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Multiple abnormalities in the feet and associated changes elsewhere in the skeleton: The case of 3A-7 from a Capsian Site in Algeria

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A B S T R A C T

A skeleton with a number of abnormalities is described with full discussion of alternative diagnoses. In this complex case, the primary diagnosis is of avulsion of the stem of the bifurcate ligament causing a fracture of the anterior process of the calcaneus. The bilateral fracture identified in Skeleton 3A-7 from Site 12, a Capsian site in Algeria, is a result of the feet being inverted and plantar flexed: the fracture is prone to non-union, which is asymmetrical here. There is also a separate anomaly of the feet, 3rd cuneiform and 3rd metatarsal coalition, which was not the cause of trauma. The bifurcate ligament is a major stabilizer of the lateral Chopart (transverse talar) joint, and the trauma could lead to further issues: however, multiple other traumatic changes in 3A-7 most likely occurred at the same time, rather than as the result of pre-existing foot trauma. The asymmetry of the calcaneal condition and asymmetry of the sequelae of the original trauma led to long bone asymmetry, the result of locomotor difficulties.

Introduction

The Capsian is an early to mid-Holocene (10,000 to 7000 cal BP) forager culture known from thousands of sites in the Maghreb, especially in eastern Algeria and southern Tunisia (Lubell, 2001). It is notable for its open-air and rockshelter sites which, because they contain enormous numbers of land snail shells, are known either as *escargotières* (French) or *rammadiya* (Arabic) because ash and charcoal are a major component of the deposits. While land snails were certainly an important source of animal protein in the diet, Capsian groups also consumed large and small mammals (aurochs, hartebeest, gazelle, lagomorphs), perhaps some birds and a still undetermined amount and kind of plants. Capsian sites often contain numerous human burials. Aïn Berriche (hereafter Site 12) is an example of such a site, located in eastern Algeria near the town of Berriche. In 1930, the site was excavated jointly by two teams, one from the Logan Museum at Beloit College, Wisconsin and one from the University of Minnesota in Minneapolis, Minnesota. We will focus here on one burial, Skeleton 3A-7, from the trench excavated by the University of Minnesota team (Jackes and Lubell, 2014; Jackes et al., 2015).

Eight skeletons were excavated from the Minnesota trench and some details have been described elsewhere (Haverkort and Lubell, 1999; Jackes and Lubell, 2014; Jackes et al., 2015). Here we will discuss only Skeleton 3A-7, but there are limitations to our information. The skeleton was excavated at the end of the season, was neither sketched nor photographed, and there is extensive damage. We have only a description written by Lloyd Wilford, the site supervisor, in his field notes and diary (Wilford, 1930a,b) and from this have attempted to reconstruct the position of the skeleton (Jackes et al., 2015). It is unfortunate that we have no idea where

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the feet, sternum and clavicles were found, because all exhibit abnormalities. The unusual mortuary practices, involving manipulation of the body after initial burial, with removal of some bones, and the placement of a number of other bones in positions indicating purposeful disarticulation, is typical of skeletons at this site. This post-mortem treatment and the AMS radiocarbon date 3A-7 (UOC-0422: 8043 ± 58 bp; 2 σ range and probability, 9092–8700 cal BP, 98.9%), confirm it as a Capsian burial (Jackes et al., 2015).

The original inventories of 3A-7 bones showed that the skull, tibiae, fibulae and right patella, as well as one distal pedal phalanx, were missing. There is, however, a fragment of the right patella among the material (and fragmentary phalanges no doubt represent digits of the hand, which have not been studied in great detail). It is likely that the feet and hands were in positions indicating that at least partial articulations of their joints were maintained, otherwise small bones might have been lost in the rushed excavation and lifting of the skeleton. There was one indication of partial dispersal of the left hand – the left 1st metacarpal (MC I), unlike all the other bones, had calcite crystals enveloping the shaft, contributing to an expansion and splitting of the bone cortex. Several bones of the feet also retain limited evidence of some calcite encrustation, suggesting that hand and foot bones had been grouped.

Sex and age

The sciatic notch indicates a male. The individual was adult, with fusion of all epiphyses. The vertebral end plates show fully adult status, without remnant billowing or indications of neurocentral fusion. The right pubic symphysis is complete, the left has breakage of the ventral edge of the lower half. From the Suchey–Brooks pubic symphyseal casts (Suchey, 1987), the match with a morphology approaching stage IV-2 is clear. On both sides there is remnant billowing on the distal half of the symphyseal face, the dorsal border is distinct, with a slight sharpening along the margin in the distal half. The superior third of the ventral portion shows a minimal hiatus in the ventral rampart. The iliac auricular surfaces are too damaged to allow extensive assessment.

Only the left fourth rib can be assessed for age change phase: the pit depth, taken at the centre point, is 3.8 mm dorsally and 5.4 ventrally, the pit being U-shaped with relatively sharp wall margins. The rims are gently scalloped with greater anterior topography (cf. Fanton et al., 2010). While the rib morphology was assessed as phase 3, at most phase 4, the vertebral appearance suggests that this individual would not be in his 20s (Loth and İşcan, 1989; İşcan et al., 1987), but at least in his 30 s (Salem et al., 2014). It will become evident that age assessment is not easy, especially in view of the absence of the dentition: the general bone quality does not suggest a man beyond early middle age.

The feet of 3A-7

Both calcanei have a bony projection superior to the anterior articular facet. This bony projection is not fused to the left calcaneus: it remains a separate fragment (Fig. 1, inset). The fragment was not broken post-mortem, but rather appears to have had a close soft-tissue attachment to the calcaneus. Some lipping at the margins of the calcaneus surface is evident, but there is no sign of a pseudoarthrosis between the fragment and the left calcaneus. Held as though it were articulated with the left calcaneus through a

Fig. 1. Left calcanei of 3A-7 and 3A-6, showing the abnormal superior anterior bone fragment in place on the 3A-7 calcaneus. The inset shows (at the same scale) the avulsed fragment, enlarged and reshaped by reactive processes, and the area of fibrous attachment on the anterior body of the 3A-7 calcaneus. Photo MP.

Fig. 2. Right calcanei of 3A-7 and 3A-6 demonstrating the position of the fused avulsed bone fragment on the anterior process of 3A-7. Photo MP.

fibrous connection, the fragment projected 14.29 mm from the calcaneocuboid articular surface on the proximal-distal plane and 20.09 mm on the medial-lateral plane.

The projection on the right calcaneus was fully fused. It measured 14.21 mm from the superior (dorsal) to inferior edge, 22.74 mm from the medial to lateral edge, and it projects 14.69 mm distally from the calcaneocuboid articular facet. The line of fracture between the calcaneus and the fragment is still patent inferiorly, with a heavy structure of callus built above it.

Figs. 1 and 2 illustrate the 3A-7 calcanei together with those of 3A-6, providing comparison with the most complete male calcanei from the Minnesota trench.

On the right superior calcaneus two grooves cross the projection (Fig. 2). From their orientation, the grooves must reflect the path of the calcaneocuboid portion of the bifurcate ligament. This portion should attach just beyond the articular margin of the calcaneocuboid joint on the dorsal surface of the cuboid. The ligament is deep to the extensors, digitorum brevis/hallucis brevis: since they also cross the projection, we can expect some contribution to the projection topography, because there will be an attachment just proximal to the anterior prominence. The extensor digitorum brevis gives rise to the four medial tendons to the middle and distal phalanges of digits 2, 3 and 4 (the large toe portion is the extensor hallucis brevis). We can expect there to have been some abnormality of locomotion because the extensors would not have functioned normally to dorsiflex the forefoot. A deep groove can be seen also on the left fragment, in the more lateral position, specifically suggesting the course of the calcaneocuboid portion of the bifurcate ligament.

The right cuboid is markedly more abnormal than the left, which has only slight lipping of the joint surfaces (Fig. 3). Both cuboids have a nodule of bone forming at the dorso-lateral border of the calcaneocuboid joint surface, but on the right the whole dorsal surface has abnormally developed bony projections and an extension of the proximal articular facet onto the lateral aspect of the dorsum. In fact, the calcaneocuboid articular facet has lipping and is abnormal in shape, the “beak” on the plantar aspect having become elongated (Fig. 3). The right cuboid dorsal surface has developed an articular surface, related to the inferior surface of the fused promontory fragment. Further, the dorso-lateral area just distal to the calcaneocuboid articulation has small nodules of bone within the area of the joint capsule where the fibularis brevis crosses to the base of the 5th metatarsal (MT V). The left cuboid has slight lipping in the area of the dorsal articulation with the calcaneus, but an articular facet had not developed as it had on the superior surface of the right cuboid, and the bone surface abnormality is minimal.

Both naviculars exhibit a limited degree of lipping of the articular margins: in both there is bony growth on the plantar surface, primarily in the region of the attachment of tibialis posterior, and on the right proximally, in the area of the plantar calcaneonavicular ligament (spring ligament). The right navicular (Fig. 3) has slightly more bony growth than the left, suggesting that the spring ligament's function in supporting the medial longitudinal arch of the foot may have been compromised.

Both 1st cuneiforms are present. The right has a small spicule just distal to the articular surface for the 2nd cuneiform. The corresponding region on the medial surface of the right 2nd cuneiform is marked by spicules of bone. These can also be seen on the left 2nd cuneiform which also has ossifications in the area of the attachment of the plantar intercuneiform ligament arising from the 1st cuneiform. The 3rd cuneiforms have an irregular articular facet on the medial side, a small spicule that projects medially from the articular surface for the 2nd metatarsals (MT IIs). On the distal surface of each 3rd cuneiform there is a pit near the plantar (inferior) edge (Fig. 4). The pit is 1.75 mm deep on the right 3rd cuneiform and 1.55 mm deep on the left.

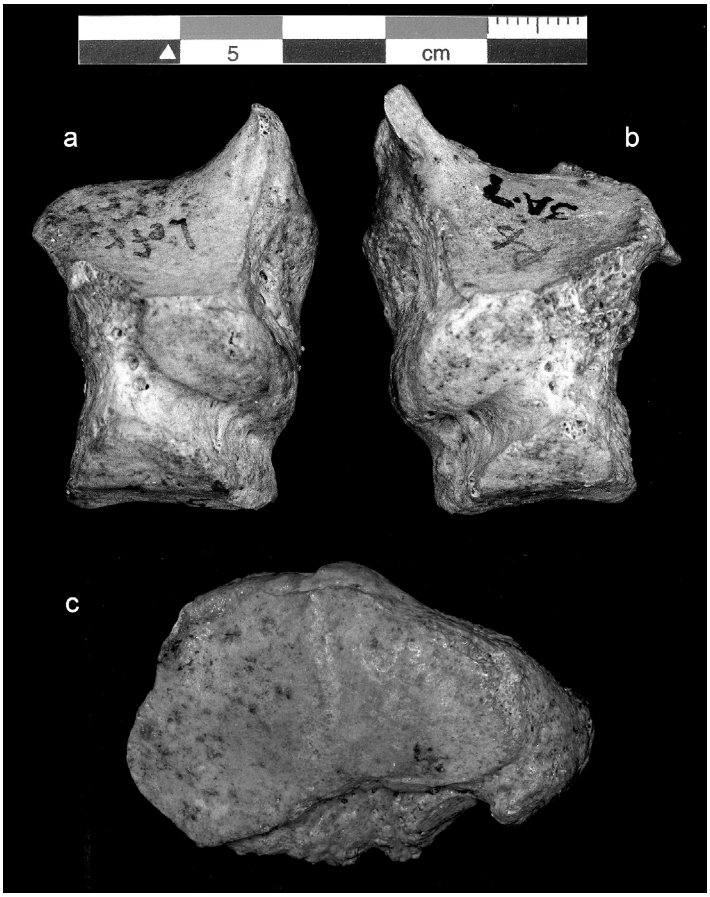

Fig. 3. Lateral view of left (a) and right (b) cuboids. The proximal surface for articulation with the calcaneus is at the top. The greater abnormality of the right proximal facet is evident, with a lipped "beak" forming an extension on the plantar surface. The abnormal bone and extension to accommodate the right fused avulsed projection can be seen on the dorsal surface of the right cuboid. Right navicular (c), distal view, shows reactive bone on the plantar surface (abnormal bone is visible at the very bottom of the image). Photo MP.

The 3rd metatarsals (MT IIIs, Fig. 4) each have an elongated proximal articular facet with bone growth towards the inferior (plantar) surface, and they also each have a pit that accords with the pit on the 3rd cuneiform in location and size. The pit is 1.09 mm deep on the right metatarsal and 1.86 mm deep on the left metatarsal. MT III is more anomalous on the left than on the right (Fig. 4). We will discuss the anomalous pits below.

The right MT I and MT II have no changes apart from a slight sharpening of the proximal articular surface margins. Nevertheless, the proximal 1st digit phalanx appears to have cystic destruction beyond the plantar margin of the proximal joint surface. MT III on the right, as pointed out above, is anomalous proximally, but not distally. MT IV has cystic destruction of the lateral portion of the head (Fig. 5). MT V, although without degenerative changes proximally, has gross alteration of the head: while there are subchondral cysts, the major abnormality is nodular new bone formation within the joint area, much of it with very fine porosity (Fig. 5). The right proximal 5th toe phalanx articular facet is broad, dished and irregular to accommodate the enlargement of the head of the 5th metatarsal (Fig. 5).

The left MT I has arthritic lipping distally, particularly on the plantar surface, but MT II has no marked abnormalities. The proximal right MT III is discussed elsewhere: distally the only abnormality is a pit on the dorsal surface of the shaft, just proximal to the head. MT IV and MT V appear normal.

The fourth metatarsals (MT IV) differ in length from side to side. The mean of multiple measurements taken four times over a five week period shows that the maximum dorsal length of the right was consistently 4 mm longer than the left. While the widths of the shafts appear different, no consistent differences in maximum and minimum shaft diameters could be demonstrated. Nevertheless, the right MT IV appears to have a broader shaft while the shaft of the left MT IV appears more angular and narrow.

In summary, the right and left calcanei have abnormal projections from the anterior process, the right fused, the left unfused. In association with the reaction on the cuboids, it appears that there is a pattern of abnormalities coinciding with the calcaneocuboid portion of the bifurcate ligament. A slight proliferation of bone can also be seen along the superior border of the naviculars, coinciding with the location of the calcaneonavicular part of the bifurcate ligaments. Further, the inferior naviculars have substantial amounts of additional bone along the attachment points for the plantar aspect of the calcaneonavicular ligaments.

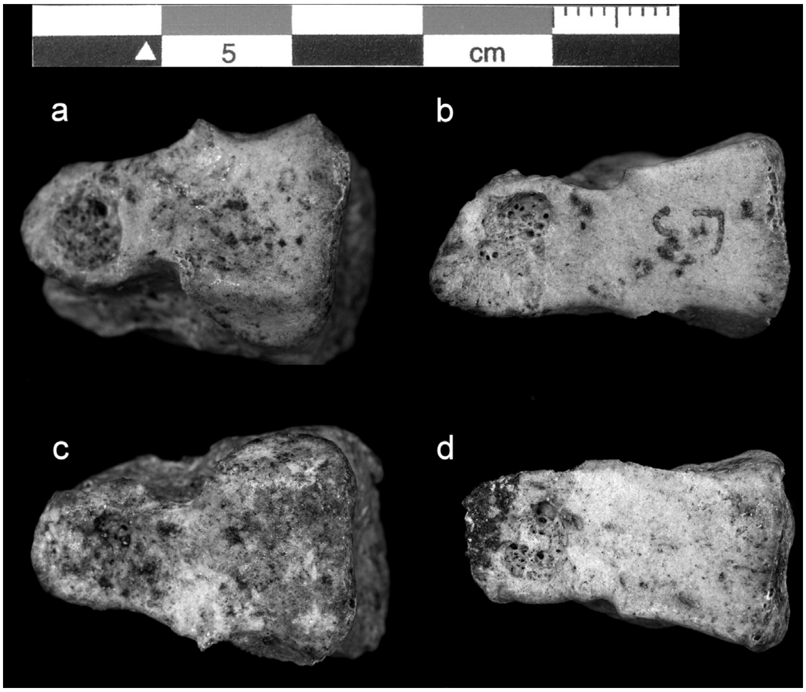

Fig. 4. Left 3rd cuneiform (distal view) (a) and MT III (proximal view) (b); right 3rd cuneiform (distal view) (c) and MT III (proximal view) (d). In each bone a pit occurs near the plantar (inferior) edge indicating cartilaginous coalition. Photo MP.

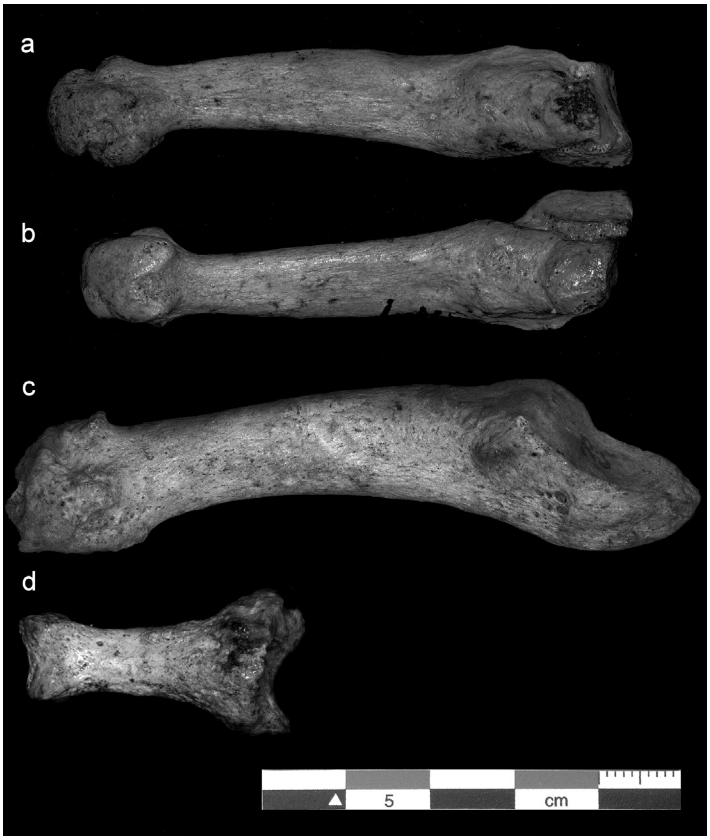

Fig. 5. The right (a) and left (b) MT IV, plantar view. The right MT IV is longer, appears more robust and has cystic destruction of the head, which does not fully explain the extra length. The right MT V (c) has normal proximal articular surfaces, but the head is again abnormal with cysts and nodular deformation of the articular surface. The right fifth digit proximal phalanx (d) articular surface for the MT V is also altered. Photo MP.

Suggested primary diagnosis

The calcaneocuboid portion of the bifurcate ligament provides stability to the lateral part of the foot between the calcaneus and the cuboid, while the calcaneonavicular portion, attaching just medial to the calcaneocuboid portion, provides a restraint on movement between the calcaneus and the navicular. Ligaments can be stretched or torn, partially or completely, and a ligament sprain can involve avulsion of a fragment of bone cortex. Thus stress placed on a ligament can result in failure of bone at the site of insertion, such that a portion of bone separates at the point of stress. The primary diagnosis for 3A-7 would be avulsion of the calcaneal anterior process as a consequence of sprain on the calcaneocuboid ligament. Instability of the calcaneocuboid joint and interference with the functioning of the extensor digitorum brevis would result.

Asymmetry between the two feet suggests that there was more weight-bearing on the left foot than on the right, initial trauma being perhaps greater on the right, involving perhaps an open wound over the lateral right foot, so that some early immobilization of the right led to union of the avulsed fragment. The fibrous connection of the left calcaneus and its avulsed fragment, the apparently heavier shaft of the left MT IV, the greater deformity of the proximal MT III articular surface, all suggest more weight-bearing on that foot.

Ossicles: rejected primary diagnosis

While bifurcate ligament trauma may be a primary diagnosis for the abnormality of the calcanei of 3A-7, we need also to consider the possibility of accessory bones. An accessory bone is "composed of normal spongiosa surrounded by a thin cortical shell [and] does not fit into a matching defect in an adjacent bone" (Freyschmidt et al., 2003:993). On this definition we may exclude accessory bones from our assessment of 3A-7, but it is necessary to consider one among the number (Mellado et al., 2003) of different accessory bones known, simply because many can be confused with avulsion fractures (Köse, 2012). We will limit our examination to the os calcaneus secundarius.

The os calcaneus secundarius is a small ossicle located along the edge of the anterior articular facet. It is not the most common accessory bone of the foot and ankle, and is without clinical significance, but radiologically it can be confused with an avulsion fracture of the anterosuperior calcaneal process (Mellado et al., 2003). The accessory bone appears during foetal life (Anderson, 1988:529) and is associated with a notch in the anterior calcaneal facet, which it joins through a ligamentous band (Mann, 1990:18; Hodge, 1999:308). Its presence in archaeological specimens may be recognized when the associated notch on the calcaneus is preserved: lacking that marker, the os calcaneus secundarius may be impossible to differentiate from other accessory bones (Anderson, 1988:529). In only one case has a "fused", or rather, incompletely detached accessory bone been observed, an example considered to prove the congenital or genetic origin of the variant accessory ossicle (Mann, 1990:23; Fig. 5).

Os calcaneus secundarius can generally be differentiated from a fracture by its continuous cortical surface, defined ovoid margins and the associated notch in the calcaneus: on these grounds the 3A-7 abnormality cannot be associated with the os calcaneus secundarius. However, while Yu and Cody (2009:317) state clearly that the accessory ossicle itself is completely surrounded by cortical bone, Mann (1990:18, 23; Fig. 2) illustrates the fact that the calcaneus below the anterior articular talar facet will show smooth, blunted trabeculae and that the medial margin of the ossicle will be roughened. Nevertheless, while radiographic discrimination between the os calcaneus secundarius and a fracture of the anterosuperior calcaneal process is difficult, this is not a problem with regard to dry bone since the ossicle occurs medially, in association with the anterior articular surface for the talus: reference to Figs. 1 and 2 shows that this joint surface is not associated with the abnormalities of the calcanei.

Further genetic or congenital variations

Would specific tarsal morphology pre-dispose to the conditions seen in 3A-7?

The anterior process, or promontory (Piatt, 1956), superior to the calcaneocuboid articular surface, may vary in length and robusticity (Renfrew and El-Khoury, 1985). Garvin and Rominger, (1957:470) note "a considerable variance in the degree of elongation and prominence" and state that "most patients" with calcaneal promontory avulsion "have a more prominent anterior process". Their sample, however, consisted of only 12 patients and no actual evidence was provided of this association.

It must be understood that the "too long" anterior process of the radiological literature, commonly referred to as the "anteater sign" (e.g., Brian and Mahraj, 2005:453; or "anteater nose", Pearce et al., 2011) is not seen on the area of the calcaneus with which we are concerned: it occurs on the anteromedial calcaneal process between the talus and cuboid (Lui, 2006:903.e1) towards the navicular (el Hayek et al., 2009:164). The "too long" process is related to an inherited condition of calcaneonavicular coalition which may be osseous (fusion of the process with the navicular), but can be non-osseous, that is, cartilagenous or fibrous. While tarsal coalition is itself rare, the calcaneus is involved in most cases, with non-osseous coalitions most common and often bilateral (Zaw and Calder, 2010:350). Silva (2011 illustrates a calcaneus demonstrating the clear difference between the condition in 3A-7 and calcaneonavicular coalition.

A further consideration might be calcaneocuboid non-osseus fusion, but the appearance of the cuboids rules this out as relevant to 3A-7. As discussed above, and illustrated in Fig. 3, the joint surface margins and the reactive bone on the dorsal surface of right cuboid body point to a condition quite separate from the type of joint surface anomalies seen with coalitions.

There are coalitions involving tarsals, however, which seem relevant to 3A-7. Surface defects on the articulating surfaces of the 3rd cuneiform and the 3rd metatarsal (MT III, see Fig. 4) can indicate coalition, with the incidence varying widely among populations (Silva, 2011; Table 3). The coalition can be osseous or non-osseous (cartilaginous or fibrous). The non-osseous coalitions can be recognized by an articular facet defect with one of several manifestations – a small pit, a crease and a small pit, or a large pit, and can sometimes result in the elongation or broadening of the articular facet (Regan et al., 1999). The condition is usually present bilaterally, though it can occur unilaterally without side bias. There appears to be no arthritic, infectious or traumatic basis to the defects and they are consistent in appearance and location, on the inferior (plantar) third of the articular facet. Regan et al. (1999) note that similar features were observed in the late 19th century in ten of 313 dissections, identified as "non-osseous coalition". Skeleton 3A-7 (Fig. 4) displays a pit bilaterally on both the 3rd cuneiform and MT III, suggesting cartilaginous coalition.

Could the calcaneal abnormalities suffered by 3A-7 have been caused initially by the bilateral tarsal/metatarsal coalition? Stevens and Kolodziej (2008) have shown that 3rd cuneiform-MT III non-osseous coalition can be a trivial condition without clinical significance, and Day et al. (1994) have described a case in which unilateral osseous fusion was likewise completely asymptomatic. The situation might be different for an individual lacking the support of modern shoes and modern smoothed walking surfaces. While the location of the burial site is in a wide valley, the Capsian hunter-gatherers might have engaged in some form of transhumance (Lubell et al., 1976) and could have moved into the rocky shelter of mountains in the winters, to Djebel Sidi Reghis not far to the west or to high land around Djebel Amamat el Kebir to the south-east of the site.

Trauma

Sprains

We have no particular reason to consider that disability was related to any prior congenital abnormality in 3A-7. There may, however, have been earlier minor trauma which predisposed to major problems.

Instability of a joint can result from trauma to a ligament, when stretching is involved. Weindel et al. (2010), tested the feet of cadavers to determine how injury to the ligaments could result in a greater range of motion possibly predisposing the individual to further trauma to that ligament. They found the increased ability to plantarflex and dorsiflex with the dissection of the bifurcate ligament was significant compared to the range of movement prior to dissection. This predisposition to further injury can result in repetitive trauma over an individual's lifetime. Konradsen et al. (2002) found that recurrent ankle sprains occur in 11% of all patients who had suffered inversion injuries of the ankle, including sprains and "small avulsion fractures" (less than 5 mm). Thickening of the ligament can result from injury and can predispose to fractures (Choudhary and McNally, 2011; Petrover et al., 2007).

Fractures

Fractures of the calcaneus relevant to a study of 3A-7 are those termed "extra-articular fractures" – any fractures that exclude the posterior articular facet (Daftary et al., 2005). We can exclude from consideration, for example, falling straight down from a height and landing directly flat on the feet, which can result in bilateral calcaneal defects, because that type of fall is a common cause of intra-articular fractures (Karasick, 1994).

Extra-articular fractures of the calcaneus include ligament avulsion fractures and nutcracker or compression fractures of the cuboid. These fractures account for approximately one third of all fractures that affect the calcaneus in a clinical setting: in a study of 140 patients, 49 had suffered extra-articular fractures, all but one unilateral (Schepers et al., 2008). Of these, 19 were anterior process fractures, eight were extensor digitorum brevis avulsion fractures, and eight were tuberosity medial process fractures (Schepers et al., 2008).

The extensor digitorum brevis attaches to the calcaneus on the anterior process, just lateral to the bifurcate ligament (Karasick, 1994:169). If the foot is forcefully inverted, an avulsion could occur and it is difficult to differentiate between this fracture and the avulsion fracture of the bifurcate ligament (Schepers et al., 2008). The resulting fragment from the extensor digitorum brevis avulsion can also be confused with the os peroneum (Yu and Cody, 2009), an accessory bone lateral and plantar to our area of interest. In fact, these diagnostic difficulties arise in clinical and radiological settings and they are not relevant to 3A-7 in whom no abnormalities of the lateral calcanei are evident.

Compression or nutcracker fractures are rare (Petrover et al., 2007) and can be excluded in the case of 3A-7, even though the result can be the separation of a bone fragment, up to 15 mm by 22 mm in size (Robbins et al., 1999), often larger than the fragment that results from a bifurcate ligament avulsion fracture (Yu and Cody, 2009). However, both cuboids in 3A-7 have retained their full physiological length (Fig. 3) and show no sign of forceful compression.

Our diagnosis is, then, a bifurcate ligament avulsion, alternative diagnoses having been ruled out. These avulsion fractures often involve the forceful inversion and plantarflexion of the foot (Daftary et al., 2005; Karasick, 1994; LeBlanc, 2004; Lui, 2011; Robbins et al., 1999; Schepers et al., 2008). A small fragment of the calcaneus, where the bifurcate ligament attaches, can avulse and this fragment, averaging 12 mm in length and 19 mm in width (Robbins et al., 1999), can persist in up to 40% of sufferers if not treated properly (Schepers et al., 2008). The increased interest in this fracture, now more common in women, can be attributed to the position in which the foot is held while wearing high-heeled shoes (Hodge, 1999; Ouellette et al., 2006). Because of the association with modern footwear or particular athletic activities it is very unlikely that a situation comparable to that in 3A-7 would be reported, and indeed literature on a comparable bilateral bifurcate ligament avulsion has not been found. Barefoot climbing on rocky slopes, with the feet slipping down between two rocks is the envisaged scenario.

Sequelae

In clinical practice, the injury presents with a specific location of pain, just above the half way point between the tuberosity of the base of MT V and the lateral malleolus, but has often been misdiagnosed as ankle sprain (Degan et al., 1982). Thus, the literature can give some limited insight into the complications of individuals who have suffered these fractures without immediate treatment. In many cases, disability is described (Pillai et al., 2005; Yu and Cody, 2009). The injury often presents with an inability to bear weight on the affected foot, but in some individuals there may be a few hours delay after the injury before a sudden onset of inability to bear weight (Hodge, 1999; Pillai et al., 2005; Ouellette et al., 2006). Immobilization and non-weight bearing for an extended period is often sufficient treatment, and might have been possible for 3A-7 since the fragments were not displaced: had they been, the situation would have been much more serious (Trnka et al., 1998).

Since 3A-7 appears to have suffered an undisplaced avulsion, the calcaneocuboid joint was not destroyed by early arthrosis, but the injury was not trivial. The joint is an important part of the mid-tarsal (transverse) structure which has a “crucial role in the balance and stability of the foot” (van Dorp et al., 2010:541). Nielsen et al. (1987) note the important contribution of the bifurcate ligament to the stability of the lateral foot. Nevertheless, Piatt (1956), in reviewing several cases, considered that the disability was not very significant, even when there was non-union. Of course, for a Capsian individual, without stabilizing footwear, dependent on foraging for subsistence, in an environment where long-distance walking was probably necessary and in which short distance walking over uneven surfaces would have been constant, the pain may have been considerable. The pathological changes to the heads of the right MT IV and V (Fig. 5) would alone have caused great discomfort. It is evident that traumatic changes have occurred to both the left and right metatarsals, with major deformity to the right, accompanied by infection, but the area of the proximal dorsal MT IV associated with the passage of the appropriate extensor digitorum brevis tendon is also unusual.

Evidence for at least one traumatic episode

There is very good evidence for at least one major traumatic episode, leaving Skeleton 3A-7 with multiple injuries and a degree of long term disability and significant arthritic changes in the lower spine and in the right elbow.

Asymmetry is notable in the clavicles: the right clavicle is narrower (right mid shaft maximum 12.91 mm vs 14.55 mm on the left, measured at the lateral end of pectoralis major attachment), giving an impression of reduced robusticity on the right. The left clavicle is normal, but with strong muscle markings at the deltoid attachment and particularly for the costoclavicular ligament. Rani et al. (2011) have reviewed the surface anatomy of the costoclavicular area on the clavicle and noted that handedness is most likely to be correlated with a rhomboid fossa – that is, a depression at the attachment point on the clavicle – but in the case of 3A-7, we have rough elevated attachment areas, minimal on the right and extremely large on the left. The area of the left costoclavicular ligament insertion appears to be unusual (cf. Rogers et al., 2000: Fig. 2B), large, without a depression, but broadly scattered with small pits.

On the medial right clavicle, deep scallops in the antero-inferior margin of the costocartilagenous joint are associated with the large pits and nodules characterizing the medial joint surface (Fig. 6). Variations in the sternoclavicular discus (Barbaix et al., 2000) cannot provide a full explanation for what we see: it is likely that the alteration to the medial end of the 3A-7 right clavicle occurred before full fusion was complete. Partial union is achieved in all males by age 25 and complete union before age 30 (e.g. Cardoso, 2008): Skeleton 3A-7, with all observable long bone epiphyses completely fused, was certainly fully adult. More importantly, not only was vertebral ring epiphyseal fusion complete, but any sign of the neuro-central synchondroses and the billowing topography of the end plates had long been obliterated. The acromial end on both right and left clavicles has the normal adult appearance. We can suggest, therefore, that the traumatic event occurred by about the mid-twenties and many years before death. As Peterson (2007:750) notes “physeal fracture may occur in the twenties”, that is, disruption of the area between the metaphysis and the epiphysis may occur very late in comparison with other bones. Such a degree of disruption of the medial end of the clavicle requires strong impact because of the “ligamentous constraints of the joint” (Robinson et al., 2008:686): the irregularity of the anterior medial end of the right clavicle could have resulted from a very heavy blow to the right shoulder. An explanation of trauma as the cause of the unusual surface is strongly suggested by the sternum itself.

Unfortunately, the manubrium is incomplete (the cranial portion of it represented only by fragments). We have four sternal bodies, but the fourth is truncated and deformed: the body appears complete on the left side, but on the right, the notch for the 6th costal cartilage is abnormal. The lower portion of the costal notch is absent, together with half the body (Fig. 7). Whether the anomaly is the result of trauma or of a developmental defect cannot be definitively stated: we cannot rule out an anomalous fourth sternal body, but the large range of variants illustrated by Barnes (2012) does not reflect the apparent disruption to the third/fourth body alignment or the partial cleft. The xiphoid was not found among the curated bones.

The ribs are not markedly abnormal, apart from the left first rib which has extensive ossification into the costosternal cartilage (the length of cartilage ossification is 13.25 mm). The ossification is cranial, and is nodular anteriorly. There is limited evidence of similar ossification on the right. This indicates specific strains on the left upper body: costal cartilage calcification can occur in males before middle age in response to stresses on the thorax (Barchilon et al., 1996). The abnormality of the costoclavicular ligament attachment on the left clavicle should be considered in association with the ossification of the costal cartilage on the left first rib, to which it attaches. Both first ribs, especially the left, have marked scalene tubercles for the insertion of the scalenus anterior (Fig. 8), perhaps indicating that the head and neck were held flexed and slightly rotated to the right. A further indication of possible abnormal posture of the head and neck comes from localized ossification of the posterior longitudinal ligament at C.7. Unfortunately, C.6 was damaged but the superior central canal margin was probably slightly altered. Our best evidence of disruption at C.6–C.7 comes from the unusual conformation of the superior uncinate process of the uncovertebral (Luschka’s) joint which is seen most clearly on the

Fig. 6. Two views of the right clavicle showing the abnormality of the right medial joint surface. The cut mark is a result of postmortem bone manipulation (see also Haverkort and Lubell, 1999: Fig. 16). The scalloped joint margin is angled up from the well marked pectoralis major attachment area. Pectoralis major lies along the antero–inferior portion of the clavicle. The posterior continuation of the joint surface displays a break, probably from 1930. Fig. 6 inset is marked to delineate the two views of the same irregular margin above the pectoralis major attachment area. The sharply angled surface beyond the margin is truncated by the break in the bone which is shown by hatching. Photo DL.

Fig. 7. Composite image of the sternum, anterior and posterior views, with a lateral view of the right side showing the defect of the fourth sternal body. Photo DL.

Fig. 8. Comparison of the first ribs, inferior view. The larger scalene tubercle on the left for insertion of scalenus anterior and the ossification of the cartilage at the medial end are notable. Photo DL.

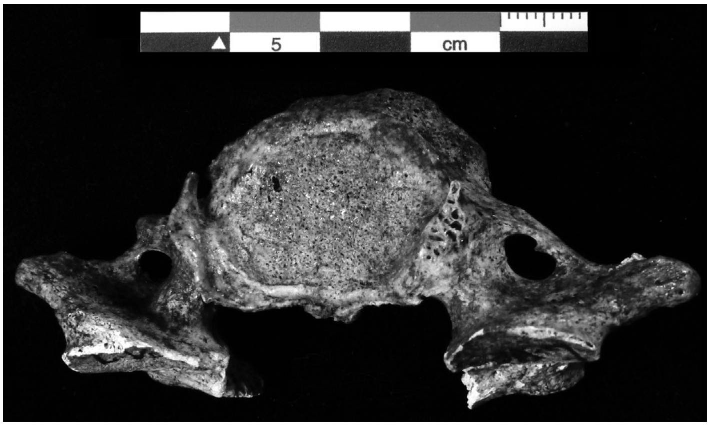

Fig. 9. The unusual left uncinate process of C.7 is clearly seen, with arthritic lipping above and posteriorly and a ventral extension to the joint surface. The right is similar, but broken, so that the degree of abnormality cannot be judged. There is some ossification into the posterior longitudinal ligament. Photo DL.

undamaged left side of C.7: the uncinate process has an anterior projection (Fig. 9).

The thoracic vertebral bodies show evidence of Schmorl's nodes, most strongly in the region of the 4th to the 7th thoracic vertebrae. The endplate damage is especially severe on the inferior central surface of T.5 and the superior body of T.6 (Fig. 10), with deep anterior-posterior nodes. Detailed studies show that this sagittal noding, especially in the superior centra, is exceedingly rare at this level of the thoracic spine (Jackes, 1977, 1988). The central and anterior-posterior noding on the vertebrae, with indications of (non-osteoporotic) compression to the anterior superior T.3 and T.4 centra, suggest trauma resulting from a fall: the compression of the superior left side T.7 body supports this. The transverse process costal facets on T.9 have arthritic changes, with marked abnormality on the left: the facets on the left 9th rib are also altered (the head of the right rib is missing). Unfortunately, the lumbar vertebrae are very broken, but the surviving fragmented lumbar centra have strong osteophytic changes. The 5th lumbar osteophytes are very marked for such a young individual.

Evidence for a fall comes especially from the right ulna and radius. The coronoid process of the right ulna displays an anteromedial oblique fracture and the lip of the coronoid process above the prominent area for the insertion of the ulnar collateral ligament (the anterior portion) is very arthritic. Arthritic lipping is greatest in the area of the sublime tubercle, the antero-medial aspect of the coronoid process. The right radial head suggests a depressed fracture of a portion of the head, the radial notch of the ulna (Fig. 11) displays a marked abnormality. We could posit a varus posteromedial rotational injury force, caused by a fall onto the hand such that the humerus was forced down onto the ulna, resulting in the elbow being pushed medially. The right distal humerus has marked changes to the margins of the articular surfaces: the lipping is in the form of a thickening of the margins, rather than sharpening of the edges of the joint surfaces (Fig. 12).

The left radius and ulna proximal portions have postmortem damage but there is minimal arthritis on the left distal humerus.

Fig. 10. T.6 superior view of the centrum. The anterior posterior Schmorl's node is very deep. Photo DL.

However, there was some abnormal stress on the left arm because the area of the origin of the posterior portion of the medial collateral ligament is represented by a process on the distal surface of the left medial epicondyle (Fig. 12). Since the left olecranon process is missing, the distal attachment, the insertion, of the ligament on the ulna cannot be observed clearly. We might envisage unusual elbow movements such that long-term and specific stress was put on the left elbow. Morrey (2012) shows that the posterior portion of the medial collateral ligament is active, providing stabilization, during flexion.

Walking aid?

The strong muscle marking of the left clavicle and the calcification into the costosternal cartilage of the left first rib may be associated with abnormal posture and locomotion and could be related to the use of an aid to walking, taking some weight off one foot. The evidence points to the left foot having been the primary weight bearing foot, whether or not a walking aid was used.

In general, we have indications of a major episode of trauma as a young adult. The right elbow appears to have suffered severe trauma. The right distal sternal body was also apparently injured. The right clavicle is abnormal medially. While more weight bearing on the left foot would suggest a walking aid of some sort used on the right, the right elbow trauma (with some possibility of dislocation as in the "terrible triad injury", Mathew et al., 2009), makes it highly unlikely that any type of stick or pole would have

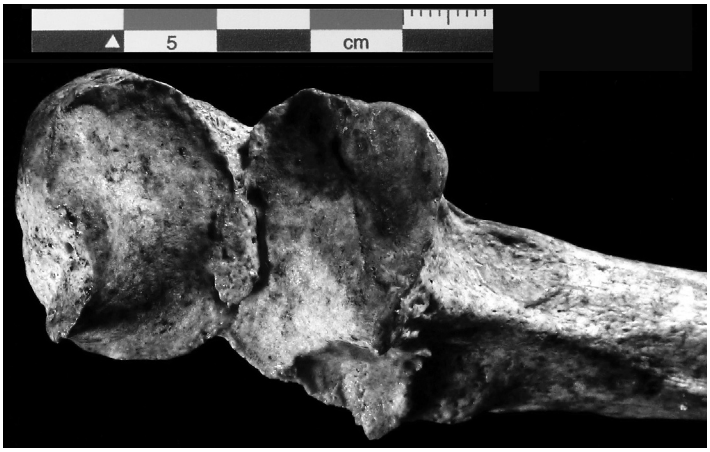

Fig. 11. The right proximal ulna, showing disruption of the joint surfaces at the radial notch and the coronoid process and arthritic changes in the trochlear notch. The attachment of brachialis is strongly marked below the coronoid process. Photo DL.

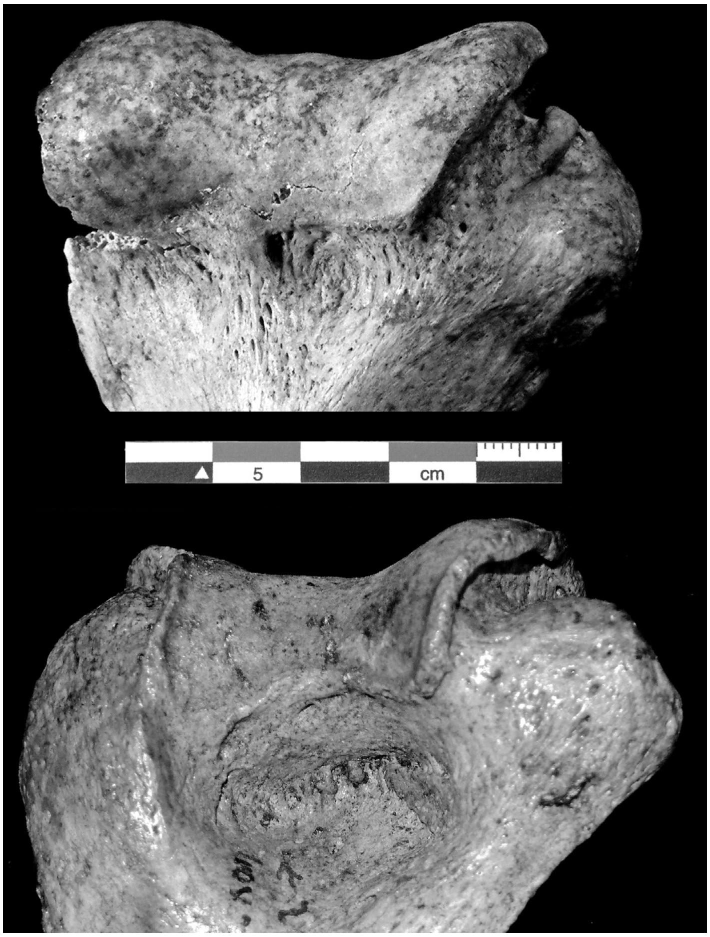

Fig. 12. The distal left humerus, anterior view, with a large bone spur on the medial epicondyle and (below) posterior view of the distal right humerus showing changes to articular margins. Photo DL.

been used exclusively on the right. Weight bearing on the left leg with a pole held in front and, more often, to the left would lead to strong asymmetry in stance and locomotion, and this is supported by evidence of asymmetry in the long bones. The left femur had a very high pilastric index in comparison with the right (Table 1). This indicates that the right femur shaft was a rounded bone with lesser strength under bending stress, while the left femur had a high index, indicating a stronger triangular shape at the mid shaft, with a robust pilaster. Since the femora are incomplete, care was taken in measuring, beginning with exact comparison of the length of the shaft itself (maximum and physiological femoral lengths cannot be taken). Because the right femur now has very slight splitting of the anterior shaft surface, avoiding the area with splitting was important, but the measurement point could be placed at exactly the 50% point of the area of the shaft itself: the bones were aligned on an osteometric board allowing accuracy to one millimetre. The measurements were taken 12 times in 2014, in three separate sessions, then averaged. When the last three sets of measurements were

Table 1
Measurements of the femora (mm) taken in 1935 and in 2014. %DA refers to the percentage difference of right from left, the antero-posterior values on the left being the greater.

Measurement	Wilford 1935		Jackes 2014		%DA
	Right	Left	Right avg.	Left avg.	
Midshaft AP	31.5	32.5			
Midshaft transverse	30.0	29.0			
50% AP			31.5	32.6	−3.59
50% transverse			30.0	28.2[a]	5.88
Pilastric index of average values	105.0	112.1	105.1	115.6	−9.48

[a] Sample standard deviation = .028.

taken, it was noted that they were placed almost exactly on a pencil mark which must have been placed by Wilford when he described the Site 12 skeletons (Wilford, 1935). Table 1 indicates that the right diaphyseal breadth is greater. In fact, the %DA values ($(R - L)/(R + L/2) * 100$) suggest that there is an unusual asymmetry in Skeleton 3A-7: Auerbach and Ruff (2006 Table 3) found that the mean asymmetry of the femoral midshaft diameter was 0.39%, 3.55% for humeri and 2.33% for radii (in a world-wide sample of 514 males). The pilastric index (mid AP/TRA) * 100) is particularly notable for the side discrepancy: the high index on the left indicates greater bending and torsional stress.

Beyond the asymmetry in the femora, we have even greater asymmetry in the humeri. Five different dimensions were taken at the humeral midshafts, each one three times, after experimenting to establish the consistency of the method. All dimensions were greater on the left, by 6.2–7.8%, and the discrepancy was as high as 10.6% when the humerus transverse measurement was taken strictly in the plane of the distal articular surface. Similarly the 50% shaft length transverse dimensions were greater on the left radius, and especially on the left ulna (7.85% greater). The left clavicle maximum diameter was 11.95% greater than the right. It seems clear that the right arm would not have been preferentially used with some form of walking aid.

We envisage a pole held so that the left elbow was in flexion, with particular stress being brought to bear on the posterior collateral ligament when the pole moved lateral to the body, so that stabilization of the left elbow was required. The well-marked area for the insertion of the anterior portion of the ulnar collateral ligament may suggest that the right arm could have been used, together with the left, to hold a pole and this is supported by the strongly marked distal attachment of the brachialis tendon, medially on the ulna below the coronoid process. Brachialis is a major flexor of the elbow. The attachment area for the pectoralis major on the right clavicle, which would act in flexing and adducting the right upper limb, also suggests such an action. Major weight would no doubt have been born by the left arm, but the right could be rested by holding onto a pole. Consistently holding the right arm adducted and flexed would no doubt provide protection and reduce pain in the elbow joint.

Discussion

The skeleton 3A-7 displays multiple abnormalities: the most unusual are abnormalities in the feet, especially of the calcanei. We interpret these as arising from trauma to the bifurcate ligaments which caused avulsion fractures of the anterior processes of the calcanei, with subsequent union of the avulsed fragment on the right but non-union on the left. The calcaneal fractures are likely to have occurred in a stumbling fall, perhaps between rocks, with the feet rolling inwards and pointing down (inversion and plantar flexion of the feet): at the same time there were other traumatic changes to the skeleton, especially related to falling on the right arm and shoulder. The calcaneal condition, and the asymmetry of the sequelae of the trauma, also led to long bone asymmetry, the result of locomotor difficulties.

The left avulsed calcaneal fragment which did not reunite was probably not displaced. Tarsals, metatarsals and phalanges display varying asymmetries, deformities and degenerative changes. The whole scenario suggests greater trauma to the right foot and subsequent weight bearing more on the left than on the right foot.

It seems likely that the right side of the body was compromised and that the left had more stress placed on it, perhaps in association with a pole used predominately in the left hand to assist in locomotion. The right clavicle is less developed than the left in terms of shaft size and muscle marking. The right sternoclavicular joint was abnormal. The right side of the distal sternum was deformed and there had been major trauma to the right elbow. Forces operating on the left side of the body are indicated by ossification of the left first rib cartilage, the high pilastric index on the left femur, the greater transverse diameters of the left clavicle, radius, ulna and humerus, and the indication of great stabilizing tension on the posterior ulnar collateral ligament origin on the left distal humerus. We envisage that the major traumatic event, a fall onto the right arm and shoulder, initiated by avulsion fracturing of both calcanei, occurred one to two decades before death.

Acknowledgments

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