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Tiptoeing through the rest of his life: A functional adaptation to a leg shortened by femoral neck fracture

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ABSTRACT

Salvage excavation of a Roman cemetery (1st–2nd century CE) at the site of ancient Erculam (region of Campania), Italy, yielded the skeleton of an older male with a healed fracture of the femoral neck that reduced the femoral neck angle and resulted in leg shortening. The right foot shows bony alterations that appear to have developed as a consequence. The distal joint surfaces of the first and second metatarsals extend dorsally for articulation of the proximal phalanges in hyper-dorsiflexion. I argue that, in order to compensate for the shortened leg, the man lengthened it functionally by bearing weight primarily on his toes when he walked, rather than striking the heel first and then pushing off from the toe. The severity of degenerative joint disease in the right knee and in the metatarsophalangeal joints suggests that the injury occurred years before the man's death. This case adds to the bioarchaeological record of individuals who adapted to impaired mobility in the past, and it may be of interest to scholars who study the bioarchaeology of impairment and disability.

1. Introduction

The ancient cemetery of Erculam (also known as Herculia) is located in the modern town of San Marco di Castellabate on the western coast of southern Italy (Salerno province, in the region of Campania), roughly 400 km south of Rome (Fig. 1). The cemetery was discovered in 1983 (Fiammenghi, 1992) and dates to the 1st or 2nd century CE. This report focuses on the skeleton of an older adult male from one of the primary burials recovered at Erculam during salvage excavations by Italian archaeologists in 2004 and 2005 (Di Paola, 2006). He had sustained a fracture of the femoral neck that reduced the femoral neck angle and resulted in leg shortening. Three aspects of this case are described in this paper: the probable mechanism of injury, the consequences of the injury, and the implications for mobility impairment.

The mortuary treatment of this individual was no different from the others buried in this cemetery. Each adult skeleton had been interred in an extended supine position within a rectangular earthern pit covered with terracotta tiles (*a cappucina* style), indicating that they were of limited financial means and low social status. Libation tubes or the upper portions of amphorae may have marked the graves (e.g., Prowse and Small, 2009; and Toynbee, 1971), but none were in place at the time of the cemetery's discovery. Most burials did not have grave goods, but a few bronze coins and small terracotta vessels and glass bottles were recovered.

Historical data indicate that the ancient community had a maritime-based economy, so it is likely that many of the men who lived there made their living as fishers. Some, however, could have been merchants, worked a trade, or been engaged in agricultural activities related to the cultivation of grain and the maintenance of orchards and vineyards (Carré, 1993; Kolendo, 1993; Meijer, 1986: 218, Morely 2002).[1]

2. Materials and methods

The human remains from the Erculam cemetery are stored at the site of Velia, located in the Italian town of Marina di Ascea, some 35 km south of San Marco di Castellabate on the Tyrrhenian coast. The skeletons of 29 individuals were studied at Velia in the summer of 2013. Many of the skeletons were incomplete, and the bones were fragmented. This individual, however, was sufficiently complete to determine that he was a male, based on skull morphology and the size of long bones and joints. The pelvis was damaged postmortem, but the morphology of the greater sacroiliac notch

[1] Although diet and subsistence activities have not been reconstructed for Erculam itself, I refer interested readers to the comprehensive reviews of diets, water-related occupations, and agricultural activities for the nearby Imperial Roman coastal site of Velia by Craig et al. (2009) and Crowe et al. (2010).

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Fig. 1. Map of Italy showing the locations of the archaeological sites of Erculam and Velia, with Rome and Naples included for reference.

and the absence of a ventral arc on the *os pubis* supported this assessment (Buikstra and Ubelaker, 1994). Age-at-death estimations are imprecise for adults, but this individual appeared to have been an older adult based on greater than 50% obliteration of the sagittal suture and a fine-grained pubic symphyseal face (Buikstra and Ubelaker, 1994), as well as an edentulous mandible with fully remodeled alveoli and one remaining maxillary molar with severe asymmetrical wear, scored according to Lovejoy (1985) and Smith (1984).

3. Results

The skeleton displays a well-healed fracture[2] of the proximal right femur (Fig. 2). When the femoral head is in anatomical position, the shaft segment distal to the neck is shifted superiorly and anteriorly, leading to a slight medial rotation of the femoral shaft. There is also a pronounced reduction (*coxa vara*) of the femoral neck angle that shortened the right leg. There is no evidence of avascular necrosis. Although the femoral head is not affected by arthritic change other than slight marginal lipping, the right distal femur and proximal tibia exhibit eburnation and grooving (Fig. 3); the right patella is affected by marked marginal lipping.

There are marked pathological alterations in several bones of the right foot. When the first metatarsal (MT) is articulated with its corresponding first proximal phalanx, it is clear that range of motion at this joint permits hyper-dorsiflexion (Fig. 4). This MT1 exhibits marked marginal lipping, erosive lesions, and eburnation of the distal subchondral surface, as well as a pronounced insertion site for *peroneus longus* on the plantar aspect of its proximal end. The MT2 and articulating proximal phalanx are affected to a lesser degree. Eburnation is visible on the distal subchondral surfaces of

[2] Congenital or developmental dysplasia (dislocation) of the hip was ruled out in the differential diagnosis due to the normal appearance of the acetabulum. A slipped capital femoral epiphysis was also ruled out since the abnormality of the neck in this femur occurs outside what would have been the limits of the fibrous capsule.

Fig. 2. Frontal aspect of left and right femora. Although partially obscured by post-mortem erosion, the right femur displays a healed fracture of the neck with reduced neck angle.

the first and second proximal phalanges (Fig. 5); unfortunately, the phalanges distal to these were not recovered during excavation.

Additional lesions that may be relevant to interpreting the mechanism of injury in this case are a crush fracture of the fifth lumbar vertebral body and Schmorl's nodes on the superior surfaces of the sixth through tenth thoracic and the first and second lumbar vertebral bodies, as well as extensive marginal lipping on the third through fifth lumbar vertebral bodies. The left distal femur, proximal tibia, and patella exhibit degenerative joint disease, although the lesions are not so pronounced as on the right side. Contrasting with the osteoarthritis in the lower limbs, the upper limbs display only slight marginal lipping at the shoulder and elbow joints. There is no evidence of trauma to the pelvis and there are no talar or calcaneal fractures. Two of the recovered 40 rib fragments (most of which are less than 10 cm in length) display evidence of trauma, although not necessarily from the same event. In one example the fracture is well healed and may have occurred at the time the femoral neck fracture was sustained, while in the other the fracture callus consists of unremodelled woven bone, indicating an injury only some weeks before death (Lovell, 2008).

4. Discussion

Three aspects of this case warrant discussion: the probable mechanism of injury, the consequences of the injury, and the implications for mobility impairment. Since the femoral neck is well protected by soft tissues, the fracture must have been caused by indirect blunt force trauma rather than a direct blow (for a discussion of mechanisms of injury, see Lovell, 2008), but how that indirect force was transmitted to the femoral neck is not entirely clear. The reduction in the femoral neck angle is consistent with a fall onto the feet from a height, with the force of impact transmitted upward. Supporting that scenario are the collapse fracture of a vertebral body and the Schmorl's nodes, although it cannot be determined if all of the injuries were sustained at the same time. Contradicting the scenario of a fall from a height is the absence of any evidence of trauma to the left leg or to the os coxae, tali, or calcanei. Indeed, the vertebral lesions could have resulted from lesser forces if the vertebral bodies had been weakened by a pre-existing condition such as osteoporosis.

Osteoporosis is strongly associated with fractures from low energy events (Bergström et al., 2008; Metcalfe, 2008), such as a fall from a standing height (Galloway, 1999: 251–252; and, for a review of preexisting bone loss and fragility fractures, see Beauchesne and Agarwal, 2014), particularly falling sideways (Anderson et al.,

Fig. 3. Marginal lipping and eburnation with grooving on the condyle of the right femur.

Fig. 4. The right MT1 and proximal phalanx in hyper-dorsiflexed articulation, with dorsal extension of the articular surface of the MT1 and extension of the proximal articular end of the proximal phalanx. A clump of hardened mud adheres to the plantar edge of the distal end of the MT1.

2013). Such falls typically are associated with an underfoot event, such as a slip, trip, missed footing, or turned ankle (Baxter et al., 1985; Manning, 1983). Clinically, the majority of patients presenting with femoral neck fractures are those with osteoporosis. A poor diet can contribute to poor bone mass (see Agarwal, 2008; and Beauchesne and Agarwal, 2014), and given the apparent antemortem tooth loss, this man may have had difficulty maintaining good nutrition for many years. Although his low social status makes it possible that he engaged in physical activity in his younger years that mediated somewhat against fragility fractures, he may have reduced his level of physical activity as he aged, minimizing that benefit. Since there is only slight marginal lipping at the shoulder and elbow joints, the extensive marginal lipping on vertebral bodies may have been age- rather than activity-related. Unfortunately, bone quality and quantity could not be assessed. No radiographic facilities were available, bone samples could not be taken from consistent sites on the femoral shafts or metaphyses due to postmortem breakage, and the infiltration of silt and sand would have confounded radiological images of bone density. Post-traumatic atrophy of the injured femur could not be evaluated because postmortem damage precluded measurements. Both tibiae were intact, however, and they did not display any difference in dimensions taken at the nutrient foramen (following Buikstra and Ubelaker, 1994), other than differences that could be attributed to observer error.

While the disparity in severity of joint changes between upper and lower limbs is not uncommon, I interpret the lower limb arthritic lesions as secondary to the femoral neck fracture and the subsequent alteration to the man's normal gait, rather than invoking age-related degenerative change (although age is probably a contributing factor). Joint degeneration in the lower limbs was nearly universal among the other six older adult males in this skeletal sample, but in no case did the degree of lipping or porosity approach the severity seen in this man. No other individual showed evidence of eburnation.

As Judd and Redfern (2012) stress, to properly evaluate traumatic conditions in paleopathology we need to consider how this man experienced life as a result of his injury. The impact of the injury on his quality of life would have been immediate and also long lasting (see, e.g., Mays, 2006). Today, nearly 90% of individuals with hip fractures undergo surgery (Kaffashian et al., 2011). Fewer than half those receiving surgical repair recover their pre-fracture competence in activities of daily living; only one-fourth regain previous levels of social functioning (Center, 2013). Six months after sustaining a fracture, just 15% of hip fracture patients can walk across a room unaided and some 25% of those who were ambulatory before a hip fracture require long-term care afterwards (Marottoli et al., 1992).[3] It seems likely, then, that shortly after the injury this man was carried home and put to bed, and then he was assisted when he attempted to sit, stand, and, eventually, to walk. Although family members likely prepared meals and attended to chores within the household before his injury as well as after, family income or provisioning would be reduced while he was unable to work for a wage or obtain food through his own activities. Although he was no longer a young man, it is reasonable to assume that, given his social status, he was not able to retire from wage earning or contributing to his family's well being. Although he survived his injury by many years, he would not have been able to return to most tasks associated with a fishing or agricultural way-of-life, other than those tasks that were sedentary (e.g., mending nets, sharpening tools), and if he worked as a merchant, his activities would have been limited to those that did not require him to carry goods.

While I cannot determine the type of medical treatment that might have been available, historical sources indicate that Roman medicine to a large degree followed the Greek system of Hippocratic humoral therapy, although medical practice frequently included mythology and folk traditions (Cilliers and Retief, 2006; Israelowich, 2015; Nutton, 2004). Patients of limited financial means probably used non-professional treatments. The fracture appears to have caused immobilization, so I do not believe that this man received medical intervention to stabilize the fracture. He probably benefited from some form of medication to relieve pain, such as alkaloids from the leaves and seeds of henbane and the roots of mandrake. Opiates from poppy capsules would have been available, as well (Cilliers and Retief, 2006; Riddle, 1986).

Given the alterations to the bones of the foot on the affected limb, it is reasonable to imagine that the man limped while bearing weight on the toes of his right foot. The pronounced insertion of *peroneus longus* suggests habitual extension and eversion of the

[3] Most hip fracture patients in North America utilize post-surgery rehabilitative services, both formal and informal (Kaffashian et al., 2011), so it is difficult to estimate the difference in recovery time between surgical patients and individuals who do not have access to acute medical care. Comprehensive reports on disability worldwide do not address this issue, nor the physical and social implications of hip fracture, but focus on needs in the delivery of health care and rehabilitation (e.g., World Health Organization, 2011, and see a list of WHO resources on disability at http://www.who.int/disabilities/publications/en/).

Fig. 5. The right first proximal phalanx showing extension of the proximal articular end and eburnation on the distal articular end.

foot. Indeed, Garland (2010: 21) cites Celsus (De Medicina 8.10.5) as observing a femoral fracture in the Roman world that resulted in bone shortening requiring the injured person to walk on the tips of the toes in order to compensate for the uneven leg length.

The bioarchaeological record of mobility impairment of this type and associated ambulatory aids is limited, but Knüsel et al. (1992), Knüsel and Göggel (1993) and Belcastro and Mariotti (2000) have identified in archaeological skeletons changes to the brachial skeleton that are associated with mobility impairment and crutch-sustained locomotion. The absence of such bony modifications in the man from Erculam and the presence of the pronounced alterations to the foot suggest that he did not use a crutch in place of the injured leg, but transmitted weight on his injured leg. He may have used a staff or walking stick as an aid for balance, but not for primary weight bearing. Since the length of the first MT is slightly greater than the reduction in the functional length of the leg, he probably maintained a slight bend at the knee while walking, which may be implicated in the degeneration of that joint.

While observable mobility impairment can be recognized in this case on the basis of the skeletal evidence for fracture and subsequent bony modifications, the interpretation of the social experience of this man in relation to his injury is more complex. Many scholars distinguish between medically-defined impairment (i.e., functional constraint) and socially-defined disability (e.g., Cross, 2007; Marsteller et al., 2011; Thomas, 2007; Zakrzewski, 2014, 2015). However, a fluid boundary exists between disabled and able-bodied individuals, since a disability may not be permanent or may manifest in only certain circumstances (Zakrzewski, 2014, 2015). It is also the case that some functional constraints may appear only with advancing age (see Zakrzewski, 2014, 2015). In terms of a Roman conceptualization of disability, Graham (2013) reviews paleopathological and mortuary data and argues that Roman attitudes toward disability played out in a context where most people's lives were affected by physical impairments (see also Garland, 2010: 20), and hence these impairments were viewed as the norm and not treated differently in the mortuary realm. In the absence of commemorative monuments, as is the case with the Erculam cemetery, the disposal of the body may be crucial for discerning the individual's social identity. Thus, the burial of this man in the communal cemetery, in a manner consistent with other adults, suggests that while he may have been recognized as mobility impaired, he was not socially identified as disabled.

5. Conclusions

Based on the available fracture evidence, the most parsimonious explanation is that the injury was caused by indirect trauma associated with an underfoot event (i.e., a slip, trip, missed footing, turned ankle) that resulted in a fall from a standing height, causing a fragility fracture. Circumstantial evidence that supports the possibility of a fragility fracture due to underlying osteoporosis includes a vertebral body crush fracture and Schmorl's nodes in seven vertebral bodies. Subsequent to the injury, this man adapted to locomotor modification that resulted in more pronounced degenerative joint disease in the knee and foot of the affected limb than can be attributed to age alone. One rib may have been fractured at the time of his fall; another rib was fractured only weeks before his death, but whether it was associated with his altered gait cannot be determined.

This man's condition made him unique among the individuals in the skeletal sample, although the representativeness of that sample of the buried population and of the living population of the community cannot be ascertained. Importantly, however, he was buried in the same manner as other adults in the Erculam cemetery, indicating that his social identity was not adversely affected by his impaired mobility. This also provides support for the conclusions reached by other scholars that functional impairments of this type did not constitute identification as "other" in the Roman world.

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