Marathon Man: Evidence of Stress Fracture in a *Homo antecessor* metatarsal from Gran Dolina site (Atapuerca, Spain)

Laura Martín-Francés[1], María Martinón-Torres[1], Ana Gracia-Téllez[2,3], José María Bermúdez de Castro[1].

1. National Research Centre on Human Evolution (CENIEH), Paseo de la Sierra de Atapuerca s/n, 09002 Burgos (Spain).
2. Universidad de Alcalá, Facultad de Ciencias, Dpto. de Geografía y Geología (Área de Paleontología), Alcalá de Henares (Spain).
3. Centro Mixto UCM-ISCIII de Investigación sobre Evolución y Comportamiento Humanos. Monforte de Lemos 5, Pabellón 14, 28029 Madrid (Spain).

INTRODUCTION

Periosteum covers the cortical bone and is involved in maintaining bone formation throughout life. Bone formation can be physiological, as seen in juveniles, or pathological, as a response to tissue injury. Periosteum function is of crucial importance during healing processes with the formation of new bone (Marks and Odgren, 2002). Studies have shown that bone responds to different insults in the same manner (e.g., Schultz, 2003). This lack of specificity makes of periosteal reaction one of the most recorded conditions in archaeological and fossil collections. The type and location of the lesions may help reconstruct subsistence activities, locomotion habits or occupational activities in past and recent populations (e.g., Skinner, 1991; Villotte et al., 2010).

Here we present the paleopathological study of a 4th right metatarsal -ATD6-124- (Fig.1), assigned to the Early Pleistocene *Homo antecessor* species from Gran Dolina-Atapuerca site.

METHODS

In addition to the macroscopic technique, we included two microscopic techniques -microtomography (mCT) and scanning electron microscope (SEM)- to describe the lesion and to diagnose the most likely aetiology. The fossil was scanned with mCT (mCT 80, Scanco Medical) at 70 kV, 140 mA and isometric voxel size= 30 mm3. The image stack was imported into AMIRA software to observe the inner structure and reconstruct a 3D model of the fossil. SEM (FEI, model Quanta 600) was used to characterise the texture of the lesion.

RESULTS

Periosteal lesion. The dome-shaped lesion is highly focal, covers almost entirely the medial aspect of the diaphysis and has created a protuberance on the bone surface. Its dimensions are length 25.8 mm, width 8 mm, and a maximum thick value of 2.5 mm. SEM images revealed a highly porotic and disorganized morphology, identified as woven bone. This morphology would correspond with Rana's (2009) classification as thick irregular or class C periosteal reaction (Figs. 1 and 2).

Cortical lesion. The mCT images revealed disruption of the cortical bone restricted to the medial surface. On parasagittal 2D sections we identified a series of transverse and radiolucent lines (microcracks) that penetrate 2.2 mm into the bone, and a radiolucent area of 12 mm located 40mm from the proximal epiphysis (Fig. 2).

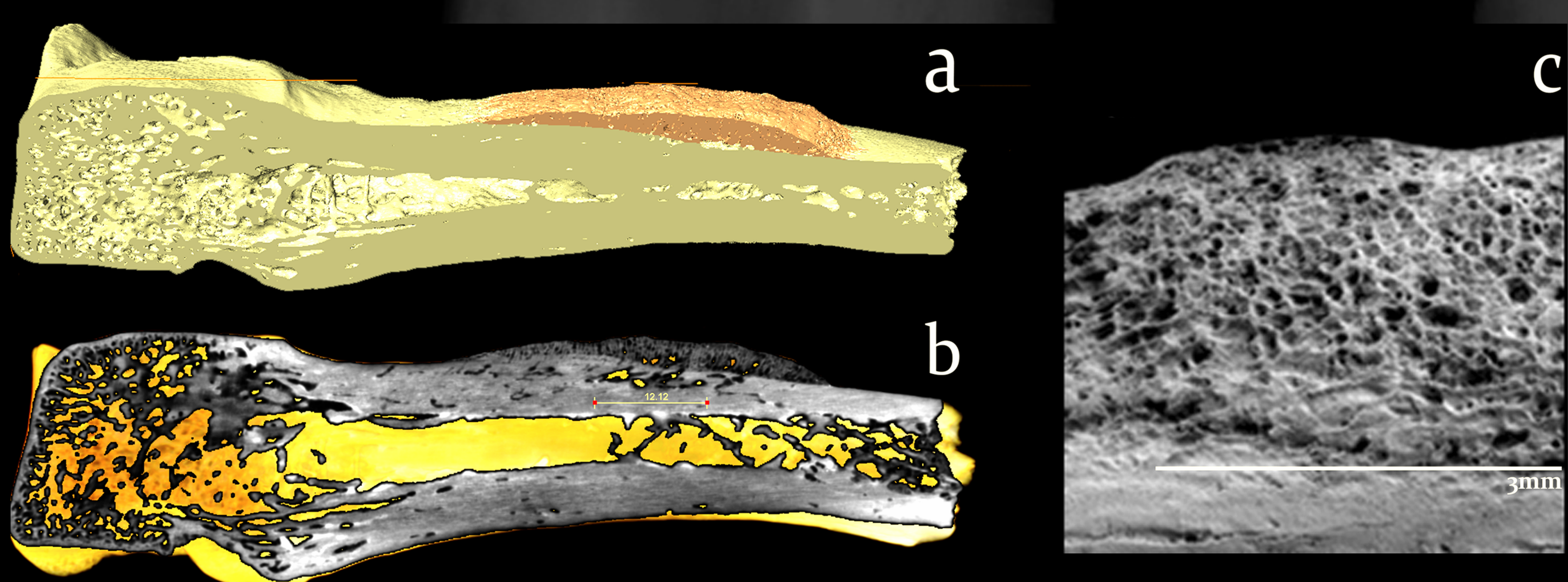

Fig. 2. ATD6-124. 3D reconstruction (a) -cortical bone in yellow and osteoblastic lesion in orange-. Parasagittal 2D section (b) showing the area of periosteal discontinuity(12mm). SEM image (c) porotic texture of the lesion.

DIAGNOSIS: STRESS FRACTURE

Fracture is a type of trauma and consists of the disruption of the bone structure, normally involving the adjacent tissues. In maturity bone is in continuous remodelling, osteoclastic cells produce resorption and, subsequently osteoblasts enhance the formation of new bone. Physical activity has been shown to strengthen the bone. However, strenuous, excessive and/or continued stress during the phase of osteoclastic activity could produce imbalance in the remodelling mechanism making the bone more prone to fracture (e.g., Ruohola, 2007).

A metatarsal ***stress fracture*** corresponds to an indirect fracture (Hawkins, 2005), and it would be the consequence of repetitive forces (e.g., Anderson, 1990; Arangio et al., 1998). The application of stress, namely repetitive forces and load, would cause microcraks on the bone surface. If the stress is maintained microfractures will develop into a transverse fracture (e.g., Ruohola, 2007). Stress fractures are commonly incomplete, the healing process usually leaves no trace of the fracture and there is a perfect bone alignment. Thus, its diagnosis relies on the identification of other signs such as inflammation, bone turn-over and callus formation (Anderson, 1990). We consider stress fracture the most likely cause of the ATD6-124 lesion. The identification of microfractures, the lack of medular involvement and the bone remodelling would be signs in favour of this diagnosis. In addition, the location of the micro-fractures coincides with the weakest point of the metatarsal shaft according to Arangio (1998).

Fig. 1 ATD6-24. Dorsal (a) and medial (b) views. Lesion localized on the medial aspect of the 4th right metatarsal.

DIFFERENTIAL DIAGNOSIS

We provide a differential diagnosis and suggest a likely aetiology for the ATD6-124 lesion.

The lack of signs related to infectious processes -medullary cavity involvement, cloaca and sequestrum- as well as the type of new bone formation allow us to discard ***infection*** as probable cause. We ruled out ***skin ulcer*** since the area is not in direct contact with the skin (Ortner, 2003).

We consider that the lesion could not correspond to a ***tumorous formation***. We discarded: **a. Osteolytic tumours** since ATD6-124 lesion is of osteoblastic nature. **b. Osteoblastic tumours: b.1. Osteosarcoma**, because the trabecular and the medullary canal are not affected in ATD6-124. **b.2. Ewing's sarcoma**, since the metatarsal does not present radiant bone spicules. **b.3. Osteomas**, because of the histological nature of it (dense lamellar bone), location (preferably on the skull) and appearance (polished ivory-like button) does not match the ATD6-124 lesion. **b.4. Chondrosarcoma**, it develops on the metaphyseal area of long bones and it is of nodular morphology (Ortner, 2003).

Suresh (2011) published the case of a 4th metatarsal periosteal reaction due to a palm thorn. He observed osteolytic reaction, where the thorn was embedded, and osteoblastic on the opposite surface. Despite the similarities between this and ATD6-124 case -same bone element, periosteal new bone formation, and the lack of infection signs-. We have not observed any major osteolytic lesion that would be the main sign to support the ***exogenous corpus hypothesis.***

We consider ***Hypertrophic Pulmonary Osteoarthropaty*** unlikely because rarely affects metatarsals, the new bone forms along all surfaces of the diaphysis, even extending into the metaphysis of the bone (Ortner, 2003).

CONCLUSION

We conclude that the lesion displayed by ATD6-124 corresponds to a stress fracture. The lesion would be at the stage of bone turnover from woven to lamellar bone that is, in the process of callus formation. Stress fractures are the consequence of load demands, muscular fatigue or a combination of factors (e.g., Anderson, 1990; Arangio et al., 1998). Stress fractures were first described in soldiers (Leveton, 1945). Nowadays its incidence has increased due to fitness popularity and to marathon races. This type of continued, prolonged and strenuous activity puts in risk the integrity of the bones, especially of the lower leg. The tibia counts with the 55% of the fractures and the metatarsals with 23% (Hartmann, 2011). Recently Pablos et al., (2012) suggested that the morphology of the *H. antecessor* left talus (ATD6-95) could be associated to an increased body mass, higher biomechanical demands and great robustness. The stress fracture in ATD6-124 metatarsal implies a failure in accommodating the forces that was receiving. This could be in turn related to a poor anatomical adaption, flat-footedness defect or specific locomotive practices, which may imply high levels of repetitive stress (e.g., O'Brien et al., 2003). Due to the scarcity of pedal fossil remains we cannot determine if the stress fracture is the consequence of these conditions, as suggested by some authors (e.g., Queen et al., 2009).

As hypothesised for non-human primates and other hominin species pathological events can reflect behaviours (e.g., Lovell, 1991; Skinner, 1991; Gardner and Smith, 2006). For instance, the musculoskeletal markers observed in Neanderthals might indicate stress due to locomotion over hilly terrain (Gardner and Smith, 2006). We believe that the *H. antecessor* metatarsal fracture was related to muscular fatigue or increased load to the metatarsal heads (e.g., Anderson, 1990; Arangio et al., 1998) due to prolonged and continued walking/running. Moreover, the hilly terrain would increase the risk of lower leg lesions.

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