority are provisioned for, or conversely, lavishly prepared where the most frequently occurring arrangement is relatively austere. On occasion, the sheer theatrics of a particular deposition draw attention to a sense of negative emotion or possible stigma in contrast to those that comprise its contemporaries; the haphazard handling of an older probable female in Mórrope, a church site from Early Colonial (post-European contact) Peru. Burial U4 05-32 shows extensive affliction attributed to severe treponemal disease and was discovered deposited in no particular pose compared to the handling of her estimated contemporaries, as if simply tossed into interment with little care. Dated to a point in time that reflected a threshold of tumultuous social and cultural transition, it was suggested that perhaps this apparently callous treatment might be part of shifting attitudes toward disease and physical deformity (Klaus and Ortner 2014). There is great variability in the reasons that such a burial might stand out or what beliefs might have contributed to their eccentricity, though, and not all are necessarily couched in mistreatment or social rejection (Murphy, 2008).

The purview of archaeological “deviance” was extended to offer avenues of explanation for the presence and mortuary handling of remains with indicators of pathological conditions vastly in excess of the typical condition of remains in the surrounding community. In spite of the weighty aftereffects of a description like “deviant”, an important distinction was created in the assessment of mortuary treatments, one that prioritized individualized attention and a focus on Why questions that demanded

greater contextual focus to decode. Sometimes, and perhaps even skewed by the connotations of the term, explanations for deviance in the burials of individuals with marked physical and pathological differences fell into the realm of disease taboo and apprehension for dead 'others', a climate of fear purported to surround the beliefs of a place and people about the reasons why illness and disability appear in the first place. Superstition and caution abound, though it is pointed out that a focus on fear, revulsion, and stigma may be more recent than is sometimes believed (Tsaliki, 2008; Schug, 2016). Perhaps this is because of the unfortunate appeal of the sensational, or it may be a product of the tacit negativity of the term, which is particular to English-language research on the subject compared to the terminology adopted in German research on deviant burials (Aspöck, 2008).

Whether due to statistical patterning or biases on the part of the examiner, the presence of a severely or atypically affected individual within—or just outlying—a burial community startles archaeologists looking to use funerary characteristics to infer experiential realities of the past. The relative obscurity and invisibility of people with disabilities in the archaeological record has been attributed in part to the habitual overlooking by archaeologists, compounded with and exacerbated by the unequal distribution and representation of burial assemblages to their living counterparts (Waldron, 2000). It was not uncommonly believed, for instance, that severe impairment represents an untenable cost for an ancient society to mitigate. Emphasis on the intensive physical activities and demands of hunting and gathering economies placed a sense of 'realism 'on the idea that impairment and disability requiring especial investment in care

for activities of daily living would constitute an “economic hazard” (Winzer, 1993). A nominal textbook in human evolution in the 1970s went as far as to postulate the fate of such individuals, as early as in childhood, to have “died early, and were not missed” (Birdsell, 1972).

The concept of disability, irrespective of its relationship with care that past societies may or may not have given, was also nebulously defined at this time—especially in its dependence on social and technological constructs and attitudes not extending further back than modernity. The definition of disability is itself a non-straightforward entity. Multiple models exist to describe and contextualize disability as a term in social, medical, and identity dimensions. A criticism of palaeopathological literature as it regards defining disability is that it frequently does so through the very narrow medical model, with little to no incorporation of social constructions for disability (Southwell-Wright, 2013). This also problematizes—or highlights the problematic nature of—using the term 'deviant’ to describe burials of unexpected patterning. 'Deviant’ is, of course, a loaded word. The ascribing of a term carrying value-judgmental connotations to the simple presence of outliers in a funerary assemblage runs no small risk of attracting an unnecessary negativity or othering of such cases. Since the study of impairment and disability in the archaeological record already faces the biasing pressure of present-day, culturally constrained attitudes about such concepts, it is crucial that field terminology reflect a philosophy unburdened by these preconceptions (Aspöck, 2008). Work conducted under the umbrella of 'deviant’ burial analysis was nonetheless an important precedent for breaking into an interest in the “extraordinary bodies” that were too often

left out of focus (Shakespeare, 1994; Garland-Thompson, 1997). Writ narrowly, the insisted paradox of an antiquity of disability and concomitant practices of care seems either an artifact of the 'nasty and brutish' image of hardship in the ancient world or a proscription by way of social resources.

Ralph Solecki's publications on the discovery and burial treatment of the Neanderthals of Shanidar Cave are sometimes credited as having been the first, or among the first, attempts at understanding the presence and apparent survival into old age of several pathological remains of hominin ancestors, most particularly through the inference that this was the result of invested care and depth of emotion (Solecki, 1971). Descriptions and discussion of the Shanidar Neanderthals take a speculative turn in the assessment of the burial of Shanidar 1, an individual with multiple upper body growth disruptions and a suite of extensive scarring along the left side of the facial skeleton. The conclusion is offered that some part of this individual's condition was congenital in nature and thus an obligate life of disability, noting as well that an old, remodeled cranial fracture implies the availability of means to recover and survive well past the point of the initial injury. This is concomitant with the observation that a highly mobile hunting and foraging subsistence economy would have presented a tremendous difficult curve for the participation and survival of this individual; thus within the paragraph it is suggested that acceptance and some, probably intensive form of assistance explains Shanidar 1's presence in the burial record with apparently non-disabled peers. Interestingly, Solecki also reports finding a unique pattern of tooth wear on Shanidar 1's remains, focused on the frontmost teeth, and offers the suggestion that without the use of the growth-disrupted

limb, this individual may have reconstituted subsistence activities to the cooperation of the unaffected limb and dentition.

The rise of bioarchaeology as a field had brought forward the ability to reconstruct the presence of disease and physical trauma in human skeletal samples, expanding the range of types of data that could be extracted or inferred from the ancient world. More recently, informed by developments in social theory with respect to disability and impairment, questions about care practices and the participation of care recipients in the broader survival context re-emerged. These operated on the principle of compassion as the salient element behind care, another avenue of the intensified capacity for prosociality in human evolution and a plausible element of the variety of explanations for the evolution of altruism at the time. Describing care as compassionate seemed to fit with the predictions of evolutionary theory in the context of altruism. Yet this served as a conflict to the archaeological context, where, critics argued, it was not possible to reconstruct a strictly compassionate motivation or behavior. The very notion was discouraged as irresponsible and speculative, with no place in serious scientific discourse. The archaeology of compassion is a surprisingly contentious arena given the relative non-controversy surrounding compassionate and altruistic behavior in evolutionary theory. This seems to be particularly true the further back in time a given assessment travels—the study of compassion and care in Neanderthals is, for instance, an especially heated zone of debate (Dettwyler, 1991; DeGusta, 2002).

Under specifications of such models as reciprocal altruism and social niche specialization, individuals become valued investments in communities when unique

contributions from the individual mitigate the costs of provision of care (Sugiyama and Sugiyama 2003; Thorpe 2017). This becomes problematic, however, when applied to cases in the funerary archaeological record in which circumstances of reciprocity for individuals in receipt of long-term care are unclear and unapparent, a scenario which begs the question: What can the archaeological and skeletal records indicate about 'compassionate 'behavior when no overt evidence of utilitarian specialization exists for a given site? A contrasting explanation offers that motivation to cover costly care requirements is embedded in compassion. Compassionate intentions afford the mutuality of caring behaviors; among members of mobile hunting and gathering groups, for instance, shouldering a broad suite of 'costs 'associated with subsistence activities (risky hunting, cooperative care of younger kin, food-sharing, etc.) builds trust and creates a framework of interdependence favoring the collective survival of the group (Spikins, et al. 2018). In other words, accommodating the needs of impaired members of the group is really factored in in the same fashion as other costly activities of daily living; when individual survival is maximized by communal survival, a transactional nature of care relationships is less apparently advantageous. In a wider evolutionary perspective on this scenario, altruistic and compassionate motivations do not present a conflict of interests for individual survival outcomes; cultivation of a socially cohesive micro-environment creates new terms and conditions of life in the surrounding macro-environment that do not require compassion and altruism to be checked against competition.

Like affordances on the individual level, group-level niche construction gives rise to the inheritance of selection environments whose exerted pressures are modified and

negotiated continuously and across generations (Laland et al. 2015). In turn, it is suggested that these care-investing and environment-negotiating dynamics became involved in the evolution of the extended lifespan characteristic of human life history, the decision to provide compassionate care a direct driver in shaping this feature by collective effort at reducing rates of mortality (Sol et al. 2015; Sugiyama and Sugiyama 2003). The propensity for care to mitigate and reduce overall mortality may then doubly play into the plastic character of human life history when early-life stressors are survived at cost to later-life outcomes (Kuzawa & Bragg, 2012; Temple 2019). The burden of 'payment 'from such trade-offs, in other words, may be softened, though not offset, by continual provision of conspecific care.

Here it is important to emphasize that under a care model, individuals afflicted with long-term impairments are not simple, passive recipients of care behaviors. In particular, characteristic of prehistory are smaller-scale societies in which subsistence and other lifeways were frequently quite communal, with individuals tightly interconnected with one another. Tilley (2015) reminds that in these settings especially it ought be taken into consideration that at least two modes of response to care provision over long periods of time exist for these communities—most particularly, assimilation and accommodation. In the latter scenario, receipt of care enables some reciprocity of labor, where the communal strategy structurally adapts to the inclusion of an affected community member in ways that permit and integrate that member's contribution to group survival and persistence. Such was the case of the Lanhill burial 7.

Lanhill was a barrow monument from the Neolithic Cotswold-Severn culture in Great Britain, excavated in several waves beginning in 1855 and concluding around 1963. There are no obvious signs of daily activity in the immediate vicinity of Lanhill Long Barrow, and no signs that it might have been in any significant way different than other Cotswold-Severn communities; it is estimated that Cotswold-Severn society was semi-sedentary, with little evidence for permanent settlements aside from barrow monuments, but animal materials and trace remains suggestive of some degree of pastoralism in their subsistence styles. Little to no material culture or grave goods are otherwise associated with Lanhill burials, not unusual for Cotswold-Severn barrow communities.

Lanhill Burial 7 (LB7) comprises the remains of a probable male adult of around 50 years at age of death, discovered in the 1936 excavation, and bearing an injury at the distal epiphysis of the left humerus, likely sustained somewhere in adolescence. This was dated to be the last, most recent of the interments at this particular burial site. The injury was associated with a displacement of the articular surface that locked the head of the ulna into the olecranon fossa, resulting in fixation of the whole forearm in a 80 to 85 degree angle with respect to the upper arm; in reality it was probable that normal contraction of surrounding muscles would have resulted in the permanent flexure of forearm against upper arm at closer to a 90 degree angle, severely restricting movement. The left humerus shows significant disuse atrophy and growth disruption; all other limbs are well-developed and robust, with muscle attachment sites indicative of a highly physically active lifestyle. Tilley speculates that, perhaps ironically, attempts to provide

care at the time of the injury may have resulted in furthering its complications—that the dramatic angle might be a consequence of trying to treat the injury or rest the affected limb improperly. As a result, through the rest of the lifespan, LB7 would likely not have been able to participate in tasks requiring extensive use of both upper limbs. This did not seem to have any bearing on lower limb utility; LB7 has the same degree of wear and development to lower limb morphology as all surrounding members of the burial group.

The other constituents of this burial group, interestingly, also show a suite of their own individual impairments; LB7 is not the only individual who could be speculated to have some sort of disability. Severe vertebral degeneration, antemortem tooth loss, chronic oral infection, and osteoarthritis of the temporomandibular joint appear several times in individuals in the Lanhill barrow; complications to mobility and activities of daily living do not necessarily appear to be uncommon for this group. Lanhill Burial 2 sports a fracture to the right zygomatic process, perhaps contributing to subsequent temporomandibular joint dysfunction; several individuals are edentulous. Several of the individuals are estimated to have been relatively long-lived, with the category for 'older adults' covering at least 6 of the total 24 burials.

Given his degree of similarity in condition to others in the group apart from the restrained left arm, and given the appearances of several other individuals whose conditions could have affected their activities of daily living and constituted unique care requirements (such as processing foods for the edentulous and temporomandibular arthritic individuals, for instance), functional limitation and impairment do not appear to have divided up this community at least in terms of their arrangements in death. Their

contrasts and similarities as estimated in life perhaps indicate a survival by collaboration, where provision of care might have been more specialized as *accommodation* of a particular affliction's impact on group participation. In other words, bodily difference and constraints on the normal activities of everyday society were mitigated in part by social fluidity—adjustment and adaptation of communal norms in the face of a variety of physical challenges. Tilley is cautious in interpreting much further than this suggestion of accommodation, regarding greater specificity as spurious for the evidence presented (Tilley, 2015).

For understandable reasons, it is generally not considered possible—or at least, not epistemologically responsible—to try to extrapolate overtly cognitive phenomena from the archaeological record, and this is particularly the case in bioarchaeology where the chief embodied evidence is what can be read in the human skeleton. There is even skepticism that inferring evolutionary precedent for complex cognitive phenomena like language from broader, earlier evidence for symbolic capacity (Botha, 2010). Nevertheless, in recent years a resurgent interest in the evolution of cognition has led some archaeologists to branch into heretofore proscribed territory, namely an interest in how the archaeological record could shed insight into the materiality of symbolic thought and innovative production. Such an archaeology of intentionality broadly underscores the range of complex behaviors associated with species-typical human characteristics. Spikins (2009) has produced some bold scholarship into how cognitive and behavioral phenotypes considered in present-day Western society as disabilities, especially autism, might instead have acted as drivers of innovation in material culture and an impetus for

increased intragroup cooperation in the past. One fundamental caveat must be made very clear here: autism, and for that matter any cognitive phenotype, do not skeletonize. Inferences about specific cognitive systems from the archaeological record are problematic for similar reasons; to get past ad-hoc speculation, a sufficient 'bridge ' theory has to come about to adequately link the two domains (Botha 2010). Additionally, as with any inquiry into disability in the past, the social constructions that scaffold various impairments as experienced by the individuals within their community and society make the diagnostics and even the 'medicality' of a given syndrome extremely subjective. A proposition will be made here, therefore, to consider the current approachable focus of research interested in these tenuously-accessible experiences in the past as one interested in the study of difference accompanying impairment, and where difference and survival outcomes show participation in broader, group-level resilience.

When the body itself is a cultural object, it immediately occupies a dual role in these contexts—it is what remains of the once-living, actively sentient cognitive system, and also a longitudinally iterated product of that system and its coexistence with other cognitive systems in its social setting. Perhaps this part goes without saying. Creative productions and material intentionality are hardly fully separable from their embodiment in the cognitive spaces of their creators, even if the individual objects themselves are not crafted for any specifically practical or social purpose. To view the body, the biological object, however, beyond its role as the creator of material artifacts and symbol systems, and as contiguous with the materiality of its creations, is what is being suggested here. Burials best exemplify this concept in how variable mortuary treatments are with respect

to how the decedent's remains are prepared, which pieces are assigned to a funerary environment, or whether the physical body is buried at all in the first place. The suggestion that a burial environment is also a symbolic one is not a new idea; even early processualists mention the idea, although usually more with skepticism than approval. An emerging focus has been placed on the social or symbolic materiality of the remains themselves; while it is more typical to treat mortuary sites as a dyad of body and burial environment where the body may be subject to culturally-contingent features of its treatment, but otherwise distinct as the biological object in a contained cultural space, recognition of the participant duality of bodies as social, cultural, and symbolic objects is increasingly appreciated (Sofaer, 2006; Dornan-Fish, 2013).

Disability may highlight the underestimated contiguity of biological and cultural within and immediately surrounding the body in ways akin to that of research in the burial representation of occupation and roles in the labour force . Under a combined theory of extended-mind, niche-constructing, and affordance, the body is a biological object and also a social agent—and so are its tools of accommodation and adaptation. When the social body of an individual, in other words, is the composite of its corporeality and its created means of affordance—a compromised leg and the walking stick that bolsters it, for instance—the whole of its personhood includes both body as object, and object as body. This dissolution of hard distinctions may be of assistance to bioarchaeologists integrating the perishable domains of the living mind with its nonspeaking, taphonomic epilogues.

THE BODY AS CREATIVE NEXUS

With terms like ‘impairment ’and ‘disability’, the accompanying association is with loss or corruption of function, a net reduction in the options of livable experiences. To some extent this is inarguable; life after events that confer impairing characteristics is a far cry from that which was lived before it. What is under-explored and understated in archaeology and elsewhere is that these are not binary modes of being—that is, to be abled is not to be ‘on’, nor disabled, ‘off’. Instead, just as human beings construct implements and environmental modifications to suit the demands of functions we do not naturally possess, the body under disabling conditions might be said to exist in a state of ‘reinventing the wheel’, facilitated by the responsive plastic nature of osteological and interrelated biological systems.

To explore this supposition further, a case study in which impairment exists, but in at least one definition or sense, disability is not apparent, warrants discussion. Lovell (2016) reports on the remains of an older adult, probable male retrieved from salvage excavations of the primary burials at the cemetery of Erculam in southern Italy display a range of skeletal alterations associated with serious injury and long-term prognosis. Erculam is a cemetery dated to roughly the first or second century CE, serving a community of mostly maritime subsistence and economy. Most individuals at the Erculam cemetery were interred in rectangular pits covered in terracotta tiles, with few to no grave goods, leading to the interpretation that this community was of generally lower social status and limited material wealth.

The primary injury of interest concerns a fracturing of the right femoral neck, reducing the femoral neck angle and resulting in a relative shortening of the affected limb. The fracture is well-healed, with little arthritic change in the immediate vicinity of the femoral head. There is lipping and eburnation at the right patella, distal femur and proximal tibia, but the tibia itself is intact and dimensionally identical to its twin. The much more involved loci are a set of bones of the right foot bearing significant pathological alterations. The first metatarsal of the right foot is affected at its articular surface with the neighboring phalanx by notable lipping and erosive lesions. Its distal subchondreal surface shows eburnation, and on its proximal end's plantar surface is found an unusually pronounced insertion site for the peroneus longus muscle. Metatarsal 2 is affected similarly, to a lesser degree than the MT1. The first and second proximal phalanges articulating with the MT2 show eburnation on their distal subchondral surfaces; regrettably, no further digits distal to these were retrieved at the excavation site. A crush fracture of the fifth lumbar vertebra may be of interest to questions of this individual's prognosis, as is the extensive lipping on the third and fourth lumbar vertebrae. No signatures of trauma are found in the pelvis, and there are no signs of fractures of the calcaneus or talus.

Reconstructions of the mechanics of injury imply the source of the femoral neck fracture was from indirect blunt force; the femoral neck is cushioned by soft tissue, affording a measure of shock absorption. It is probable that the blow was elsewhere, and the force of the blow travelled down to the femoral neck, which then bore the impact. Subsequent reduction of femoral neck angle is consistent with a fall injury from height;

however, the lack of evidence for injury on the opposite leg, os coxae, tali, or calcanei does not suit this conclusion. The relevance of lesions in the vertebral column is less clear, as it is not necessarily the case that all injuries would occur in the same event.

A sideways fall, on the other hand, is well in line with the pattern of femoral neck injuries resulting from the destabilizing effects of osteoporosis, subjected to relatively low-energy force. Clinically, the majority of patients seen with femoral neck fractures are osteoporosis sufferers, supporting this suggestion. Causal factors in osteoporosis frequently involve poor diet, and this individual's extensive antemortem tooth loss renders this a feasible etiology for the conditions precipitating the fracture. Since the burial environment and treatment suggest the individual would have been of low social status, it would not be unreasonable to surmise that sustained difficulty with access to adequate nutrition was another facet of the makeup of the fracture. Low social status in turn dispenses with some of the 'luxury 'of relegating provision of care to a servant class, likely narrowing the pool of resources down to those that could be found communally within kin or class. In other words, evidence of long-term care in a context tightly constrained by paucity of material wealth and social status suggests a more personal connection with care than one outsourced to another service or labour source. As such, paradoxical to the assumed or expected outcome that scarcity of means would always and automatically drive communities to abandon members with above-typical needs, in this case it would appear more that this group responded cooperatively, with the individual's very bodily form undergoing physical specializations that mitigated the cost to contribution balance of its impact and the care it required to sustain longevity. Because of

this interdependence and accommodative strategy, Lovell suggests that, in the sense of the social model of disability, this individual is impaired and dealing with functional limitations as a result, but *is not* disabled (2016). This highlights the nuances of using multiple terms and multiple forms of definition for each; impairment and disability are not rigidly categorical, and choosing only one of its facets to represent a canon for the entire range of phenomena deliberately ignores its diversity and ingenuity. Cooperation under mutually strained resource availability in this case effectively dissolved disability in the sense of the social model.

In this way, normal processes of skeletal remodeling and healing are participatory elements of the plasticity of the human skeleton and the creativity of skeletal structures to respond to insult with surprising variability given the relatively simple options available—making, or breaking, bones. While it would not be responsible or accurate to posit all healing and remodeling as positively adaptive--a long bone fracture, for example, can heal in a less-than-ideal posture, resulting in even greater eventual loss of function--the base capacity of this system is to respond dynamically and with considerable flexibility. When viewed in this light of potential, it becomes possible to posit agent input on the responsivity of a plastic system; as both the locus and the experiencer of skeletal trauma, disease response, congenital or growth disruptions, and so forth, an embodied continuity exists in every instance of a human agent faced with injury, illness, and impairment. “Top-down” processes of cognition--the “active” experience and perceptive center of the individual--maintain close connections with their somatic counterparts in tissue and peripheral systems. Signaling within distal afflicted tissues is

relayed via the innervation of the spinal cord to cognitive loci of processing these signals; yet there is an implicit suggestion persistent in the literature of systems of experience that the body ‘feels ’pain and stress and the cognitive kit of the selfsame body ‘experiences ’it.

This is true to an extent; to verbally assess a painful experience, or formulate a multistep plan of response to the painful stimulus or event, is by rights a property of “higher-order” signaling systems such as those that characterize executive cognition. To a further extent, however, this is an unnecessary and artificial divide. To invoke an old metaphor, the brain-in-a-jar lacks, for instance, input from any system of tissues, structures, or compounds save those of the brain and spinal cord, and exists therefore in a suspension of permanent and total sensory deprivation, a status not possible to entirely replicate in living persons. In isolation this suggestion fits well with rebuttals to Cartesian dualism in cognitive science; in the context of the skeleton as a tissue system, it is wholly crucial to sidestep preoccupations with central and executive control in favor of more comprehensive outlooks on the interplay of central and peripheral systems. Connectivity of peripheral to central, and tissue type to tissue type signaling processes, is fundamental to the operation of the skeleton at all levels--including its great elasticity, within the rigidity of its range or kind of responses. Bone remodeling is exemplary of this integration.

Because a crux of the argument that will be explored in depth throughout this document is the situating of disability within an understanding of behaviors of innovation and generativity, embodied in the everyday productions of the people affected by disability in some form or another, it merits spending some time discussing the

difficulties faced by archaeologists interested in reconstructing behavior from limited material evidence and remains, drawing on similar principles and problems faced in other disciplines when they engage with similar core questions. Inferences of symbolic behavior and intentional signaling will be contrasted with the way that behaviors of generativity specific to disability or attributed to ‘difference’ that overlaps with, or doubles as functional descriptions of disability, are framed in the research that seeks to unpack them.

MATERIAL IDIOSYNCRASY AND SOCIAL TRANSMISSION

Leo Kanner once described the random, nondirectional, often repetitive productions of his patients as containing little to no meaning, content, or purpose, dubbing these productive behaviors of clinical salience with the telling moniker "autistic disturbances" that are “semantically and conversationally valueless” (Kanner, 1943). Lacking the mutuality of the signaling that would ordinarily occur between two interlocutors of the same linguistic background, such "disturbances" as echolalia, however novel their structure or composition, present with an opacity of intent for onlookers. Thus in contexts such as those of Kanner's clinical practice, the apparatus and products of these generativities are relegated to 'useless', placed in a void walled off from their typically-developing equivalents. It is argued here that, rather than symptoms of a maladapted or pathological version of communication and self-regulation, "autistic disturbances" are another or a further manifestation of the plasticity and creativity of human cognitive and embodied systems. The products of neurodivergent creativity--those

selfsame 'pointless', random behavioral tics--have also been described with the considerably less loaded term 'idiosyncrasies'. An invention of idiosyncratic nature is intimately neologistic--its context is that of its creation and creator, irrespective of whether the result is of social value of explicability. Idiosyncrasies, like "autistic disturbances", are singularities of embodied invention; their usefulness as signals or viable techniques are, at least initially, irrelevant to the decision to create them or not. In a recent review of surveys with parents of children with echolalia, this is made more explicit in the observations from several interviewed parents that directly address the independently expressive nature of their children's utterances. General trends in the review showed a tendency to affirm neurodiversity, emphasizing that their children's difference was of no tangible detriment and did not require intervention; a recurring sense that there was positive impact in choosing not to interfere in echolalia expression, as it constituted a unique expression of joy; and also a sense of subversion of social norms, a point of pride that in just one behavior, these children reject the normative pressures of society. One parent, whose name was concealed with the marker PRNT030, gave the following response:

"I have always seen echolalia as something that is just to be thought of as another part of diversity in humans. I know other parents and other groups that are very concerned with saying it is one or the other, I don't think like that. Why can't people come to understand that maybe it just is different. But I think that because it is different it makes people uncomfortable and then they want to put it in the behavioural box or put it in the

communication orientated box. It's just human difference, its beautiful when I hear it" (Cohn, Harrison, and McVilly, 2023).

Ambiguity and tenuousness of 'usefulness' need not be a permanent fixture of idiosyncrasies. The great plasticity of human behaviors, bodies, and embodied cognitive experiences can be said to have here expanded in ways that mitigate the 'cost' of highly plastic forms. Spikins (2009; 2018) makes these tradeoffs explicit: ingenuity or less-constrained innovation, permitted by the concomitant factor of neuroatypicality. These phenomena need not be so rigid, however--a product of extremely plastic capacities of an organism may well have value irrespective of the immediately utilitarian applications it may or may not present with. They are reflective of an underlying flexibility and unconventionality of function perhaps unanticipated under the normalizing effects of selection in isolation; part and parcel of the systems interacting with selection, perhaps (although not necessarily exclusively) especially in prosocial species.

When random productivity occurs with material substrates, a potential door for archaeology to enter the discussion opens. Much has been made--and continues to be made--of the phenomena involved in the evolution of "the modern human mind". That there is ambiguity remaining in the estimated evolution of "the" modern human body ought impress the further complicated nature of asking after "the" modern human mind--assuming that such a distinction exists or is of importance (Spikins, 2009).

ACHEULIAN TOOLS, 'OVERIMITATION', COSTLY SIGNALING, AND THE ARTS

Behavioral inheritance is a crucial arm of the Extended Synthesis, specifying that the systems and products of social learning, social transmission, and modeling or

imitation contribute to evolutionary change in equal and frequently interactive capacity with natural selection (Laland et al., 2015). However, there is an emphasis on the distinction between forms of social and behavioral transmission as functions and indicators of cognitive fluidity, particularly the nuances of forms of imitation, emulation, and other social learning tasks. It is remarked that

"Distinguishing between imitative and non-imitative learning is not always easy, and there have been very few experiments that would detect motor imitation unequivocally, so we cannot really evaluate how frequent and important it is in the animal world ... "the behavior has to be displayed in order for it to be inherited... variations in the individual parts are not constrained" (Jablonka and Lamb, 2014).

Acheulian tool production en masse has garnered some questioning as to whether or not it can be specifically characterized as this kind of learned, iterative process of the individual that results in the mass-production of era-characteristic implements still persisting in the archaeological material record. The phenomenon responsible for the spread of idiosyncratic manipulations of raw materials in the Acheulian is proposed to be a form of horizontal behavioral inheritance--overimitation. Overimitation can be understood as repetitive behavioral innovations, that, when observed, are rigidly and ritualistically imitated by observers. Overimitation operationally describes an exaggerated form of imitative learning, the latter of which is emphasized in the literature on social learning that characterizes many of the most novel events of human cognitive evolution. In overimitation, attempts to replicate an observed behavior involve broad, imprecise replication of the components and features of that behavior; this is

characteristic both of the earliest phases of acquisition of and of a frequent phenomenon in autistic development. In the case of the latter, overimitation occurs largely in place of typical imitation, a distinction such as that from emulation. Acheulian overimitation perhaps sits somewhere between these dimensions; idiosyncratic events of interaction with raw materials result in production of inestimable pragmatic value. When these rites of production are executed repetitively--as in many inventions of neurodivergent 'stimming' behaviors--a self-contained cycle of generation and iteration becomes apparent and readily observable by conspecifics. The suggestion from this interpretation of the material record in flint point productions of the Acheulian can be summarized thus: flint technology, and the archaeological evidence thereof, is resplendent and iteratively patterned because initial superficially random innovative events become subject to the processes of social learning that spread through a given community of social organisms. Research into the emergence of the unique characteristics of Acheulian material culture observes that the integration of social and technological cognitive capacities is a prerequisite for these behaviors of materiality, emerging in evolutionary time far sooner than the direct material evidence (Rossano, 2017). This is where the strengths of bioarchaeology stand out: bioarchaeological approaches favor holistic, multidimensional, and contextual appraisal of evidence from the past. Is it not improbable that in instances where both material productivity and skeletal assemblages co-occur, bioarchaeology can make informed estimates of the embodied relationships between biological and material data possibly a function of the lived experiences of the past.

Mundane adjustments to the body and the immediate extrasomatic environment, for the individual facing the added constraint of impairment, hearken back to the concept of 'vital 'affordances—the "multiplications of the conditions of possibility of living" (Dokumaci 2017). These embodied adaptations emerge of necessity from the flashbulb moment where the disconnect between exploitable niche opportunities and the needs or limitations of the organism acts to catalyze a novel response from that organism. Viewed thus, the act of responding adaptively to the affordance problem represents a niche constructed on the very small scale, the embodied moment-to-moment of life with a demanding physical condition; these solutions will hereafter be referred to as 'micro-niches', distinct from niche-constructing at the 'macro- 'level of community-wide shifts in strategy.

Characterizing a production--be it of the body, or by the body, as in materials or techniques--as a 'micro-niche 'invites the observer to begin to form linkages between the highly individuated and the socially curated with particular respect to where these factors made contact in the lifeways of a community whose mortuary record persists to offer inferences thereof. Impairment and disability may then be examined in terms of embodied niche construction, wherein the interfacing of body-environment-cognition is understood as an innovative and iterated somatic process. Here, a 'non-normative 'body is already a specialization; its peculiarities, whether overtly 'adaptive 'or not, are inherently novel material, and what feedback this body processes into embodied simulation varies accordingly. Predictions of embodied niche construction additionally

include the use of material constructs and ritual behaviors as means of 'translating' embodied experience into shared meaning (Stotz, 2010; Stutz, 2012).

However, material productions need not have strictly symbolic content in order to have symbolic value; and if the recitative abundance of these engravings is any indication, another context for the find emerges. Repetitive, seemingly non-directional ritual behavior is a perennial association with neuroatypicality. In clinical interpretation these small rituals are usually denoted unproductive, without meaning for either the ritualist or any observers; yet like the 'vital affordances 'in manual technologies of daily living', these same abstractions are structural elements of that individual's environment (Dokumaci, 2017). 'Stereotypy', in other words, is a form of agency—a shaping of the world that creates a non-normative individual's self-evidence (Cohn, Harrison, and McVilly, 2023). Idiosyncratic ritual—'poetics 'free of attachments to existing requirements for 'meanings 'in the narrow sense—is in this way a font of creative ingenuity (Rodas 2018). That is, the generative quality of what Kanner referred to as 'disturbances' introduces forms of creativity that may encourage 'useful' innovations but which have value independently of overt utility.

Furthermore, the suggestion has been made that material manipulation in the form of pigment use and modification of natural materials served symbolic purposes as adornments, acting as signifiers of social identity (Henshilwood et al. 2009; Hodgson 2014; Sterelny 2011; Zilhao et al. 2010). It may be useful to think of idiosyncratic modifications as 'micro-niches'—individual-level negotiations with body and space and society—distinct, but closely linked to 'macro-niches 'constructed at the level of

community and communal lifeways. It would be gravely mistaken, it should be emphasized, to assert that any and all spontaneous and memetic productions, including art and material culture, belong strictly with neurodivergent creators. Indeed, the 'medicalization 'and pathologizing of these variations on human generativity is a core element of critiques from the social model of disability and its derivatives. A key aim and argument of this paper is instead that where memetics and stereotypy appear in archaeological contexts—including in 'meaningless', non-utilitarian productions—they may speak to the inclusiveness or accommodation in prehistoric communities for a wider range of behavioral phenotypes, such that constraints and stressors on these communities do not necessitate their exclusion. The suggestion has been made that the extensive plasticity and variability of human brains speaks to a non-modular emergence of cognitive modernity; put another way, the emergence of a 'modern mind 'would be one of many different 'kinds 'of minds, an untyped spectrum of cognitive modernity inclusive of and defined by neurodivergence (Spikins 2009). The unfortunate fatal shortcoming of Spikins 'model of autistic 'different minds 'and the inclusion in societies thereof is that it leans into models of autistic difference that require the interpretation of autism as the absence of empathy.

Among behavioral mechanisms of inheritance are systems of symbol production. Reconstructions of symbol systems are controversial in archaeology; it was a stipulation of processual archaeology that symbolic, representational content was unavailable and inaccessible in material contexts. This stipulation is particularly prevalent the further into prehistory symbolic analysis is attempted; the definition of a symbol, to a degree, is

constrained by its property of intelligibility. The Middle Stone Age site of Blombos Cave famously contains a collection of pieces of etched ochre, the production of which has earned it a place squarely in the middle of a heated ongoing dialogue about 'modernity ' and symbolic communication in the past (Henshilwood et al. 2009; Hodgson 2014). The geometric patterning featured on these artifacts was produced in a repeating series of etch marks of varying consistency. Researchers interested in the relevance of the Blombos engravings to the study of linguistic communication specifically have made efforts to determine the intelligibility of the carvings. Recent work has argued that were these etchings reproducible as discrete units, theoretically anyone would be able to perceive their patterns as such, even if people in the present day could not naturally 'understand ' them. This principle would exclude the engravings as constituting representational symbol systems like language, if the perception of discrete units could not be achieved under empirical conditions. In finding that study participants could not accomplish this parsing task reliably, the conclusion was made that the Blombos engravings are at best simple aesthetics (Tylen et al. 2018). Interpretation and contextualization of the etchings preserved in Blombos Cave has faced this problem of epistemology.

Reflecting disabled identities in the mortuary record requires an additional level of attention to detail in drawing on inferences about intentional and symbolic behavior, beyond the assessment of pathological remains alone--to interpret such individuals in social contexts outwith the clinical characteristics of their skeletal pathological conditions is very specifically the extra depth provisioned and prioritized by bioarchaeologies of care and those accounting for the synergy of pain, suffering, and adaptation (Tilley, 2015;

Martin and Harrod, 2016). This is a bioarchaeology unsatisfied with simplistic description - underserved by explanations of periodic stress and binary transition. Accounting for the contributions of impaired individuals--those forced to find innovation in the dace of disability or to negotiate, in a vacuum, the social and communal 'costs' of supporting their survival and livelihood--is accounting for the same adaptive capacity ascribed at the species level. When evolutionary reconstructions of human persistence appear in concomitance with the remains of individuals bearing the signatures of significant impairment, and especially where skeletal evidence suggests that conspecific care seems to have played a role in any given disabled individual's longevity, it can hardly be dispensed with that a relationship of sorts has emerged from the confluence of the demands exerted by the impeding condition, the exceptional and vital plasticity of the existing impaired form, and the social energies expended or exchanged in provisioning for the enhanced/exacerbated needs of such individuals. Interpretations of care in the past have typically been forced to occupy a narrow range of impressions: first, a kind of grim utilitarian view emphasizing the mitigation of costly care through the contributions of the care recipient; second, as evidence of the ancient emergence of compassion; lastly, with a shrewd skepticism that archaeology is well-enough informed at all to distinguish attitudes and behaviors surrounding care or compassion in the first place.

CRUEL TO BE KIND: CARE AND COMPASSIONATE BEHAVIOR IN THE PAST

Interrogating the concept of compassion in archaeologies of impairment, disability, and ‘care ’is problematized by the terminology in those questions. Neither ‘impairment ’nor ‘disability ’mean the same things, at the same time, within and across cultural groups. ‘Disability ’under the social model of disability could, for instance, not exist at all—in a group or society where no conditions warrant additional constraints. ‘Impairment ’is sometimes scrutinized for its embedment in the medicalization of ‘anomalous bodies. ’Consensus does not even exist among present-day scholars of the subject area, with some using the two terms interchangeably. So, too, the contextualizing verbiage that bioarchaeologists employ to reconstruct the worlds of those long-gone, when the presence of unusual burials and the unusual bodies resting there inspires interpretive questions about the antiquity of bodily difference. There is a very well-intentioned bias that creeps into this work, complicating the push to recreate the lives of these individuals and their communities as those individuals and communities experienced them. Dettwyler (1991) raises this caution in her critique of the state of archaeology of disability at the time of its publication. Bioarchaeological analysis already depends on justifying the premises it must suggest in absentia of explicit details and from missing information in the necessarily sparse burial record. The 1991 critique acknowledges this, and this does not make up part of the criticism; it is substantive leaps away from this data in the interpretive step that is being addressed. By assuming stable, static definitions for impairment and disability, these analyses impose additional

assumptive, static definitions for phenomena like ‘care ’and ‘compassion, ’without doing much to question the parameters of each. Put briefly, ‘compassion ’is as flawed an operational term as ‘violence ’or ‘warfare’, and must be adapted for the multi-contextual, multicultural, multimodal approaches of bioarchaeology in the 30-odd years since Dettwyler’s critique was published. At that time, the conclusion was brought to heel on the grounds that archaeology simply did not have the tools, techniques, and theory to go any further than speculation on missing, irretrievable data that would have provided contextual grounding to the conclusions of other scholars. We now have much of the equipment—literally and conceptually—that was unavailable in 1991. Yet epistemological issues persist—we are only so much more organised and of a mind on what impairment and disability are. This is perhaps an ideal time to put these problems to task.

So, what complicates the study of ‘compassion ’in bioarchaeology of anomalous embodiments? For one, ‘compassion ’as an operational term is dependent on the normative belief systems and social structures of a given community at a given time—sometimes in entirely different climatic or ecological states than what exist in those places now. For another, a substantial chunk of the literature Dettwyler was critiquing placed compassion within the entanglement of ‘moral decency. ’If terms like ‘compassion ’and ‘violence ’are fraught with baggage, the conceptual universe of ‘morality ’is crushed by it. Can concepts like compassion and care be addressed without ‘morality ’clinging to their coattails? A short answer as of the time this paper is being

written is a definitive Yes. Our wording must be as thoroughly steeped in the multiple evidentiary lines character of our discipline, or we might as well excavate sandcastles.

A possible alternative to the encumbrance of the term ‘compassion ’with the rhetoric of morality is to, as Shakespeare (2006) does, reconstitute it as interactional, relational, and definable only within the particularistics of the most evidentially robust reconstructions of the community in question. If the concept of compassion remains mired in the biased quest for human universals, it will fail to produce the actualities of variety in those universals. How might it be possible to split this term from mooring in the trappings of ‘moral decency’? It might be possible to do this from the lenses of adjacent phenomena with fewer obligatory ties to specific cultural mores. Terms like prosociality, cooperation, and resilience examine the drives, capacities, and natural histories of group survival and social organization, and none demand conceptual anchoring in singular ethical or ‘moral ’assumptions. They helpfully emphasize specific components of behaviors and beliefs that would fall under the umbrella of compassionate acts and attitudes. For this, bioarchaeology must once again challenge its myopia on the visible skeleton. An example of this problem is with the—largely reasonable—extrapolation from signs of premortem wound healing that this is attributable to intervention towards the longevity and well-being of that individual. Without careful integration into as many more contextualizing details as are available, it is possible to misconstrue the intentionality of signs of compassionate care, or to incorrectly attribute provision of care as absolutely resultant of affection or kindness (Dettwyler, 1991).‘Care ’may be a useful metric of compassion nonetheless, since it is a prosocial

action and thus can be hypothesized to be motivated by compassion. ‘Care ’manifests in the skeleton in the form of signs of bone healing, in resilience in times of nutritional stress observable in tooth enamel deposition patterning, and in inclusivity of burials of individuals whose conditions would introduce functional limitations. A bioarchaeology of care therefore still gives the abstract concept of compassion some grounding.

, BIOARCHAEOLOGY OF CARE AND THE INDEX OF CARE

Lorna Tilley created the ‘Index of Care ’out of notes and records from her doctoral studies, to codify a system for the interpretation of ‘care ’in human remains. The Index is a detailed four-step system founded upon collating the most contextual details from the most possible dimensions, then working stepwise through a rhetorical process to parsimoniously isolate a plausible conclusion about the subject in question. The ‘null hypothesis ’in an inquiry into care behaviors and survival outcomes states that care was not a relevant driver in an individual’s survival, longevity, and/or parameters of inclusion—that the individual was not dependent on the invested labour of others in the community in order to live in that community, and that the individual did so independently of this input. In other words, the null hypothesis reads that if it can be assessed that an individual’s functional limitations from illness, injury, or congenital variation, were not sufficient to render them non-contributive and unable to subsist without care invested in their welfare, then it is not responsible to skip to the conclusion that care was the crucial axis of their survival. The Index revolves around this null hypothesis, answering its warning with a demanding precision and a massy data reserve, all drawing on the utmost capacity for contextualization of any given site or individual

within a site. In shortest form, its four steps are cataloguing differences and performing differential diagnosis, followed by assessment of potential functional limitations with the support of clinical analogy, then building from these steps to reason out what care provision would have comprised for the situation. Fascinatingly, Tilley does not emphasize or 'require 'the fourth step—the integrated, interpretive step drawing on all its predecessors, where social theory is engaged at greater depth and research questions expand into other dimensions of lived experience and meanings. This is a painful place to suppress the model's potential, and critics of this permitted omission are often baffled by the way this seems to throttle the strengths and purposes of the Index as a methods-driven piece and a bridging of stringent interpretive minimalism with the flourishing of new multidisciplinary foci and the social theory in which they are dyed to the wool. The unfortunate drawback of critiques such as Dettwyler's is that the responses in the literature and methodology that result of them are predisposed to be rigid and minimalistic—when the critique is that too much is being interpreted of too little, it is somewhat predictable that the riposte becomes exceedingly narrow in the name of precision. This limits the creativity of innovative theoretical approaches, for fear that their suggestions and tentative conclusions be seen as too spurious. The Index of Care, in reducing the emphasis of its fourth and final stage, risks falling just short of addressing all slices of this problem of epistemology. This is also likely not necessary. Impairment and disability are both highly fluid modes of being, and across experiences and lived histories of these bodies it is frequently neither utter reliance on conspecific care, always, all the time, nor bootstrapped individualism's idea of an independent person. There is

nuance in the anomalous body, in constant relational negotiations with itself, and between it and the worlds in which it participates. Further, even within a broad, simple, stable pace of life for an impaired or disabled person, the conditions exerting the stress are not necessarily fixed constants in the arithmetic of their experiences. Indeed, many chronic illnesses and functionally limiting clinical conditions fluctuate in their impacts, at times 'flaring up 'and requiring a different negotiation of needs, and at other times remitting to a more consistent state to which individuals, their strategies, and their care arrangements are better accustomed. Receipt of care provisions does not preclude the different body from also holding its own domains and unique terms of engagement; such bodies are neither severed islands adrift in an isolating individualism, nor passive, dormant vessels for the compassionate labour of others. The inhabitants and experiential authors of such bodies raise stern criticisms of the manner in which their worlds are discussed and often 'flattened' into these one-dimensional caricaturizations, from which they themselves are left conspicuously absent as agents. Overboe (2006) refers to this in critiquing the medicalization of his cerebral palsy and the institutional language used to do so, remarking that it "fails to capture their vivacity". This "vivacity" of anomalous bodies highlights their custom sets of strengths and vulnerabilities—a vivacity not necessarily smothered when interdependence and care behaviors are part of the mosaic pictures of these lives.

Taking the previous discussion together, it can now be asserted that a), 'compassion 'can be suitably operationally distinguished and defined; b) that for the purposes of and applicability to bioarchaeological survey, compassion as an operational

concept can reasonably be couched in observable skeletal and burial-context cues for the provision of care by conspecifics; and c) that to do so does not also necessitate the 'flattening 'of experiences of bodies of distinction to suit the image of high quality stringent science. There are, however, other recurring ideologies within this arena that are insufficiently criticized (except perhaps by persons with their own bodily anomalies, to whom these otherwise invisible biases are glaring and obvious). Integration of present-day social theory and movements can address this directly—yet, curiously, Tilley in particular expresses reticence toward these, taking a negative, skeptical stance on the relationships between activism and science in caregiving and functional limitation research on the presumption that its heated political climate is in some way disruptive to the scientific pursuit of bioarchaeologies of disability (Shuttleworth and Meekosha, 2017). Additionally unhelpfully, there remain uncritically-accepted suppositions in the very foundations of its philosophy. One of these is the recurring concept of 'non-contribution' presumed to underlie the relational characteristics of caregiving toward functionally limited members of a given community. Not entirely unlike the manner in which economic definitions distinguish "disabled" from "not disabled" on the criteria of compatibility with the labour force, 'non-contributors 'are those members of a society or community automatically presumed to be insufficiently productive or cooperative because of the particularistics of the specialized needs of their embodiments (Winzer, 1993). Characterizing the cultural myriad as universally concerned about 'productivity 'is an imposition in the first place, but under these tacitly held founding premises, it seems almost taken for granted that individuals that required care are relegated to the opinion

that they must have also been ‘non-contributing ’members of their communities. The statement that care is ‘costly ’behavior is uncontroversial; frequently, however, ‘costly ’ appears to be conflated at least tonally with ‘burdensome, ’skewing the basic foundations for any assessment of caregiving in humanity’s historical or deep past toward the attitude that the presence of a functionally-limited member of a community must be of negative consequence to that community, which requires assuming that there must be some other serious reason than labour participation driving the decision to do so. This is the mirror image of the critique that extrapolating compassionate intent from evidence of caregiving is irresponsible, because there may be other reasons that the decision to give care is made. Thus, care is certainly not a foolproof perspective for interrogating compassion in the past, and should be able to invite complex interpretations that do not rely on simply rejecting or failing to reject a null hypothesis.

COMING TO TERMS: ‘COMPASSION ’AS OPERATIONAL DEFINITION

Goetz, Keltner, and Simon-Thomas (2010) deconstruct the term compassion using a meta-analysis of many psychological test results that focused on the organization of many emotional and cognitive states that are frequently interchangeable in vernacular speech, and too often conflated in academic argument. The resultant operational definition for ‘compassion ’reads as: “… the feeling that arises in witnessing another’s suffering and that motivates a subsequent desire to help.” (p. 2) This specification separates the concept of compassion from those of empathy, pity, and morality, among other similar terms, into a composite affective state that is action-oriented. ‘Pity’, a common synonym, is excluded here due to the connotation of the receiver of

compassionate action as occupying an inferior state from the perspective of the giver. Interestingly, the departure from synonymity with ‘empathy ’is predicated upon the observation that empathy is also a stress state; the “vicarious experience of another’s emotions”. This creates the phenomenon of ‘empathic distress, ’a state independent of the decision to intervene in the suffering witnessed. Put another way, compassion is an actional, behavioral decision process, and this actional component sets it apart from empathic distress; it is not reflexive in the same way that empathy itself can be, though empathy is an important route toward the motivation to intervene. As a counterexample, it is worth considering the axis of syndromes and neurotypes in which ‘low ’or ‘no ’ empathy are diagnostic features, whose constituent persons are nevertheless fully capable of compassionate action in the absence of a typical presentation of empathy. Paradoxically, then, empathy is not strictly a requirement for compassion, although it is commonly at the root of its motivation to action. The nuance created by this allowance is well in keeping with propositions by Spikins (2009) and others that no single ‘modern human mind ’ever evolved, but rather a diverse range of neural attributes with as much plasticity and variation as the bodies they accompanied.

Interestingly, compassion often competes with empathic distress whilst still co-occurring with it. Compassion can be costly—the experience of empathic distress mitigates the degree to which the observer judges whether to intervene, and whether or not they are able, and to what extent. The ‘burnout’ experienced in ‘compassion fatigue ’ by care workers is one example of such cost in its most strained and chronic form. Conversely, there is the intriguing evidence suggesting that the experience of

compassionate action triggers the vagal nerve response, resulting in a dramatic decrease in stress states for the participants (Beauchaine, 2001). If the distress, and the investment of action, are costs bundled into the experience of compassion, then this vagal phenomenon may act to further reduce the margins of that cost, and resolve as mutual and collective benefit.

Goetz, Keltner, and Simon-Thomas (2010) also test this definition under the lens of evolutionary paradigms, describing the adaptationist perspective that emotions themselves are adaptations. In this view, compassion functions as a direct adaptation toward the wellbeing and care of vulnerable offspring and other conspecifics, emerging as the affective aspect of behavioral systems of caregiving. Caregiving behaviors are reported as sharing broad similarities across a wide variety of cultures, and include shared dimensions of touch and vocalizations unique to contexts of soothing and comforting. Similar behaviors are also observed in chimpanzees and bonobos, implying the possibility that these are common to primate ancestry. Under models of sexual selection, arguments for an evolutionary role for compassion point to the potential benefits of choosing partners who express compassion due to the applicability of these behaviors to the care of offspring; compassion under a sexual selection lens is thus of appeal because it implies a propensity toward investment in caregiving and cooperation. Cooperation as an axis of compassion is not restricted in evolutionary perspectives to kin, either. Applied to non-kin relations, it can be seen as an important element in the formation, navigation, and maintenance of larger-scale networks and mutual agreements, bolstering social

cohesion and mitigating conflicts over space and survival needs. In this view, compassion evolved as a strong promoter of cooperation, a mechanism for just such mutual and collective benefit.

THE SIMA DE LOS HUESOS INDIVIDUALS

In bioarchaeology, the subject of violence in human history and ancestry is a contentious and complicated one, and a frequent and unchallenged underscoring explanation (or, more accurately, dismissal) of disability—and its apparent, presumed obscurity—in the past. In the discursive camps that lean towards a singularly violent antiquity, a prominent example of the depth of time in which hominin nature is characteristically violent is the finding of Cranium 17, at the large burial complex of Sima de los Huesos in Atapuerca, Spain (Sala et al., 2015). Cranium 17 is the "very complete," completely preserved facial skeleton of an estimated young adult, based on the functional appearance and light degree of wear on the third upper molar. The significant findings on Cranium 17 are two large depression fractures to the frontal bone that appear to be perimortem in origin. The fractures lack the typical patterning for breakage of dry bone, and so it is not believed that taphonomic damage was causal thereof. These fractures are described as Traumas 1 and 2, both of which show no signs of bone remodeling, and the margins of which imply that both were delivered in a single or nearly-immediate series of events of localized blunt-force trauma. Trauma 1 is described as having sharp fracture outlines with well-defined borders and radial lines, featuring a notable 'notch 'in outline. Both the inner and outer tables of the cranium are involved, and the overall appearance is of a perforating strike. Trauma 2 shares these

features as well as a delamination exposing the diploë. Based on the force and direction of the impact, they also appear to have been delivered with the same implement. Accidental fracture from striking outcroppings or other features of the pit in which Cranium 17 was found was ruled significantly less likely than striking from an object, as the former scenarios favor presentations on the lateral surfaces of the cranial vault, not the frontal. Both are featured on the left side of the frontal bone, a recurrent feature of injuries derived from one on one conflict due to the predominance of right-handedness. These were likely fatal, given the close proximity in perimortem timing. Taken together, these presentations point to the conclusion that Cranium 17 is—at the time of publishing—the oldest evidence of interpersonal violence in a hominin.

However, a potential counterexample to the image of ancient, essential predilections to violence has been found at the very same site in contemporaneous proximity to Cranium 17: Cranium 14, a subadult individual with prominent, noticeable pathological alterations (Garcia et al 2009). Cranium 14 is an almost-complete neurocranium, missing the face, mastoid and petrous processes of the left temporal bone, ethmoid bone, right occipital condyle, and the central part of the sphenoid bone. It appears that this individual presents with a case of lambdoid single suture craniosynostosis. The most notable features are two completely open synchondrosis of the spheno-occipital and jugular epiphyses. The alterations are severe and involve both ectocranial and endocranial surfaces. Based on the size and dimensions of the cranium, and assuming that the hominins at Sima de los Huesos follow the same or a very similar pattern of brain growth and development, Cranium 14 appears to belong to an individual

of between 5 and 8 years of age, or only slightly older, dying shortly after acquiring adult brain mass. In human development, there is a great deal of variability in the timing of closure of the jugular synchondrosis, but in all cases this occurs well before the age of 18 years; Cranium 14's is fully open. The left lambdoid suture is nearly complete, while the right lambdoid suture features a small Wormian bone. Such lambdoid Wormian bones are a recurring peculiarity of the Sima individuals, but are never found fused. A noticeable ipsilateral occipitomastoid bulge is present, giving rise to an atypical inferior-ipsilateral tilt to the skull. The foramen magnum, external occipital crest, inion, and suprainiac area are all twisted at an 8 degree angle to the left, as referenced by the sagittal suture. The glenoid cavities, a common measure of the facial symmetry of the ears, are displaced. Frontal squama projects somewhat contralaterally on the right side. Several asymmetries are also found endocranially, particularly in temporal lobe areas, including a few large, well-developed subarachnoid fossa on the parietal bones. These features suggest that Cranium 14 presents a case of premature fusion of the lambdoid suture, a highly uncommon birth defect—unilateral lambdoid synostosis is exceedingly rare.

The 'misshapen 'features observed in Cranium 14 are a secondary response to lambdoid synostosis rather than a causal element, affecting the growth patterns of other sutures in a compensatory fashion that follows a predictable pattern. It is deduced that because of this known trajectory, the synostosis in Cranium 14 likely began prenatally, in about the third term of fetal development, and possibly as a consequence of some event of intrauterine trauma. The alterations produced by this condition worsen throughout postnatal growth and development. Nutritional deficiencies are ruled out as causes due to

the absence of skeletal signatures of key vitamin inadequacies. In living populations, craniosynostosis is often associated with elevated intracranial pressure and the presence of intellectual disability; if this was the case for the hominins of Sima de los Huesos as well, Cranium 14 survived into early or even middle childhood with increasingly intense pathological sequelae in anatomical and quite possibly cognitive and behavioral domains. Viewed through the principles of the Index of Care, it is not overreaching to entertain the possibility that this would result in pronounced functional limitation that required substantive caregiving in excess of typical pre-adult needs, yet Cranium 14 reached nearly as far as the first decade of life with this severe condition. Even if, as critiques like those of Dettwyler (1991) and DeGusta (2002) caution, it was not the case that this automatically implies intensive, directed, compassionate caregiving, it nevertheless appears that Cranium 14 was at minimum treated no differently than other individuals in the same phase of life.

Superficially, this might seem very at odds with the image of the hominin populations at Sima de los Huesos as the flagship signature of the antiquity of a deep proclivity for violence. Stripped down to essentialized categories—idyllically tender, and mercilessly destructive—this constituency might seem an incongruity, where surely one must be the outlier and the other normative and characteristic. An alternative exists, however: that the great depth of time and distance into ancestry of both destructive and inclusive behavior is a testament to the deep ancestry of potential and plasticity. For two strikingly different behavioral landscapes to coexist in the same time, place, and people need not be reducible to norms and outliers. If met on even ground, bioarchaeologies of

compassion and cooperation are not an affront to the exploration of ancient conflict; they have merely been left under-recognized and under-explored, and their inclusion similarly does not require that existing paradigms be deposed and replaced wholesale. Rather, they invite the prospect of increased nuance and complexity in the reconstruction of ancient—and even evolutionarily deep—behavior.

Since care is a costly investment, there is a strengthened emphasis on energetic expense in the face of resource availability and procurability when understood in eco-evolutionary terms. When external resource constraints act as final limiting factors in the lifeways of a community inclusive of individuals with significant impairment, a twinning of responses can occur. One avenue operates at a group level of construction--the shift, accommodation, adjustment, and so on of communal behavioral practices; another concerns the activity of the impaired body itself and what it constitutes as a resident and participant of a dynamic survival environment. This 'mismatch 'of environment, resources, and constituents in need of those resources is central to the idea of affordances (Gibson, 1979; Withagen and van Wermeskerken, 2010; Dokumaci, 2017). The impaired body is engaged constantly in the navigation of vital affordances as they co-occur with the variegated pressures and demands the impairment makes of limited resources. As such, the building and use of micro-niches in daily events not predictable by the demands of a comparatively unimpaired body has the inherent spark of innovation at its centre. Because they are products of an ongoing negotiation process of affordances and constraints unique to the experience the individual has of impairment and disability, each act of productivity, whatever its result, is a flexure of the necessarily enhanced plasticity

of behaviors and physically experienced phenomena in that impairment. This means also that seemingly ‘random ’and ‘meaningless ’productions by such individuals have value not anticipated under normative experiential conditions of body and environment.

The drawback of an evolutionary outlook on spontaneous material production is that explanations of the nature of the relationship between behavior and evolutionary success necessarily hinge on the ability to conclude that a given production must have had definitive adaptive value. This view is exceedingly exclusionary and cannot account for the vastness of motivations and contexts for material activity and behavioral innovation, particularly not in a highly plastic species as human beings. Cultures of technology have risen spontaneously and vanished nearly as rapidly, only to reappear again in geographically new areas by activities of new populations; in this, there is a resemblance to the emergent properties of individual languages. Also like language, material behavioral genesis functions on semantic principles in a variety of symbolic contexts. They are, for one, inherently an expense. Costly signaling theory has been applied to drive explanations of ostensibly artistic achievement. It has been posited artistic and performative abilities allowed certain individuals to carve out ‘social niches’ that buffered the accompanying material and care expenses; some have gone further, to attribute material creativity, fine and performing arts to a specialization within sexual selection strategies, raising the appeal of potential mates on the basis that these abilities were indicators of underlying ‘skill’ relevant to a number of fitness traits (Sugiyama and Sugiyama, 2003; Miller, 1997; 2000). Because it is an expense--of raw resources, time, and physical exertion--objects produced for no overtly pragmatic reason serve as

signifiers of the makers' capacity to perform such feats. That is--the costs in production of a given item are functionally fundamentally "honest" signals, under costly signaling theory, because otherwise the endeavor is wasteful under resource-challenged conditions. The evolution of spoken language has been characterized hypothetically as following this same trend, wherein the "cost" of producing linguistic signals is offset by the mutual understanding that the cost is paid in good faith. There is nothing inherent to the complexity or simplicity of linguistic items chosen that reliably makes them more or less honest; the suggestion in costly signaling theory is that the capacity itself is a two-way product of a mutual assumption of trust (Hurford, 2014). Otherwise, the effort and energy in linguistic systems over another form of communication is in essence an unnecessary expense without conferring any trade in benefits. Spontaneity and generativity are further features of linguistic systems, highlighting the propensity of initially random productive events to systematize in human social settings.

There is an adaptive property of spontaneous production events when placed in the context of the heightened demand for innovative responses to a disabling feature or condition, however. In this case the driving adaptive factor falls within the realm of affordances; occurring on the level of the individual, alongside or in tandem with adjustment, modification, or accommodation of the individual body. To further consider this with costly signaling in mind, a double purpose can be said to emerge: because production of an adaptive tool or somatic strategy is costly, and because to do so under deceptive pretenses entails negligible benefit in an environment of scarcity, the invention of such means can be considered an honest signal. How this signal is read by other

members of the community is negotiable and variable for reasons of culture and social convention, but may include those outlined in the vulnerable ape hypothesis. This hypothesis suggests that many of the features we regard as foundationally typic to our species are a result of how the diversification and interaction of human populations also reintroduces emergent deleterious traits, which are contextually redefined by each social climate that experiences this coexistent 'hereditary disability and genetic risk '(Winder and Winder 2015). It draws heavily from the social model of disability when it asserts that such common traits of modern humans as terrestrial, hairless bodies and altricial offspring with a very slow development curve are allowances of times when human populations would not have described these traits as disabling. As such, it requires the evolutionary synthesis that is expanded to include—and emphasize—agency on the organism's part in negotiating the constraints on their survival. Constraints loosened or reimagined by the organisms that are bound by them can, under the vulnerable ape hypothesis, cease to have the power to throttle the variability of modes of being.

ALMS AND AGONIES: PAIN AS A FLUID CONSTRAINT

The vastness and fluidity of experiences that could be called disability might seem paradoxical given the conflicting narratives and nuances presented thus far in disability studies by both abled and disabled authors. This is especially problematic if trying to come up with a concept of disability that is possible to find reflected in any way in material and human remains; it is difficult to hear the voices of the individual eons after they have fallen silent. The relative obscurity regarded of disabled individuals in the archaeological record up until very recently further clouded the issue of exploring this vastness, but it remains difficult to anchor disability to a single concept when even its living worlds have such staggering variety. In terms of bodies, however, and the impacts of functional limitations, one universal element unites abled and disabled alike—the omnipresence of pain as an embodied signal. It is not a contradiction to assert that pain, agency, and joy inhabit the same body, and pain will here be treated as value-neutral, with some distinctions made from the concept of suffering (Martin and Harrod, 2016).

The social and emotional experience of pain are crucial to the full phenomenon of pain and suffering; as such, pain experience is also subject to modulation by these inputs. Kersten et al. (2020) conducted a duo of studies examining the effect that the emotional state of nostalgic recollection might have on the subjective experience of pain. The first study was an online survey of chronic pain patients, in which one group was instructed to "specifically, try to think of a past event that makes you feel most nostalgic" (p. 2), after a baseline self-evaluation of their current pain severity. Control group participants were

instructed to instead "bring to mind an ordinary event in your life" (p. 2) after the initial pain rating. Both groups were afterwards asked to rate how nostalgic they were feeling, and subsequently rate their pain levels a second time. Significance testing demonstrated that the nostalgia condition group did differ in perceived nostalgic feelings significantly in contrast to controls, achieving the desired effect as a testing metric. No significant effect for nostalgia on pain levels at Time 1, the initial rating, and there were no differences in this between the groups. At Time 2, however, a significant time effect was revealed, as well as a significant time x condition interaction--in the nostalgic group, pain ratings at Time 2 were significantly lower than those of controls. This survey study could not measure any particular change to pain tolerance, but did grant insight into changes in perceived pain severity. Nostalgic recollection would appear to have some property of relieving perceived pain intensity through one or more mechanisms; the role of emotional states and attitudes on pain outcomes is a vast area of study and will be revisited throughout this section of the present writing.

Study 2 was an in-person laboratory test using participants who were not specifically chronic pain patients, but rather, a selection of undergraduate university students in Japan. While the audience of Study 1 was composed largely of Western participants, Study 2 doubles as a possible cross-cultural window to variations in pain experience and modulation by nostalgic states. The task given for nostalgia was the same as for Study 1, prompting participants in the nostalgia group to recall an event that made them feel it most intensely. As with Study 1, pain ratings were given at Time 1 (before task) and Time 2 (after task). This time, however, a laboratory tool for assessment of pain

tolerance was employed, for which participants were fully informed and followed up with. An algometer is an instrument that applies increasing pressure to the first dorsal interosseous muscle, on participants' non-dominant hand; the procedure would be immediately stopped when participants asked to stop. A greater pressure measurement at the time of stopping is inferred as a threshold of greater pain tolerance. It was found that, like Study 1, groups did not differ in their assessment at Time 1; but at Time 2, the nostalgic group showed a significantly higher tolerance than controls, with the according time x condition interaction effect also significant. Controls demonstrated no differences across times.

Whereas Study 1 demonstrated that a nostalgic emotional state could mitigate the subjective rating of the severity of pain experienced, Study 2 was able to apply this to testing of pain tolerance, a distinction from perceived severity. It also demonstrated that the effects of a nostalgic state had outcomes in two different cultural contexts. Pain is a global, universal phenomenon, but can be shaped and contextualized by social and cultural norms, producing a wide variability in relationships between patients and their pain. It is possible that the underlying effect of the nostalgia task is to introduce a sort of priming or motivation, or alteration in expectations, recruiting the sense of looking to the past as a means of facilitating the future. While it is uncertain how broadly-applicable a nostalgic recollection task could be as part of a pain management regimen, it is of interest that nostalgia specifically evokes this past-to-present connection--continuity and persistence. It is in a sense a form of resilience distilled to a single emotional state; in contexts of shared or communal memory, the effects perhaps exceed the individual.

Shared beliefs and expectations play powerful roles in both the personal and the relational navigation of pain and illness, and these states are further defined and placed in context by the social norms that surround these attitudes and systems of belief, a point that will be returned to continually throughout subsequent discussion.

As there is such tremendous variation in both the experience of pain and the beliefs and approaches for pain across cultures, few patterns are routinely repeated in cross-cultural pain research. To attempt to reach a broad overview of trends in the research literature for cross-cultural pain studies, Pillay, van Zyl, and Blackbeard (2013) conducted a meta-analysis of chronic pain studies in a project helmed by Grey's Pain Research Collaboration, based out of a pain clinic in South Africa. Pain experiences and perception differ across individuals as well, modulated by interactions between biological processes and the social theaters in which they play out, shaped further by variations in coping and management strategies. It has been observed previously that 'physical' pain, emotions, and social attachment all share a common neural infrastructure, and can thus be viewed as a whole, integrated complex, as is modeled in Melzack's 'neuromatrix' theory, among other constructs (Melzack 2001). The meta-analysis was limited to databases that were available via/at the University of KwaZulu-Natal, and so the authors note the possibility of missing literature; the study excluded publications that concerned pediatric pain studies.

No broadly-generalizable results were definitely retrieved, but a few key trends did occur throughout the literature surveyed. One, that there is substantial cultural variation in pain *expressiveness*, or the socially acceptable presentation of symptoms

regarded as indicative of painful experience--a rough range from more 'stoic' to more 'expressive' was noted, and appeared to go hand-in-hand with associated mores and beliefs about pain. Some 'stoic' attitudes were, for instance, linked to beliefs about blame or guilt for the underpinnings of pain. These 'stoic' differences in expression also result in differences in care and care-seeking, leading to instances of underreporting and avoiding treatment. There appears to also be a relatively recurrent gendered effect in pain experience--women were found to report their pain more overall, but women's attitudes toward their pain differed wildly across cultures, especially in terms of the ways that pain is contextualized to the roles of these women in their respective societies. A study of Quichua women, for instance, showed that they attributed the chronic pain associated with older age to the level of social responsibility they held in the family and society (Incayawar and Saucier, 2010).

Another theme that reappeared most frequently was that of the concept of 'the good patient'--beliefs that patients held about themselves regarding care-seeking and care encounters, and values they associated with these experiences. Norms of compliance, cooperation, and respectful deference to the authority of clinicians appear in conjunction with variations in beliefs about how to be a 'good patient'. There seemed to be some correlation between the characteristics of these beliefs with marginalization and lower socioeconomic status; patients from groups that have historically been marginalized tended to lean toward lower expressiveness of their pain, paired to reluctance and wariness of the institution of, particularly, Western clinical medicine. Relatedly, a recurring trend in the review was that of the role of traditional and folk medicine, where

many people sought primary care from traditional healers before consulting Western clinical care, especially in cases of chronic pain. Taboos surrounding pain also appeared to be a common trend, such as notions about pain as 'weakness', shameful, and something to disclose only to peers if at all as this would otherwise be seen as inappropriate. Lastly, a persistent pattern in coping strategies varied across cultures, roughly broken up into either 'active' or 'passive' mechanisms of coping. Passive coping ensconces behaviors like prayer or seeking distractions, or maintaining an ongoing sense of hope, and it is remarked that passive coping in general appears associated with an overall lower degree of pain adjustment. A potential explanation for this is beliefs about the 'locus of control' in the relationship between individuals and their pain, a topic that will be elaborated upon shortly.

First published in 1979 and later given periodic revisions, in a publication by the International Association for the Study of Pain (IASP), pain is defined thusly:

"... an unpleasant sensory and emotional experience associated with actual or potential tissue damage, or described in terms of such damage. Note: pain is always subjective. ... Activity induced in the nociceptor and nociceptive pathways by a noxious stimulus is not pain, which is almost always a psychological state..." (1979)

This is a helpful reminder to tread with caution when extrapolating complex personal experiences from limited, physical, biological signatures, and calls to mind the distinction given in Martin and Harrod (2016) between pain and 'suffering'; the IASP definition leans toward a characterization of pain that is not reducible to simple biochemical processes, and thus fits with the more complex grounds for 'suffering'. It also

has the potential to be deeply problematic from the standpoint of disability and neurodivergence, where disconnects and alternative networks of thinking, sensing, and communicating introduce nuances of their own.

It is nevertheless fair and astute to point out that pain as a phenomenon of experience is multifactorial and does closely intertwine with psychological and social contexts, including systems of belief, expectations learned from personal experience, and norms of behavior surrounding responses to pain. *Meaning* is something sought or created for pain experiences as well, influencing the prognosis and character of an individual's relationship with their pain. The journals of Henry Beecher, a physician treating wounded soldiers and personnel at the Battle of Anzio in World War II, are cited, and these discuss the surprising observations of how differently combat and non-combat patients regarded their treatment. The soldiers tended to be less expressive and reactive about their pain and injuries, and used less pain medication than the non-combat patients. Beecher surmised that this was because of what the soldiers' injuries *meant* to them--to be wounded was to be removed from battle, increasing the odds of their survival, and in this way the pain of their injuries served as a reminder and a symbol of hope. This shifted the context for their experiences of the pain and granted it a meaning that in turn altered the approaches these patients took to care (Beecher, 1956).

Some beliefs and expectations about pain are acquired socially, while others are more personal, subjective, and an interactive product of several mind-body relationships. Neuromatrix Theory is one such perspective, revolving around a "body-self" and the interactions of psychosocial factors and brain physiology. The 'matrix' is one of sensory,

affective, and cognitive functions in perception that results in behavioral and homeostatic changes, and as a model is roughly split across domains of input and output plotted over the passage of time. Inputs include cognitive-evaluative, sensory-discriminative, and motivational-affective stimuli, paired to a series of of outputs--pain perception, stress-regulation programs/responses, and 'action programs' spanning involuntary and voluntary responses, social communication, and coping strategies. This dynamic body-self construct is potentially useful as a means of developing more comprehensive rhetoric surrounding pain as a scientific subject and a holistic experience. Body-selves may vary with culture, so as with any model or diagrammatic construct, it must remain malleable to these variations.

Linguistic and semantic frameworks surrounding pain similarly vary substantially within and across cultures. A few recurring descriptive categories are discussed here, roughly sorted into features of location, timing, intensity, quality, curability, and cause of pain. Westerners tended to distinguish physical from emotional pain compared to other cultures and language groups, in particular a "real" versus "imagined" dichotomy. Chinese speakers used a concept not found in other languages and groups, 'suan' and 'suantong', roughly meaning "sour-ish"; descriptively, it is most similar to dimensions of quality and cause in the Western categorical senses. Conversely, Anglo-American speakers of English invoked the specific concept of 'excruciating', a pain so severe it harkens back to the idea of death by crucifixion. ‘Jagende', 'shooting, intense' pain, and 'murrende', 'nagging' aching pain, are Danish terms that are similarly anchored in particular social connotations. The terms and self-reported descriptions of individuals'

pain experiences are themselves cultural items, and in turn, so becomes pain. Moore suggests the use of 'expectations' as a dimension of patient experience is more particularly akin to "packages of motivation" (Moore, 2012). These "packages" have been part of traditional healing for large parts of human history in various societies, involving rituals and ceremonies in which both the healer and patient, and sometimes also the wider community, participate in the healing actions. Two polar ends of this type of motivational, intentional, two-way care relationship are the phenomena associated with 'faith healing' for positive outcomes and 'death wish' rituals for outcomes that involve a negative step. This combination of interactive care encounters and the intentionality of the actions therein works like a sort of social placebo, where the beliefs and expectations of both parties influence the outcomes of the actions they take, an effect that has also been termed ethnomedicogenesis (Hahn, 1983).

Another chapter in the same volume continues this idea of cultural variations of pain concepts, the systems of belief and behavior that influence pain experiences, and the ways that these factors govern the care that patients seek and can access. Kalra, Gupta, and Bhugra (2012) frame the basic concept of pain from the physician's perspective as " ...the physical symptom of underlying pathology of physiological processes that causes the most human suffering in medicine" (p. 389). This grounds pain in an embodied basis, but as one part of a broader network of experiences of suffering; that pain sensation is anatomical and physiological, but only the sociocultural factors surrounding it shape how it will be expressed and treated. There is more nuance to the expression of pain, connected to attitudes that carry deeper meaning and specificity than simply grouping

expressiveness into 'stoic' or 'expressive' categorically. The example is given that patients from 'enduring' cultures--those highly resilient under histories of duress--sometimes value a less animated form of pain and expression and show more restraint against seeking help because it represents a sense of 'self-efficacy'; in other words, where some low-expression attitudes draw on a sense of shame or blame, others are rooted in a sense that to restrain in this way is to have and feel a greater sense of agency in the pain experience. The complexity and layering of social contexts for the expression of pain is demonstrated as well in the discussion given here surrounding funeral conduct among the royalty of Rajasthan, India. Royals are discouraged from expressing their own grief openly, but loud, vivid displays of emotion for the royal dead are greatly respected. The more mourners in attendance, and the louder that they weep, the greater the reverence and the more elevated the social status of the deceased and their relatives. It is felt that were royals to express this pain openly, it would signify weakness; instead, the expression is channeled into new social niches, such as the Ruudali, professional mourners who are hired for royal funerals. and their job is the grieve as loudly and dramatically as possible.

A perennial source of difficulty in cross-cultural pain research is the methodology used to conduct it. Variations in methods for the assessment of pain and pain expression beleaguers the replicability and reliability of the studies using them and efforts to standardize or make consistent representative tools for a universal phenomenon contingent on cultural influence. Some specific patterns lie with language barriers and linguistic nuance; as seen previously, terms and concepts of pain in different languages carry a variety of social and sensory connotations particular to those languages and social

contexts, and similarly, it is also difficult to produce a testing metric with verbiage that functions to hold roughly the same implied meanings across languages. Translating survey and rating-scale inventories is heavily complicated by these distinctions, contributing to the blurry and frequently inconsistent findings in trends in cross-cultural pain research. Perhaps this is because of the problem that lies at the heart of the question of human universals--trying to standardize a ubiquitous but greatly malleable component of human experience betrays the ways that very experience is shaped.

The sense of 'locus of control' is nevertheless a frequently recurring dimension of pain experiences and social attitudes, usually split down an axis from 'external' to 'internal' loci. An internal locus of control places the origins and/or brunt of the responsibility for the causes and subsequent actions of an individual's pain, and how this pain is seen by others in the community. This may for instance garner less sympathy from other people, as the belief attributes fault and duty to the individual experiencing that pain. On the other hand, this can also be anchored in or even galvanize a sense of self-efficacy and agency--if the pain is in the hands of the painful it is theirs to decide what to do with it. The external locus of control takes the causal responsibility out of the hands of the pain patient, which can on one hand unburden them of the blame and invite more sympathetic behavior from others in the community--since the person would have reached the limit on what they could possibly be tasked with doing for themselves--but can and sometimes does have a fatalistic bent, as is sometimes expressed in passive coping. Beliefs about curses, for instance, can make pain attributable to the patients' victimization by sorcery or supernatural/divine/occult forces. The relationship between

the painful body and its pain is this a diverse one not reducible to fixed rules or trends or belief systems--it is as fluid and ever-changing as any other part of illness, injury, or impairment. The painful body is forever in transition.

CROSSTALK AND INTERDEPENDENCE OF BONE AND OTHER SYSTEMS

While there is an understanding that the experiences of pain, illness, and functional limitation are myriad, highly subjective, and mutable by social and cultural processes, it will nevertheless be useful to retain a conceptualization of pain that is grounded in the embodied territory of nociception, in order to facilitate a conversation *about* the embodiment of these subjective experiences. Thus from here, 'pain' as a term in neurological and clinical contexts will be used to imply this cellular and molecular sense, tentatively separated from 'pain' as a term of experience. Pain is not so narrowly defined in clinical literature, importantly--revised definitions emphasize that pain is a multidimensional experience, and nociception alone does not a pain concept make. With these caveats in mind, the following sections will discuss pain as reduced to the functions of nociceptive and inflammatory neural substrates, which will then be integrated into the bigger picture of pain as multifactorial experience. The purpose for this is to posit that swathes of functions and interactions between individual proteins, their tissues of affinity, and the broader impact of this crosstalk act as the biomatter infrastructure of the processes by which pain-as-experience become literally embodied.

One area in which this has been posited for discussion is the phenomena encompassed in Maruyama's construct of 'senso-immunology' (2021). Senso-immunology is coined as the term for the interdisciplinary focus on simultaneity and crosstalk between systems of nociception and immune response, as well as these mechanics in and across metabolic, bone, gut, and other tissue systems. Bone marrow is

richly innervated with peripheral sensory neurons, and consequently, is a participant of signaling pathways along several types of pain-sensing fibers. It was previously understood that this innervation made bone tissue an important recipient of neural and immunological input, and more recently the observation that it engages in networks of local feedback and paracrine action; now, it is becoming clearer that the roads travel both ways, and bone is being increasingly recognized as a governing agent in other body processes, including and up to cognition.

Previous sections have discussed at length the necessitated innovation and adaptation, creation of new niches, and processes of embodiment found in the development and experience of impairment and functional limitation. This section will elaborate on the viscerality and physicality of these embodiments, by turning to the systems of crosstalk between bone and other tissues as the active players of how these embodiments and transformativities occur--and where subsequently, consequentially, their tracks may remain in skeletal tissue, long after their softer kin have faded in the postmortem environment. Bone is a living agent in these interconnected systems, but of them, is the only one to remain in the *longue durée*. Here, its interplay will be described in more detail, especially in terms of immune, neural, and essential metabolic connections, most particularly in the contexts of pain, illness, injury, healing, and nutritional or metabolic stress.

Pain in the sensory, nociceptive sense is a complex interplay of inflammatory processes, ion channel interactions, shared receptors and transmitters, and contrasting regulatory mechanisms. Pain, even in this narrow sense, is still a somewhat abstract term

for an experience that is not just one discrete process or system. In the very narrowest sense, pain *as a sensory phenomenon* is sensed by certain types of ion channels, which are present not just on nociceptive nerves, but also in and on other tissue systems, such as cell membranes of immune system cells and in metabolic regulating cells, including of bone metabolism. Ion-channel medicated nociception also shares key cytokines with these systems, weaving nociception inexorably into the heart of interactions between components of these systems. For instance, nociceptive nerves and pain-sensory neurons swiftly and directly engage invading pathogens, often before they are detected by immune cells. The three major types of sensory nerve fibers are Aβ, Aδ, and C fibers. Aδ an C fibers sense pain--Aδ are myelinated small-fibers specialized for detection of sharp, rapid pain, and C fibers are unmyelinated small-fibers that conduct 'slower' pain sensations such as aching (Maruyama, 2021). Bone tissue is richly innervated by these fibers, which themselves contain varying levels and preferred distributions of key peptides, such as calcitonin gene-related peptide (CGRP) (Masi 2012).

CGRP fibers are especially abundant in the periosteum, marrow, and in the trabecular bone of epiphyses. CGRP is a potent vasodilator also found widely distributed in vasculature, but also acts on pancreatic β cells as a powerful antagonist and inhibitor of insulin release. In immune systems, CGRP is a regulator of macrophage and neutrophil function; curiously, this is sometimes in an anti-inflammatory manner, as it acts to suppress degranulation of mast cells, and in some contexts even behaves immunosuppressively. While CGRP upregulates phagocytosis against invading yeasts, suggesting an anti-fungal propensity, it appears to complicate responses to other,

bacterial infections (Maruyama et al, 2017). There is some suggestion that *Staph aureus* may activate CGRP pain-sensing neurons to exploit its anti-inflammatory functions as a means of delaying its recognition by immune cells, essentially manipulating and thwarting the first line of defense at the molecular level (Chiu et al., 2013). In bone tissue specifically, CGRP is observed to inhibit fusion and multinucleation of osteoclasts--pain-neuron derived CGRP in bone acts directly on hematopoietic stem cells in marrow, and so has a similar dual role as in immune contexts.

The other crucial neuropeptide most secreted by sensory neurons is substance P, also a potent vasodilator and also found in abundance in vascular cells. Substance P acts on macrophages and neutrophils to stimulate their production of cytokines, and acts on mast cells to trigger mast cell degranulation. Substance P is a known stimulator of mineralization through its upregulation of RUNX2 pathways, crucial for the activity of osteocalcin (Wang et al., 2009). Eosinophils, the subtype of leukocyte implicated in asthma, allergy, and certain autoimmune conditions, are also selectively responsive to substance P. In *Leishmania major* infections, substance P acts on macrophages to instead *suppress* phagocytic activity, depriving the pathogen of one of its primary strategies of self-propagation (Ahmed, Wahbi, and Nordlin, 2001). Both CGRP and substance P are heavily involved in peripheral neurological activity, not exclusively at the behest of CNS activity. Much of their direct action on various tissues is peripheral, to such an extent that experimental models in rat studies of arthritis showed significantly slowed onset and progression of the disorder when peripheral pain-sensing nerves were ablated.

Ion-channel mediated nociception is also a crucial component of *mechanoreception*, in particular the activities of Piezo channels, 1 and 2. Piezo1 channels are mechanosensitive components of membrane 'stretch' sensing. Piezo1 channels in osteoblasts control the expression of various collagens; Piezo1 channels of the gut, however, suppress new bone formation by their action of upregulating serotonin levels. Serotonin is synthesized primarily in the gut, only produced in the brain within the brainstem and incapable of crossing the blood-brain barrier. However, it acts peripherally on other systems, including bone, upon absorption into circulation by platelets to be distributed and released across systems. In inflammatory contexts, this has the effect of triggering the convulsive contractions of gut peristalsis, and experimental models of colitis found greater resistance against colitis in Piezo1 knockouts, which had overall lower serum concentrations of serotonin. Piezo2, by contrast, is a stretch sensor for gentle stimuli, though is itself also a determinant of serotonin release through activation of calcium ion influx in enterochromaffin cells upon detection of mechanical force (Sugisawa et al., 2020; Ghia et al., 2009).

Transient receptor potential vanilloid 1 (TRPV1), better known as the capsaicin receptor, acts on ion channels to increase the excitability of nociceptive neurons. Its primary function in pain sensing is the detection of heat. Transient receptor potential ankyrin 1 (TRPA1) similarly detects molecules such as allicin, the irritant compound in garlic, and cinnemaldehyde, another common irritant, but is also directly involved in neuronal recognition of Gram-negative bacterial lipopolysaccharide (LPS), which activates CGRP production and triggers calcium ion influx. It therefore participates in

this first-line of neuroimmune interplay in response to pathogens. TRPV1 by contrast appears to be a 'double-edged sword'--in some instances expressing anti-inflammatory properties, while in others, its absence in murine knockout models is associated with increased longevity and particularly improved glucose reaction in metabolic health. These mice showed increased sensitivity to insulin; mice prone to the development of diabetes showed a substantial decline in disease progression with ablations to TRPV1 neurons. In addition, CGRP derived from TRPV1 neurons has been shown to greatly inhibit the release of insulin from β cells of the pancreas; thus, while the exact nociceptive systems of the pancreas are still somewhat mysterious, CGRP by way of TRVP1 receptors on pain-sensing neurons exerts significant regulatory effects on pancreatic metabolism, linking it to other homeostatic systems governed by pain signaling (Razavi et al., 2006; Riera et al., 2014). β cells are also highly responsive to substance P, suggesting further involvement of nociceptive regulation in glucose metabolism and pancreatic homeostasis.

Other ion channel-related pain phenomena involve the behavior and activity of autoantibodies, particularly those that target voltage-gated potassium channel complexes (VGKCCs). These antibodies do not target the ion channels directly, but rather attack the proteins that form complexes with these channels, altering their functionality and exerting effects on the synaptic plasticity of the pain neuron. By attacking a complex formed with the Kv1.1 channel at presynaptic terminals via leucine-rich glioma-inactivated protein 1 (LGI1), the neuron can become sensitized to pain signaling and overexcitation, as the typical function of this channel complex is an inhibitory one. It has been suggested that

this may be a core mechanism in complex regional pain syndrome, a poorly understood disruption in motor, vasomotor, and pain functions commonly associated with the aftermath of traumatic limb injury. Serum samples from CRPS patients show different receptor antibodies for short-term versus long-term affliction (Kohr et al., 2011; Dubuis et al., 2014).

The suggestion that these antibody mechanisms alter the plasticity of pain signaling neuronal complexes, even when no obvious damage occurs to their tissues and structures, has intriguing implications for the prognosis of pain experiences over the longer term; indeed, it has been observed that the density of intra-epidermal nerve fibers and alterations to their function has close associations with the reported severity of pain in patients with Guillain-Barré syndrome and hold a degree of predictive power in the extent to which it is disabling. Guillain-Barré syndrome is frequently post-infectious, manifesting after diseases like bacterial gastroenteritis, and most commonly features the structural degradation of nerve demyelination, introducing neuropathic pain to the case. Pain is a 'cardinal symptom' of GBS, frequently emphasizing pain in the extremities, upper leg, and back. Antibodies specific to gangliosides, the glycolipids appearing in large numbers of the surfaces of peripheral nerves, have been implicated in the pathogenesis of GBS, and it is possibly due to a 'molecular mimicry' phenomenon (p. 391). Some structural components of gangliosides are shared with the lipopolysaccharide coatings of *Camphylobacter jejuni*, for instance, and it is suggested that post-infectious hyperactivity in immune function may lead to attacks on non-pathogenic tissues because of this mistaken identity. GBS thus represents a 'senso-immune' maladaptation in the

wake of bodily responses to the very real threat of infection, one which lingers after the threat is dealt with, a long-term consequence (McMahon, La Russa, and Bennett, 2015). Under conditions of neuropathic pain, spinal cord glial cells such as the CNS macrophages, microglia, shift phenotypes, from surveillance to a pro-inflammatory form with thicker cell processes and larger size, further highlighting the tight intertwining of neural and immune systems (Salter and Beggs, 2014).

But what of neuroimmune and bone crosstalk? Neurons do not skeletonize, and thus unavailable for review to bioarchaeologists. Their connections to, and via, bone tissue, however, do, albeit subject to the same destructive taphonomic processes. It has been understood previously that brain and CNS directionally influence bone; now it is becoming apparent that this relationship is not at all one-sided. Two key molecules come to the fore: fibroblast growth factor 23 (FGF23) and osteocalcin. Both are secreted by bone tissue, osteocalcin from osteoblasts and FGF23 from both osteoblasts and osteocytes. FGF23 is then released to the circulatory system as a regulator of phosphocalcic metabolism in several tissue types. Specifically, it is implicated in the inhibition of phosphate reabsorption in the gut and kidneys, decreasing serum phosphate levels and downregulating the production of $1,25(OH)_2$ vitamin D3 (Rousseaud et al., 2016). For bioarchaeologists, however, it is osteocalcin that provides a focus. Synthesized by osteoblasts, a small amount is released to the bloodstream while the majority is stored in an inactive, carboxylated form in the mineral extracellular matrix of bone. It is the second most abundant extracellular matrix protein after collagen and becomes activated when osteoclastic activity decreases the pH of the environment,

decarboxylating the trapped osteocalcin (Calvo et al., 1996). Osteocalcin is involved in developmental processes and plays an important role in sympathetic nervous system stress responses. Despite being expressed nowhere in brain tissue, osteocalcin readily crosses the blood-brain barrier and can bind directly to brain areas, including the brainstem, ventral tegmental area, substantia nigra, and the hippocampus. Osteocalcin crosses the maternal placenta, establishing a further developmental linkage. Hippocampal anatomy appears to be partly developmentally dependent on osteocalcin in the prenatal environment, as in its absence, anatomical defects occur that lead to impaired cognition and memory function (Oury et al., 2013). Other effects of osteocalcin are conspicuous in their absence, as seen in mouse knockouts, which include an overall "passive", GABA-ergic tone to brain activity, expressing lower levels of norepinephrine, dopamine, and serotonin in addition to observable behavioral problems. An association between osteocalcin serum levels and psychiatric illnesses has been reported as well, with depression characteristically featuring abnormally low serum osteocalcin, while the reverse is seen in some patients with schizophrenia (Rousseaud at al., 2016). Osteocalcin concentrations also appear to fluctuate across the lifespan, highest at the postnatal and adolescent growth spurts, stable across most of the adult lifespan, and finally gradually decreasing to lowest concentrations in old age. Osteocalcin concentrations change through the course of pregnancy as well, dropping by as much as 50% in the first and second trimesters, and rising during menstruation (Cole et al., 1987; Martinez et al., 1985). Strongly associated with new bone formation and mineralization, it is of interest as a proteomic target for bioarchaeology of growth and development, as well as the

impact of biological stress systems. Its close association and involvement in other tissue systems is additionally intriguing, as these systems do not persist in the post-mortem period, while osteocalcin typically degrades at a relatively stable rate and is buffered against some of the mortuary environment by its sturdy mineral matrix surroundings. Serum and matrix concentrations are considered to be roughly equivalent despite the greater volume/quantity that is stored versus circulating, and thus may provide an estimate when only the osteocalcin encased in dry bone material is available (Vanderschueren et al., 1990).

A few other key neuropeptides may be of interest, particularly via their involvement in growth and developmental processes, as well as their influence on stress response mechanisms and the crosstalk between tissue systems that stress instigates. One of these is serotonin, synthesized in the brainstem and in the gut. Serotonin itself does not cross the blood-brain barrier, but circulates systemically via absorption from the gut into platelets which subsequently release it in response to particular stimuli. Curiously, its effects on bone tissue appear to be suppressive, downregulating new bone growth. Lower bone mass has also been an observed side effect of long-term SSRI treatment; however, because it has been observed that long-term depression also aggravates bone loss through linkage by norepinephrine to functions of sympathetic nervous stress responses, systemic interactivity appears once again crucial to the results of a given molecule's role (Yirmiya et al,, 2006; Rousseaud et al, 2016). Leptin appears to participate in serotonin-related metabolic activity, albeit not directly acting on bone (Takeda et al., 2002). Instead, leptin is active primarily in the brain and serves as a central source of regulation rather than

peripheral. Murine model receptor knockouts for brainstem leptin receptors develop the ob/ob phenotype that mirrors patterns of obesity in human bodies, as well as greatly elevated serotonin levels; administration of exogenous leptin to these reduces serotonin levels in addition to addressing the immediately leptin related expression of the phenotype. Leptin administered to wildtype mice also reduced serotonin levels (Ducy et al., 2000). A satiety-growth expenditure system may therefore be at work via downstream effects of the interactions between these molecules, particularly in the influence leptin exerts on serotonin. Reductions to bone density have further potential consequences: there is a significant correlation between low bone density and age-related cognitive decline, and in particular a high comorbidity between Alzheimer's disease and osteoporosis. Even in the early stages of Alzheimer's disease, there is a jump in the risk of fractures (Cornelius et al., 2014). Outcomes for brain dysfunction and disorders appear to be closely linked to the crosstalk between bone and neural tissues and peptides.

The hypothalamus--part of the HPA axis--is one of the more direct of these regulators. In addition to acting as a hub for leptin activity, the hypothalamus hosts the central components of the neuropeptide Y system. Neuropeptide Y (NPY) is an inhibitor of new bone formation, expressed centrally and circulates during starvation response. Y1 receptors are expressed in osteoblasts of cancellous and endocortical bone. NPY levels rise as caloric intake drops, initiating the suppression of new bone growth, an energy-conserving response that, similarly to leptin, originates with hypothalamic activity and goes on to influence bone metabolism downstream, with NPY receptors distinctly present on osteoblasts locally (Masi 2012). Other components of the HPA axis exert effects on

bone, some more directly than others; pituitary components are for instance able to act on bone tissue directly without passing through other regulatory mechanisms first. Thyroid stimulating hormone acts directly on osteoblasts, downregulating osteoblast transcription factors for differentiation and proliferation, acting as another route to bone growth inhibition (Abe et al., 2003). Other neuropeptides participate in the regulation of bone homeostasis through their own mechanisms. Oxytocin has a stimulating effect on both osteoblast differentiation and osteoclast formation, the former via increasing the expression of BMP-2 and the the latter by activating NF-κB and MAP kinase signaling. NF-κB also induces myeloid (macrophages, neutrophils) to conduct CGRP's anti-inflammatory effect, providing a counterbalance against the formation and proliferation of osteoclasts that NF-κB causes (Tamma et al., 2009). Osteoblasts are able to release sufficient amounts of glutamate, a primary excitatory transmitter, to activate glutamatergic receptors on bone cell surfaces; this release is regulated by the cytokines TNF-α and IFN-γ, which are also responsible for inducing apoptosis of osteoblasts. TNF is also a direct activator of nociceptors and contributes to their sensitization (Austin and Moalem-Taylor, 2010). Glutamatergic NMDA receptors are expressed on osteoblasts, osteoclasts, and osteocytes. The primary adrenergic receptor on osteoblasts is β2AR, a beta-adrenergic receptor responsive to norepinephrine that triggers an increase in intracellular cAMP levels. Intriguingly, autoantibodies against β2ARs have been found in serum samples from patients with short-term CRPS, a condition that can involve rapid demineralization of bone tissue and the onset and development of a range of psychiatric disorders (Kohr et al., 2011; Dubuis et al., 2014).

Bone can thus be seen as a non-static, highly plastic sensory and immune system unto itself, but rarely if ever in isolation from these other systems, and in several instances the connection is bidirectional, with bone directly in charge of activities in neural, immune, and metabolic function. Nowhere is this more apparent than in the network of stress responses, growth, and healing coordinated by the crosstalk between these systems. Having established this, how does it concern bioarchaeologists and the limited data extractable from the dry remains that are left long after death? Even the known connectivity of these systems does little on its own for material that no longer contains the soft tissue components comprising them--how, then, does any deeper inference become possible? One suggestion is this: go ever deeper with the finite material that remains. Though still incomplete and still beholden to the ravages of mortuary environments, relevant biological information may persist on the molecular level. Ancient DNA and stable isotope analysis have existed for some time and found some utility, but another route is beginning to advance: proteomics (and palaeoproteomics). The use of protein extraction and quantification protocols paired with the focus and precision of mass spectrometry are promising avenues for looking another level deeper at the tiny samples of data from the past that can be examined. The advantage of using individual peptides as a focus of study is that particular peptides are tissue-specific, specialized for the roles they exclusively play, and thus a more detailed, intimate correlative point of inference (Brown and Brown, 2013). In very recent years, proteomic techniques have become increasingly creative, with unprecedented results.

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DIGGING DEEPER: METHODS AND FUTURES

One such creative approach is the use of standard, mass-produced dermatology testing strips (Multari et al., 2022). These adhesive tape strips are placed on the surface of the skin in dermatological practice, typically for diagnostics of such conditions as psoriasis and atopic dermatitis. To apply these to bioarchaeological analysis was to observe how many/most sampling techniques are destructive and invasive to the remains being sampled--a persistent problem felt especially harshly in a discipline already grappling with incomplete and fragile data. This study looked at using the tape strips as a potential alternative means of collecting protein samples that might be sufficient for detecting and identification by mass spectrometry. To serve as an initial test and a control reference, strips were first placed on the skin of the forearm of a living volunteer; the focus of the study was the raided and looted coffin of a mummy from 26th Dynasty Egypt. Associated material identified this individual as named Mer-Neith-it-es, most likely originally interred at Saqqara before looting and transportation to a buyer in Australia, where the remains stayed through the present day. Looters had badly damaged the remains leaving them displaced and heavily fragmented. It was this exceptional degree of existing damage that inspired the pursuit of as close to non-invasive methods as possible--thus, if it could be established that tape strip sampling was capable of collecting enough material to be examined, not only would this entail least degree of further damage, but potentially be a richer or more complete proteome than those left after more destructive methods. The study's hypothesis draws from the observation/fact/notion that

as soft tissues decay, proteins will precipitate out of solution and eventually become bound to the surfaces of bone tissue, potentially preserving information about tissue systems that do not persist in the post-mortem environment. Together with the sensitive nature of disturbed, further damaged remains, and the additional battering of more standard sampling and extraction techniques, the skin strip approach was quite promising.

Strips were applied directly to unwashed bone surfaces on the endocranial and ectocranial sides of the cranium fragment samples, to the lingual and buccolabial surfaces of the mandible sample, and in several places along a long bone fragment estimated to the humeral diaphysis. 10 seconds with only gentle pressure were used to affix the strips, and after sampling, the strips were transferred to individual microcentrifuge tubes. To create a "blank" to this effect, strips were taken directly from the packaging and immediately placed in microcentrifuge tubes of their own. Protein pellets were retrieved and subsequently subjected to a separation protocol using SDS-PAGE gel and Coomassie blue staining; gel lanes were then cut into 8 equal pieces and sent through trypsin digestion, to prepare samples for examination by nanoflow liquid chromatography paired to high-resolution tandem mass spectrometry (nanoLC-MS/MS). Samples were examined at a m/z range of 350-1600 amu with a resolution of 35,000 and an isolation window of 3.0 m/z. The ions found to be of greatest abundance were then put through higher-energy collisional dissociation (HCD) fragmentation. Proteins were then identified with the use of Global Proteome Machine (GPM) software, plugging the raw mzXML files through the X!Tandem algorithm in order to match the recorded spectra to known peptides. In addition, a reference search was conducted using SwissProt Human Protein database,

and, to catch and rule out common laboratory contaminants, also searched against the Common Repository of Adventitious Proteins (cRAP) database. For the cranial samples specifically, merged, individual datasets were created for endo- and ectocranial.

Overall, 9 total strips were applied to the humeral fragment, which were then split into groups of 1, 3, or 5 strips to avoid the complications that would arise from trying to fit 9 strips in a single microcentrifuge tube. The results for the humeral samples were surprising--in addition to proteins of muscle and bone, several proteins specific to brain and neural tissue were identified. The study surmised that this could have been attributable to how disturbed the remains were, and therefore only be transfers from other tissue surfaces, with the other and less probable explanation that these were remnants of CNS tissues as distributed through the whole body.

The cranial fragments were differently revelatory, however. There was wide variability between which proteins were found on the endocranial versus ectocranial profiles, most disparately in the presence of keratins and skin-related proteins on the ectocranial as contracted with the numerous neural proteins found on the endocranial samples. These might represent the traces of skin and hair on the former, and brain and CNS tissue on the latter. Mandibular samples were more plentiful on the interior surface, comprising skin and muscle proteins as well as several neural proteins, including neurofilament polypeptides, alpha-internexin, and myeloid proteolipid protein. A suggested inference for these was that these may represent the remnants of the mandibular nerve, the largest of the trigeminal nerves. Contamination was rules out as a factor in these protein profiles, demonstrating an unprecedented wealth of biological

information with a minimally-invasive and nondestructive sampling technique--though the caution was given that the adhesive properties of the strips may still be too harsh for more fragile tissues such as hair (Multari et al., 2022).

Typically, protein extraction from skeletal material involves a demineralization step, which retrieves usable quantities of matter but at the expense of the structural integrity of some of its components, resulting in a lossy procedure (Cleland and Vashishth, 2014). Nevertheless, it appears to matter *where* samples are taken from, as the selectivity for particular proteins, fibers, and signaling molecules for particular regions and types of bone results in a constellation of potential data zones. Such was the case for a 2017 study using samples from rib marrow to perform shotgun proteomics, one of the earliest to do so with archaeological bone (Sawafuji et al, 2017). The study focused on 2 infant and 4 adult remains from the Hitotsubashi site in Tokyo, dated to roughly 1657-1683 CE. This period was characterized by swift urbanization and crowded living conditions, a notably high stress environment. The individuals in the study were likely lower socioeconomic status as inferenced by their burial in wooden coffins characteristic of lower classes at that time. Of the adults, 4 were estimated to be 60 or more years of age at time of death and assigned the broad category of elderly adult.

Samples were taken first with sandpaper and then fragmented into powder, placed through a demineralization protocol, and washed several times with EDTA solution before their suspension in guanidium chloride (GuHCl), Tris 2-carboxyethyl phosphine, chloroacetamide, and Tris. After digestion in trypsin, nanoflow reversed-phase C18 LC-MS/MS was used to analyze the extracted pellets. Spectra were analyzed in

MAXQUANT and ANDROMEDA, referenced against the UniProt KB database. No significant relationship was discovered between age-at-death and the *number* of proteins detected, but an effect of age cohort for *which* proteins were expressed and in what proportions was observed. Infants and adults shared 33 unique proteins; adults and elderly adults shared 46. Infants and elderly adults shared only 21 proteins. Of greater note is the shift in protein *types* across cohorts, with infant samples expressing proportionately far more and in higher proportions of proteins specialized for developmental processes. A modest sex effect was found, with males more similar to other males than to females; however, there was also a degree of interindividual variation.

Osteocalcin was detected in all samples in addition to the abundance of several types of collagens, as well as plasma proteins like ALB. In some of the samples, TNF receptor superfamily member 11A (TNFRSF11A) was detected, a critical component of the RANKL pathway in osteoclastogenesis. Most intriguingly, however, was the novel identification of neutrophil-derived proteins--and also of eosinophils. Eosinophil peroxidase was identified in all samples and is a protein exclusive to eosinophils. Eosinophils are leukocytes associated in particular with allergic reactions, but also with immune responses to parasitic infections, especially helminths. Helminth infection is difficult to detect due to the nonspecific and not obviously destructive impacts they leave on body structures, an uncertainty amplified by the nature of bone and the ambiguities of archaeological material especially. Documentation from the era of these Hitotsubashi burials does note that helminth infections were widespread at that place and time, but the

study authors caution that inference from the presence of eosinophil peroxidase is not independently sufficient to support a conclusion that this is what the samples represent (Sawafuji et al, 2017). The role of eosinophils in the development of asthma and allergies is of additional potential interest because typical immune markers for allergy like immunoglobulin G (IgG) remain difficult to detect in archaeological bone, although some have succeeded in doing so (Kendall et al., 2016; Schmidt-Schultz and Schultz, 2004). If leukocyte proteins can be targeted and identified in further proteomic studies of archaeological material, the potential for inferring and contextualizing subtle, chronic illnesses involving local- and autoimmune conditions expands. Sawafuji et al. (2017) suggest that one reason for the detection of leukocyte proteins may have been the choice of bone tissue sampled, specifically the red marrow of rib bone. Through the lifespan, much of the red marrow supply is converted to yellow marrow in maturity, such that roughly up to two-thirds of adult marrow is yellow. Rib bone, however, retains a composition of mostly red marrow through the lifespan, as do the os coxae and vertebrae, and the study authors speculate that this choice of sampling site may have contributed to the ability to detect leukocyte-specific proteins. The femur is, for instance, a common choice for sampling, in part perhaps of how much matter it comprises--using destructive sampling and extraction methods does proportionately less harm when the choice of matter is more resplendent. The suggestion is given that future studies might look to sample vertebrae and os coxae for analysis of red marrow proteomes. While the sampling and extraction protocols used in this study were of average levels of destructive, it is pointed out that one important advantage of proteomics of ancient proteins over analysis

of aDNA is that there is no amplification procedure, lowering the risk of confounds from laboratory contaminants. To assess the level of preservation of the Hitotsubashi burials, analysis of glutamine deamidation rate was also performed, in which it was determined that remains were well-preserved as well as that samples were accurate to modern human proteomes. This methodology might be less straightforwardly helpful for studies of pre-modern humans or earlier hominids, complicating their applicability for evolutionary research, but this is only one of several approaches to ancient proteins. Given the impact of demineralization techniques, however, leads to questions about how much information is being destroyed in the process of trying to analyze it. Some research has ventured into this realm, experimenting with ways of circumventing this otherwise very standard and ostensibly necessary procedure.

Cleland and Vashisth (2014) employed a modified procedure from hydroxyapatite chromatography to investigate whether or not key biological information could be found and spared if demineralization protocols could be avoided. They note that such procedures retrieve as little as just 1% or even less of the original material in a bone sample, and point out the additional time-consuming and slow nature of these protocols. In the past, attempts to bypass demineralization steps failed to yield any greater than about 3 mg of proteins for every 1 gram of bone tissue sampled, a threshold unhelpfully low for further analysis. Chromatography protocols employ phosphate buffer solutions for their means of extraction, and retrieve large quantities of proteins from their test matter, however, and do not involve demineralization. This led to the present study's inspiration, borrowing the method of using increasingly concentrated phosphate solutions

to elute proteins from the hydroxyapatite column. As hydroxyapatite is a fundamental element of bone, it seemed possible that this approach might serve to retrieve larger yields from sampled material. The modification to this liquid chromatography protocol was to use higher-concentration phosphate buffer solutions from the outset, at concentrations roughly similar to those used as final step concentrations in typical hydroxyapatite chromatography.

Samples were taken from cortical bone of the tibiae of modern cadavers and treated in several different solutions for yield comparison: 400 mM ammonium phosphate dibasic solution, a solution of 400 mM ammonium phosphate dibasic with 200 mM ammonium bicarbonate, ammonium bicarbonate 200 mM alone, and a solution of 400 mM ammonium phosphate dibasic with 200 mM ammonium bicarbonate and 4 M guanidine hydrochloride. This lattermost solution resulted in the highest protein yield per sample and the highest number of identified proteins. The most abundant proteins were collagen I alpha1, collagen I alpha2, and osteocalcin, as was the case in the other solutions' results. This solution also found a variety of other matrix proteins not retrieved in the other solution treatments, such as osteomodulin, lumican, biglycan, and vitronectin. It was surmised that the additional array of proteins found using the GuHCl solution may be a property of GuHCl's effect of increasing the solubility of these matrix proteins, where otherwise a denaturing agent would have been necessary to retrieve these. The method used in this study involves neither demineralization nor denaturation, exposing potential protein yields to less destruction than by other means. Like other methods, however, the masking effect from the sheer abundance of the most numerous proteins,

the collagens, is still present and still obfuscates lower-abundance proteins that might otherwise be detectable at the sensitivity of the test. Osteocalcin and osteomodulin were the only mineral-specific proteins found in this study, but this nevertheless shows the utility of their method for extracting mineral proteins at all, a distinct advantage afforded by the less-destructive nature of a protocol with no demineralization step. Notably, osteocalcin was only detected *consistently* in the solutions containing bicarbonate, likely because the bicarbonate disrupts the carboxyl interactions between osteocalcin and the surface of the bone matrix.It is worth asking, given that this study was performed with modern/present-day cadaver bone and not archaeological bone, what differential impact non-demineralizing methods might have on tissue that is by nature already different from its living counterpart and which is likely to suffer damage from the taphonomic environment, especially as this material is already scarce. It seems probable that the development of less-destructive sampling and extraction methods stand to benefit archaeological matter even more than present-day or living matter, as it is being gathered from a fractional set of remaining matter to sample.

As osteocalcin is one of the direct products of, and a two-way route of communication with osteoblasts, especially from a perspective interested in local activity rather than strictly that of the central nervous system, osteoblasts as intercellular hubs warrants some exploration. This is especially crucial if looking to compare tissue systems *in situ* with systems that can be recreated or simulated in laboratory conditions, and vice versa. The variety and complexity of osteoblasts' receptor activity, including the peripheral and paracrine influences from osteoblast activity, invite investigation into the

distinct mechanisms for how osteoblasts facilitate the myriad transmitters and peptides of those interactions. Ma, Wang, and Zhang (2015) suggest gap junction intercellular communication (GJIC) may be a critical element employed in these local activities, and conducted a series of trials exposing *in vitro* human osteoblasts to a suite of signaling proteins. Gap junctions are formed via proteins called connexins and serve to facilitate close communication between adjacent cells. In the case of bone cells, gap junctions serve to mediate osteoblast differentiation and new bone formation, relaying hormonal cues and local gene transcription. The purpose for the study was to assess the responses osteoblasts would have via alterations in gap junction communication induced by exposure to key peptides: NPY, substance P, and human bone morphogenic protein 2 (hBMP2). The procedure took measures of alkaline phosphatase (ALP) activity and osteocalcin concentrations, the former by an assay using an Automatic Biochemistry Analyzer and the latter assayed with ELISA. Fluorescence recovery after photo-bleaching (FRAP) using a laser scanning confocal microscope was employed to assess the effects of the protein treatments. The osteoblasts used in the experiments were thawed from freezing and assessed for viability, and were found to be over 85% preserved compared to their pre-storage state. These were cultured and observed under a scanning electron microscope for surface morphology before being exposed to the treatments or set aside as controls.

Viability was measured as an absorbance value, and was shown to increase in all samples treated with neuropeptides and BMP. A significant difference appeared between the neuropeptide treatments and the BMP treatment condition, as well as a few

correlations. A significant increase in absorption was found correlated to decreasing concentrations of neuropeptides, whereas a significant drop in absorbance correlated with decreasing BMP concentrations. An effect of increasing absorbance over time was also noted. Further, it was found that adding BMP to samples treated with the other neuropeptides appeared to diminish the stimulating effects of the neuropeptides on viability.

All treatments showed an increase in ALP activity, an effect that was greatly magnified for samples that were treated twice rather than only once, and all demonstrated a marked increase in osteocalcin concentrations, which similarly rose significantly higher for samples treated twice. Interestingly, osteocalcin concentrations were significantly higher in the neuropeptide-only and BMP-only samples than in the samples where these were combined. Changes in numbers of receptors expressed on osteoblast surfaces for each of the treatment proteins were also recorded, a significant increase for all treatment proteins' receptors over controls. The highest expressed were NPY receptors, with substance P at lowest expression. This pattern was observed again in the FRAP assessment of gap junction activity, highest for NPY, lowest for substance P, and BMP somewhere in the middle range. All treatments created a sharp significant increase in gap junction activity. Osteocalcin concentrations were highest in the NPY-treated samples, and lowest in BMP-treated samples.

The results suggest a role for GJIC in regulation of osteoblastic activity that is upregulated by NPY implying that both direct binding and gap junction signaling facilitate the local behavior of osteoblasts. It is however cautioned that at present, cellular

and molecular studies of these phenomena frequently contradict one another's findings, and with key proteins themselves often occupying paradoxical opposing roles within the same systems, bigger-picture conclusions become complicated to draw (Ma, Wang, and Zhang, 2015). What is notable about this study is, one, that it was conducted with human-specific tissue, not rodent models as is common in neural- and osteoimmunology studies. For another, it further demonstrates the local, focal governance of bone physiology and its close linkages to other tissue systems, while also doing so from the vantage point of crucial neuropeptides that have bidirectional influence in broader, central homeostatic systems. These peptides connect central and peripheral with a direct and observable presence, enhancing their usefulness as targets of inference.

To expand on this with greater relevance to bioarchaeology, it is worth making note of some work conducted with osteocalcin specifically as a proteomic target for inference. Scott et al. (2016) used ELISA to identify osteocalcin in bone sampled from the burial population of Black Friars monastery and cemetery in Odense, Denmark, a site split into two distinct time periods of use. Originally a monastery from its construction in ~1239 CE to 1536, and up to its church's demolition in 1542, Black Friars continued to be used as a hospital and residential area, including continued use of the cemetery grounds as a public cemetery. The full, formal closure of the monastery took place in ~1551 CE and marked the transition into public use, where burials would routinely continue until about the turn of the 17th century. After 1536, a number of other public cemeteries in the region closed down, drawing a large increase in burials to Black Friars, and thus the number of burials in this later, public period is substantially greater than in the preceding

era. Because of this, Scott et al. divide the whole Black Friars burial population into a monastic, medieval phase, and a public post-medieval phase, interested in what variation might exist among and between categories in osteocalcin fluctuations.

Working from the knowledge that macroscopic alterations to skeletal tissue in conditions of stress, illness, and injury take a very long time to form, such that individuals can and do die before these are expressed, it was speculated that proteins involved in bone homeostasis could undergo fluctuations well before disruptions could manifest at the macroscopic level. If these proteins could be measured, it could become possible to draw inferences about an individual's condition in the absence of, or prior to, development of larger and more visible alterations, rendering the invisible potentially more visible. It is cautioned that skeletal stress indicators are nonspecific; this is true of osteocalcin to a degree as well in the sense of using it to observe systemic stress, and also that stressors rarely act in isolation and confound the broader picture, noteworthy as well given osteocalcin's multiple roles. An indicator of new bone growth and closely associated with mineralization, osteocalcin has a known fluctuation pattern within the lifespan, with concentrations peaking at times of rapid growth and development such as the birth-to-three years old range and the adolescent growth spurt Osteocalcin levels then typically stabilize in adulthood and begin gradually declining in older age. Menstrual activity and pregnancy exert effects on osteocalcin as well, rising during menstruation and at menopause, and falling significantly in the first and second trimesters of pregnancy. Osteocalcin's affinity for different bone and tissue types varies as well, in addition to the variability of having both a carboxylated and uncarboxylated form.

Because it is so tied to mineral and matrix, there is a common confounding feature of diagenesis that is particularly salient; the mineral components of bone break away in small chunks, but these chunks also go on to combine and form larger chunks, resulting in protein loss. This is the metric referred to as crystallinity in bioarchaeological analysis of diagenesis and stability, and the study employs FTIR as the means of assessing crystallinity in the Black Friars samples. MicroBCA analysis was used to measure total overall protein content extracted from the samples. FTIR analysis was conducted using the attenuated total reflectance (ATR) method, measuring crystallinity through the infrared splitting factor (IR-SF), the two peaks in the absorption spectra that drift further apart as crystallinity increases. Macroscopic evaluation of the skeletal remains was also conducted, and classed into distinct groups of 'past-stress' conditions and 'chronic-stress' conditions based on presence and type of lesioning observed. 'Stress indicators' were defined broadly as 'any visible skeletal changes reflecting compromised health'. Past-stress indicators included signs of early-life stress; chronic-stress indicators were all active at time of death. The burials were identified as being from either the medieval or post-medieval period by way of their location in the cemetery as well as inferred from burial posture of the arms (crossed over chest or pelvis, prone).

The study sampled 20 adult individuals estimated aged 20 years of age or more at time of death. Roughly 50 mg of powder was taken from each at the posterior femur, just inferior to the lesser trochanter, and from the inferior clavicle shaft, medial to the conoid tuberosity, using a Dremel. To use as a reference point in the crystallinity measurements, a sample of bone from another cemetery of the same time period, Aarhus Vestegrade,

was assessed. Crystallinity results were found to be roughly similar between femur and clavicle samples. In contrast, osteocalcin concentrations differed significantly between the two time period for both clavicle and femur samples. In the chronic stress category, osteocalcin concentrations were significantly different for clavicle samples from individuals showing signs of degenerative vertebral changes than for clavicle samples in this category without spinal involvement. No significant differences were found between either age cohorts or sexes, nor between clavicle and femur samples *overall.* It is noted however that osteocalcin concentrations are generally distributed more consistently in the clavicle than in the femur, possibly because of variations in the timing of when osteocalcin is captured in the cortical tissue, as these timings are known to vary between bone types. The shorter periodicity of clavicle remodeling perhaps implies that clavicle samples represent a shorter and more precise window of fluctuations, and perhaps therefore more accurate. The longer remodeling rates of the femur by contrast may be representative of multiple periods of fluctuations, creating an accidental "averaging bias" while also potentially giving a longitudinal profile of these periods. Of further interest to variations in osteocalcin concentration is the influence of glucocorticoid receptors, and the different saturations of these receptors on different skeletal elements. The femur is replete with glucocorticoid receptors and thus more vulnerable to the destructive effects of glucocorticoids, in turn affecting the levels of osteocalcin in femoral tissue in addition to the high degree of stress from mechanical loading (Eberhardt et al., 2001; Scott et al, 2016). Psychological stress is briefly mentioned in the context of reading osteocalcin as a measure of the systemic effects of stress, remarking that it, too, triggers glucocorticoid

activity and affecting immune functions as well as osteocalcin levels through their actions on osteoblast differentiation. Psychological stress cannot be identified in bone tissue, of course, but the known involvement of osteocalcin in regulation of serotonergic activity and its links to direct action on brain tissue, and several disorders, a future refinement of osteocalcin measuring techniques could possibly begin to nudge open a window into making psychiatric inferences. The study is an example of how biochemical and proteomic approaches can expand the scope of assessment to stages preceding the macroscopic manifestations of biological insult.

In another study, Scott et al. (2020) return to the prospect of osteocalcin as indicator in skeletal material to peer deeper into factors that independently influence the differences between individuals' concentrations. This was performed with 46 individuals from Sct. Albert's cemetery in Denmark, dated to about 1250 to 1536 CE. The sample population comprised 30 adults and 16 subadults from the Sct. Albert church cemetery located on a small island off Denmark. The church was built around 1300 CE and saw regular use until about 1536, when the cemetery was closed and the church destroyed in the Reformation. The site was fortified at some point, as per the discovery of a moat and ramparts, and may have served as a military outpost somewhere in its occupation. About 20 mg of bone powder was taken from the proximal posterior femur, next to the linea aspera, using a Dremel tool. BCA assay was used to quantify proteins, and absorbances were measured. ELISA was once again used to detect osteocalcin in the samples. As with the 2016 study, skeletal remains underwent macroscopic evaluation to estimate age, sex, and presence and manner of signs of pathology. In particular, dental information,

indicators of early-life stress, signs of infection, nonspecific inflammation, trauma, and degenerative joint disease were points of interest to note.

No significant differences in osteocalcin concentrations were found between sexes, only a non-significant distinction in patterning, with females showing the expected reductions with increasing age, while males were much more inconsistent and variable. Subadults were similarly high in within-group variability in osteocalcin concentrations, but there were no significant differences between adult and subadult categories overall. There were also no differences of significance between concentrations for presence and absence of each pathological alteration type within the subadult group. A possible skew exists for each sex category of the adult samples, however--in the male group, the individual with the highest concentrations was also one of the cohort for 'other trauma', raising overall mean values. Only this individual returned differences of significance when testing for paired sex and presence/absence of pathological alterations. Similarly, a single individual in the female group skews these significance results because of showing signs of both leprosy and dental abcesses, the only individual to do so, and also happens to have the second-highest osteocalcin concentrations of the sex grouping. These statistical issues obscure the broader conclusions it is possible to make, and are likely an artifact of the very small sample size with which the analysis was performed, especially in the female sex category. Of the adults in the study, 22 individuals were male as opposed to only 8 females. Within the female category, there were nevertheless some distinctions of note: many of the lesions and stress indicators in the female group are characteristic of early-life stress events, an effect not as apparent for the more variable

male samples. It is thus a possibility that fluctuations in osteocalcin that *would* have been relevant and hinged on the influences governing osteocalcin concentrations were no longer visible after these earlier life stages had passed, partly due to simple turnover. It is emphasized in the conclusions that osteocalcin concentrations in archaeological bone are *not* the same as those in living tissue, but it is worth nothing that methods like those employed here can grant unprecedented visibility to previously invisible information. The use of ELISA as detector for osteocalcin is especially interesting to contrast with the results of a LC-MS/MS examination of the samples with the highest and lowest concentrations as found by ELISA: LC-MS/MS only detected osteocalcin at all in the samples with the highest concentrations, whereas for samples ELISA identified as having the lowest concentrations, osteocalcin was not detected at all. This is likely due to the 'masking' effect that higher-abundance proteins have on lower-abundance proteins, a persistent problem for mass spectrometry methods, and suggests ELISA has a uniquely sensitive utility for studies of this nature. While no real firm patterns governing or explaining the variability of osteocalcin concentrations in bone were uncovered in this study, the advantages and potential of its choice of tools are promising for future examinations. One suggestion offered was for future studies to take samples directly from lesion sites to possibly get a more accurate and representative picture of how pathological processes relate to the shifting balance of osteocalcin levels. At present it would seem that osteocalcin as a target for study is somewhat nonspecific as an indicator, not unlike the macroscopic changes it precedes; however, its usage has only just begun to be

explored in bioarchaeology, and otherwise in living tissues its roles are rather specific and better-known, and its utility seems likely to improve.

NEW DIRECTIONS, CLOSING REMARKS

Bioarchaeologists do not have access to a full timeline of the events experienced by those who leave only teeth and bones behind, but there are subtle implications in the alterations certain experiences introduce. Early-life stress events can and do leave marks, and while it is customary to infer that these represent compromised health--and they do--the fact of individuals surviving these life stages, or even merely struggling with them long enough for them to be written in bone, is a sign of the plasticity of human bodies that permits survival at a cost. Survival at a cost is, after all, still survival.

One known association with this costly transaction is between the compromised statures of famine survivors from early life and an increased risk of cardiovascular disease. Perhaps this is unsurprising from the standpoint that these metabolic stress systems operate from key signaling molecules with direct roles in multiple tissue systems, like CGRP in the pain sensing nerves that innervate skeletal tissue and their other principal function as central to vasculature. One theoretical reason for these shifting balances in interwoven tissue systems under severe stress is that there is a tradeoff advantage in the form of the "thrifty phenotype". The "thrifty phenotype" hypothesis stipulates that in the course of fetal development, if exposed to the stress of nutritional shortage, development trades short-term survival for the higher risk of later-life metabolic conditions, particularly through impaired pancreatic growth. The result weathers the immediate crisis, but predisposes the individual for higher glucose tolerance. Other

applications of this hypothesis speculate on the role that certain autoimmune disorders might represent this type of resource tradeoff, such as rheumatoid arthritis (Reser and Reser, 2010). This model is improved and expanded upon with a broader construct--DOHaD, the developmental origins of health and disease.

One suggestion is to view the HPA axis and the costly survival benefits it provides as a form of adaptive reaction norm, under the umbrella of adaptive plasticity, defined in Ghalambar, McKay, and Carroll (2007) as a "... reaction norm that results in the production of a phenotype that is in the same direction as the optimal value favored by selection in the new environment." The short-term boost to energy metabolism and immune system functions provided by the HPA axis thus could represent a plastic response to an environmental pressure. This flexibility in part lies with the nature of the axis' components; the critical feedback loops of the leptin, NPY, serotonin, and osteocalcin systems; the multiplicity of the roles of each in neural, immune, skeletal, and metabolic tissues in constant communication with one another. Pancreatic involvement of pain signaling via CGRP-rich innervation and the activity of TRPV1 nociceptive receptor channels is not yet well-understood, but perhaps this suggests another, specific tradeoff under stressful conditions--CGRP from pain neurons greatly inhibits the release of insulin, while TRPV1 might conversely promote it, as suggestions from rodent model genetic knockouts for TRPV1 expression on neurons presented with longer lifespans and higher insulin resistance. Pain is certainly thought of as inherently adaptive itself, a potent cue for aversion and threats against the usual function of a tissue or system. Yet a principal notion in DOHaD is the delicate relationship and balance between the adaptive

benefits of this mechanism's ability to radically alter its normal routines in a crisis, and the longer-term ramifications of those expenditures and their response to chronic and longer-term stress. With reference to pain specifically, this calls to mind the etiology of complex regional pain syndrome.

Complex regional pain syndrome is a *maladaptive* state of chronic pain often following a real, traumatic injury, but which persists long after the injury is resolved. It has been found associated with rapid bone demineralization and the onset of several psychiatric disorders (Rousseaud et al. 2016) and the presence of autoantibodies in serum samples against β2 adrenergic receptors in short-term cases, and α14 adrenoreceptors in long-term cases (McMahon, La Russa, and Bennett 2015). These effects in the wake of traumatic injury and wound healing have outlived their initial purpose as signifiers of bodily threat, aversive behavioral responses, and the recruitment of key molecules initiating healing; the same system that allowed for survival of major injury has become its own source of dysfunction. This mirrors the longer-term consequences of systemic alterations brought on by the actions of the HPA axis and its cascade of downstream effects. The hypothalamus governs the neuropeptide Y system, an energy-conserving feedback mechanism responsive to caloric deficit. As intake drops, NPY levels in circulation rise, suppressing new bone growth--the exchange of the tradeoff, in action (Masi 2012). These mechanisms are not themselves visible macroscopically, presenting bioarchaeologists with an additional problem, making DOHaD difficult to implement. Timing is crucial, in both the sense of stress events themselves and in the temporal windows through which samples are studied, given the way that 'hidden heterogeneity'

already exists. These narrow windows are also at odds with the longitudinal nature of DOHaD--hence the promising nature of inferences made from temporally-bound developmental thresholds displaying the effects of the HPA axis in action. Variations in individual frailty and risk further confound the picture; but, like other aspects, inclusion of further contextual information influences the clarity of this picture. When statistical analysis of a cemetery sample of individuals with and without LEH included information about birth year, estimated cause of death, and socioeconomic status, the significance of differences in mortality risk between the two groups diminished. Risk of death and future systemic disruptions rose however when looking at variations in age at first development of defects, suggesting this functions as another critical window in long-term outcomes (Temple 2014). It also coincides with measurable upticks in osteocalcin concentrations, pointing to the potential utility of studying key protein signatures to deepen insights into available material. While it would be misguided to assume a one-to-one degree of similarity between modern clinical and ancient profiles of disease and impairment, it is also work noting that the known multiple roles of these proteins might permit bolder inferences about mental health and developmental disorders, as for osteocalcin's influence on prenatal and early-life brain development.

Longitudinal inference is difficult to draw in bioarchaeology; remodeling, growth, and the confounds of advancing life stages, the muffling effect of variations in the abundance of proteomic targets, all alter the picture of what is largely a snapshot of an individual's time of death. When the timings of stressful incidences fall into particular windows of the lifespan, the effects of costly survival can persist and alter the

circumstances of later life stages. Ultimately, bioarchaeology is a contextualization of death, not life--"bodies break, and bodies die" (Temple 2018, p. 9). Bodies also do not go down without a fight so easily, and the perseverance of bodies harmed in life that yet live beyond this harm is a testament to both the mitigation of social and cultural surrounds, and the transformativity of bodies themselves.

Here is where I bring disability and impairment back to the fore. While it is true and intriguing that social relationships and community environments, perhaps even reconstructions of the taboos and values systems in past societies toward 'anomalous bodies', can be interrogated by the presence of these bodies in the archaeological record, these bodies are more than merely props for such social systems. Anomalous bodies are subjects, authors of the experience of threat and survival; the adaptive nature of altered tissue and modes and behaving and being is *exemplary* of the ingenuity of embodied processes and human experience, not a contradiction, outlier, or byproduct. Not all impairments are tradeoffs, but equally, not all impaired individuals are reducible to markers of what their unimpaired or differently-affected peers were doing. There is agency to these bodies, and it is written into the very natures of bodies' means of responding to a challenging world.

Even when one day, *all* bodies go to rest.

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