Title: Evidence of trauma in a *ca.* 1 million Year Old patella of *Homo antecessor,* Gran Dolina-Atapuerca (Spain).

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Abstract

We present the palaeopathological study of a left patella (ATD6-56) belonging to Early Pleistocene species of *Homo antecessor* (Atapuerca-Gran Dolina, Spain). The abnormal morphology observed in the inferior margin of the patella corresponds to an osseous overgrowth (osteophyte). Macroscopic and microscopic techniques, including microtomography and zoom stereomicroscope, were employed to describe the lesion. Externally, the osteophyte presents a smooth and porous texture; the limit between the more radiolucent osteophyte and the normal bone can be identified in the X-ray images. We suggest that the observed signs could be secondary to a local trauma. The lesion would have involved either the bone or related soft tissues of the left limb possibly affecting the stability of the joint. Consequently, the individuals' knee would have suffered an abnormal mechanical load that could have eventually triggered osteoarthritic changes. This is also supported by the lack of changes observed in the associated right patella (ATD6-22).

Introduction

Osteoarthritis (OA) changes including marginal osteophytes, subchondral cysts and eburnation, related to either degenerative or traumatic events (Auderheide and Rodríguez-Martín, 1998a; Ortner, 2003a; Waldron, 2009) have been widely reported in the fossil record.

The oldest examples of OA in the fossil record are those from the Pliocene *Australopithecus afarensis*, specimens AL-333w-12 and AL-333-51 (Cook et al., 1983), and *Homo ergaster*, specimens KNM-ER 803 and KNM-ER-164 (Day y Leakey 1974).

The number of OA cases documented for the Pleistocene is high. Pelvis 1 from the Middle Pleistocene sample of Atapuerca-Sima de los Huesos (SH) presents signs of OA -extensive osteophytes- in the spine. Bonmatí and colleagues (2010) related the changes to degenerative kyphosys. Osteoarthritic changes are also frequent in Neanderthals (e.g., Dawson and Trinkaus 1997; Gardner and Smith 2006; Trinkaus 1983a,b). In this species, the development of OA has been related to local factors, most likely of traumatic origin to the bone or related soft tissues. Within the Shanidar skeletal assemblage, various individuals are affected by degenerative conditions such as the postcranial skeleton of Shanidar 1, 3 and 4 (Crubézy and Trinkaus 1992; Trinkaus 1983a,b). La Ferrassie I was described as presenting OA changes associated to a post-traumatic episode (Dastugue and Lumley, 1976).

Probably the best-known case of extensive OA changes affecting the skeleton is that of La Chapelle-aux-Saints. Trinkaus (1985) described prominent marginal osteophytes, subchondral degeneration and eburnation in the articular facets involving numerous vertebrae. Dawson and Trinkaus (1997) suggested two scenarios for the spinal distribution of OA in this individual: either it was consequence of an abnormal distribution of the vertebral loading, or it was related to a trauma to the lower cervical or upper thoracic vertebrae.

Gardner and Smith (2006) described numerous OA changes in several individuals from the Krapina assemblage. More recently, Trinkaus (*in press*) has identified and described abnormalities in eight patellar remains from Krapina, including small spines, areas of irregular subchondral bone and irregular facet surfaces. Gardner and Smith (2006) interpreted the changes observed in the Krapina elements to be secondary to trauma. On the other hand, Trinkaus and colleagues (*in press*) relate the changes observed in the patellae to the general appendicular hypertrophy of Neanderthals.

The ethio-pathological origin of an osteophyte may provide information about behavioural patterns in extinct species such as locomotion habits or occupational activities. (e.g., Berger and Trinkaus, 1995; Lovell, 1991). For instance, the high prevalence of OA has been the basis for suggesting that Neanderthals' skeletons were under greater physical activity compared to other species (Trinkaus 1978).

In this study we report the pathological changes found in the left patella (ATD6-56) of *Homo antecessor* (Fig. 1). We provide the description, based on macroscopic and microscopic techniques, and a most likely aetiology; finally, we discuss possible behavioural implications.

Material and Methods

Material

ATD6-56 corresponds to a left patella of 37.2 mm (maximum height) x 19 mm (maximum thickness) (Carretero et al., 1999) (Fig. 1). The bone presents erosional damage of taphonomical origin on the medial margin of the articular surface; thus, the estimated breadth is 34.1 mm. The patella ATD6-56 was recovered from the TD6 level of the Atapuerca-Gran Dolina site (Burgos, Spain). The complete fossil assemblage from this site comprises more than 150 human remains, assigned to *Homo antecessor* species, as well as stone tools and faunal remains (Bermúdez de Castro et al., 1997; Bermúdez de Castro et al., *in press*; Carbonell et al., 1995; Carretero et al., 1999). The minimum number of individuals (MNI) of the Gran Dolina-TD6 level, based on dental remains, is eight with an age range from infants to young adults (Bermúdez de Castro et al., 2015). Thermoluminescence, ESR and U-series dating methods provided a date for the site of *ca*. 900.000 years (Berger et al., 2008; Falguères et al., 1999).

A second patella, from the right side (specimen ATD6-22), was recovered from the same sedimentary level. Carretero et al., (1999) performed the morphological and metric analyses of both patellae (ATD6-56 and ATD6-22). Based on the morphological and metrical similarities, Carretero and colleagues (1999) concluded that the two small sized and narrow patellar bones probably belonged to the same female individual (Fig. 2). The early age of complete ossification of the patellar bone, between 14-16 years old (Scheuer and Black, 2000), prevents a more accurate age assessment. However, as the oldest individual identified so far in the TD6 sample is a young adult (Bermúdez de Castro et al., 2015), it is likely that the two patellae probably belonged to a young adult individual. Unfortunately, it was not possible to associate the patellae to any other lower limb remains from the site.

Methods

In addition to the macroscopic analysis of the bone, we also employed microscopic techniques. A zoom stereo microscope (Olympus SZ61) with camera (Olympus UC30), housed at the Microscopy Laboratory of the CENIEH was used to visualise the bone growth. In addition, ATD6-56 was scanned with a Scanco microtomographic system (mCT 80, Scanco Medical), also housed at the CENIEH, using the following parameters for the scan: 70kV, 140mA, and isometric voxel size=30 μm^3. The image stack was imported into FIJI® software package in order to obtain an X-ray image to examine the new bone formation.

Results

ATD6-65 exhibits a bone-forming lesion of 15 mm (medio-lateral width) x 4.7 mm (superior-inferior height), approximately (Fig. 1). The bone spur is located along the inferior articular margin, involving greatly the medial articular surface, and extending posteriorly (Fig. 1, white arrows). The bone texture is characterized by being both smooth and porotic (Fig. 3). On the X-ray image, we identify a radiolucent area at the level where the bone growth is located, and in contrast with the radiopaque appearance of the rest of the patella. It is also possible to identify a visible boundary between the patella margin and the new bone growth (Fig. 4, black arrows).

Differential diagnosis

Bone forming lesions respond to multiple aetiologies; for instance, fracture healing, entheseal change, tumour lesions and/or infectious processes (Auderheide and Rodríguez-Martín, 1998b,c; Jurmain and Villotte 2010; Ortner, 2003b,c; Ortner, 2008).

We have not identified in any sign related to fracture, either in the X-rays or the surface of the bone (e.g., fracture lines or cracks along the cortical bone or callous formation). Thus, we have ruled out fracture as the cause of the lesion.

Since the bone growth observed at the ATD-56 is not located in any muscular insertion site (Bowden and Bowden, 2005), we can also rule out entheseal change as a likely aetiology.

We also discarded tumorous conditions based on the morphology and location of the bone growth. The osteoblastic (bone forming) nature of the ATD6-56 lesion allows us to discard osteolytic (bone destroying) tumours. Within osteoblastic tumours we discarded o*stesarcoma*, as it affects the trabecular and medullary bone, and these structures are not altered in ATD6-56. We also discard *osteomas*, as these are characterised by a lamellar bone structure, ivory-button morphology and they preferentially locate at the cranium (Auderheide and Rodríguez-Martín, 1998b; Ortner, 2003c).

Finally, the lack of signs related to infectious processes (e.g., cloaca and sequestrum) also allowed us to discard infection as possible cause (Auderheide and Rodríguez-Martín, 1998c; Ortner, 2008).

Diagnosis

Considering the morphology of the lesion and its location at the inferior margin of the left patella (Figs. 1, 3, 4) we suggest that it corresponds to a marginal osteophyte.

Disorders of the musculo-skeletal system are characterised by bone formation (osteophyte) mainly at the joint margin and at the ligament and tendon insertions. Osteophytes are defined as a fibrocartilage-capped bony outgrowth arising in the periosteum at the margin of the articular surfaces. Osteophytes are considered as a skeletal response to stress, although it is still unclear if they are a functional adaptation or a pathological process *per se*. Primarily, the development of osteophytes is strongly related to osteoarthritic changes, although other conditions such as age and trauma can trigger their formation (Menkes and Lane, 2004; Rogers et al., 1997; Van der Kraan and Van den Berg, 2007).

Discussion

Specimen ATD6-56 exhibits an osteophyte at its inferior margin. Considering the lack of other associated skeletal remains to this specimen except for the left patella, we suggest an array of possible sequence of events to explain the development of the bone spur (osteophyte).

Risk factors to account for the development of osteophytes are age, trauma (including subtypes such as fracture, dislocation, and/or deformation), and OA (e.g., Menkes and

Lane, 2004; Ortner, 2003b; Rogers et al., 1997). OA is a chronic disorder of multifactorial aetiology. Two types of factors are thought to favour the development of OA, generalised and local. *Generalised* factors include genetic predisposition, gender, age and obesity. *Local* factors comprise those conditions that result in abnormal mechanical load of a joint, such as limb misalignment or ligamentous instability (Conaghan, 2002; Östör and Conaghan, 2006; Weiss and Jurmain, 2007; Waldron, 2009). The high number of knee lesions in our species has been related not only to mechanical loading but also to the wider variety of movements of the knee joint –sliding, rolling and rotation- together with the no congruent articular surfaces (Huch et al., 1997).

If ATD6-22 and ATD6-56 belong to the same individual age cannot be the cause for the development of the osteophyte since ATD6-22 does not present any sign of osteophytic formation.

Being a monoarticular lesion, it is likely consequence of a local event that affected exclusively the left side.

Occupational tasks that require kneeling and/or squatting as well as certain activities that require repetitive and high loading exercises are believed to jeopardize knee joints (e.g., Coggon et al., 2000; Conaghan, 2002; Ezzat et al., 2013; McAlindon et al., 1999, McMillan and Nichols, 2005; Rytter et al., 2009).

Within the types of OA in the knee, tibiofemoral (TF) and patellofemoral (PF) OA have been related to occupational kneeling (Ezzat et al., 2013; Hinman and Crossley, 2007; Rytter et al., 2009). Studies showed that during knee flexion the joint forces increased, the contact areas decreased and misalignment of the patella occurs (Hinman and Crossley, 2007; Nagura et al., 2002). This will in turn contribute to the development of degenerative changes in the knee joint among people exposed to repetitive and prolonged kneeling (Ezzat et al., 2013; Hinman and Crossley, 2007; Nagura et al., 2002). The skeletal changes include the narrowing of joint space, the development of osteophytes and subchondral sclerosis (Buckland-Wright 2004; Ezzat et al., 2013; Hinman and Crossley, 2007; Rytter et al., 2009). Previous reports related skeletal changes to activities and postures in prehistoric populations (e.g., Ubelaker 1979; Trinkaus, 1975). Due to the asymmetrical nature of the lesion, that affects to the left but not to the right patella, we could rule out kneeling as the potential cause for the development of the osteophyte.

The development of a patellar osteophyte has been also related to soft tissue injury. Two clinical cases (Harris et al., 1995; Siddiqui and Tan, 2011) have recorded the development of an osteophyte on the inferior patellar margin, similar to the one observed in ATD6-56 left patella. According to these researchers, the primary cause of the pathology observed was a soft tissue injury –eccentric muscular contraction-. The posterior development of osteophytes in the patella and in the femur would have worked as a lock to prevent the patella from recurrent superior dislocation (Harris et al., 1995; Siddiqui and Tan, 2011). A third study by Cusco et al. (2009) reported similar osteophytic formation on a patella; however, the researchers concluded that the new bone formation was secondary to tibial valgus osteomy.

As the only two available bone elements are the patellae, we believe that the most plausible scenario for the development of the osteophyte exhibited by ATD6-56 right patella is a trauma event of local nature. That is, the osteophyte could be consequence of a trauma (contraction or tear) of the soft tissues (ligaments and/or muscles) resulting in extra mechanical load on the knee. However, we cannot completely rule out the possibility of the osteophyte being secondary to another type of trauma. The fracture of associated limb bones –such as the left femur and/or tibia- could have also triggered a similar course of events. This interpretation remains speculative until other bone remains can be associated to this specimen. The lesion here described would be the second one related to strenuous physical activity recorded in the *H. antecessor* sample. Previously Martín-Francés et al. (2015) described a metatarsal stress fracture in specimen ATD6-124, a condition related to high-intensity, repetitive load physical activity.

Conclusion

The bone formation in the left ATD6-56 patella can be described as an osteophyte. We believe that the most plausible explanation for the patella involvement is a local factor, such as trauma to the left limb. The event would have affected the left but not the right side of the individual. A soft tissue lesion such as ligament tear or muscular contraction, or the fracture of an associated bone, like the femur or the tibia, could have added a higher mechanical load to one of the knee joints. Primary risk factors for the development of knee injuries are repetitive, high loading exercises. Moreover, recently other example of lesion related to high-intensity and repetitive load physical activities was identified in a right metatarsal of *H. antecessor* species. Despite the suggested aetiology, we are aware that more lower limb remains are needed to support the presented hypothesis. Ultimately, this report contributes to increase our knowledge about the paleopathological record, as well as aspects on the health and behaviour/habits of the Pleistocene hominins.

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Figure Captions

Figure 1. Anterior (a), medial (b) and posterior (c) views of ATD6-56 left patella; white arrows point to the bone overgrowth (osteophyte).

Figure 2. Anterior view of right ATD6-22 (a) and left ATD6-56 (b) patellae.

Figure 3. Anterior view of ATD6-56 left patella and microscopic image of the bone overgrowth (osteophyte).

Figure 4. X-ray images of the ATD6-56 left patella; anterior (a) and inferior (b) views; the white arrows point to the osteophyte and the black arrows point to the boundary between the patellar bone and the bone overgrowth (osteophyte).

Figure 1

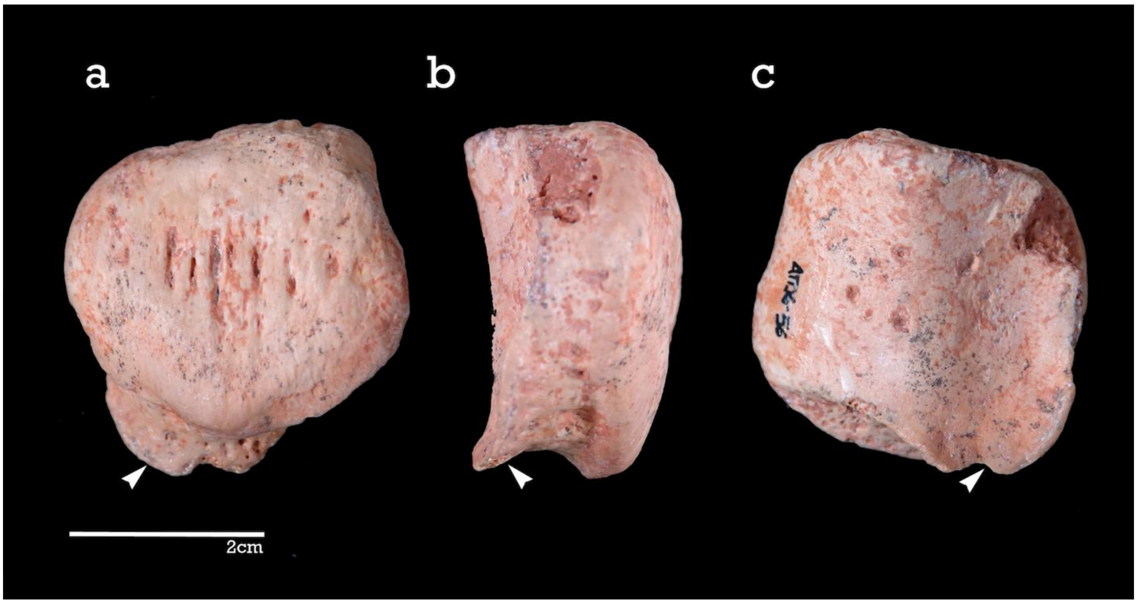
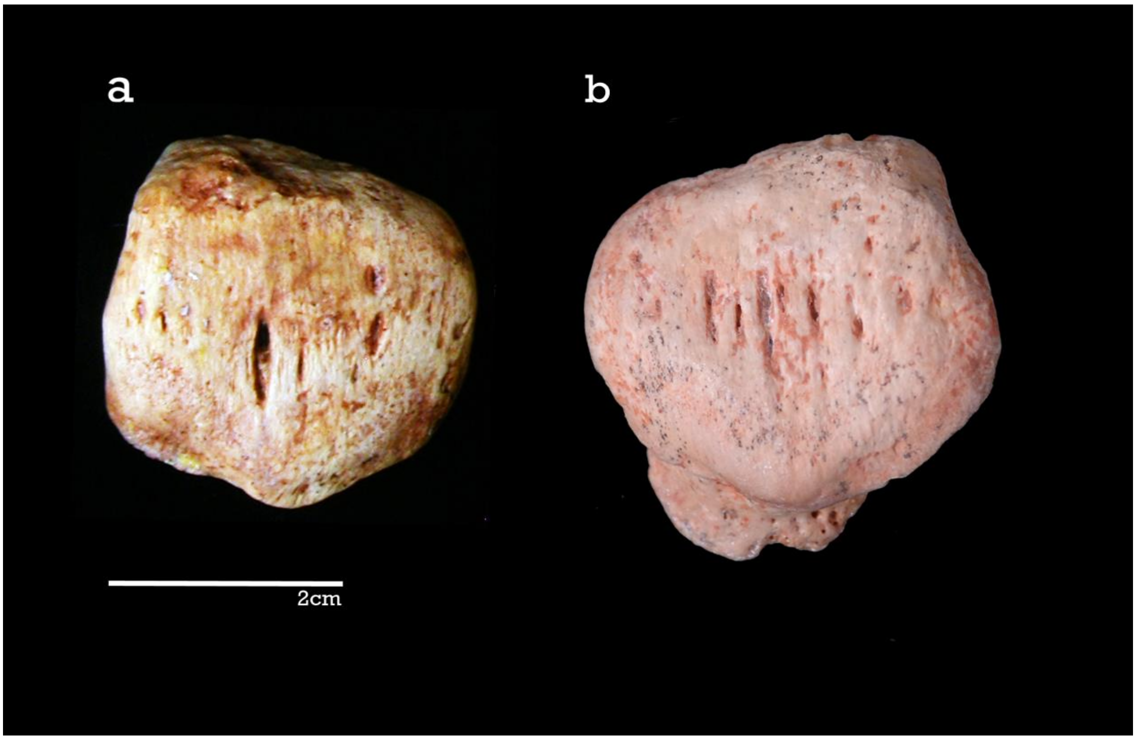


Figure 2



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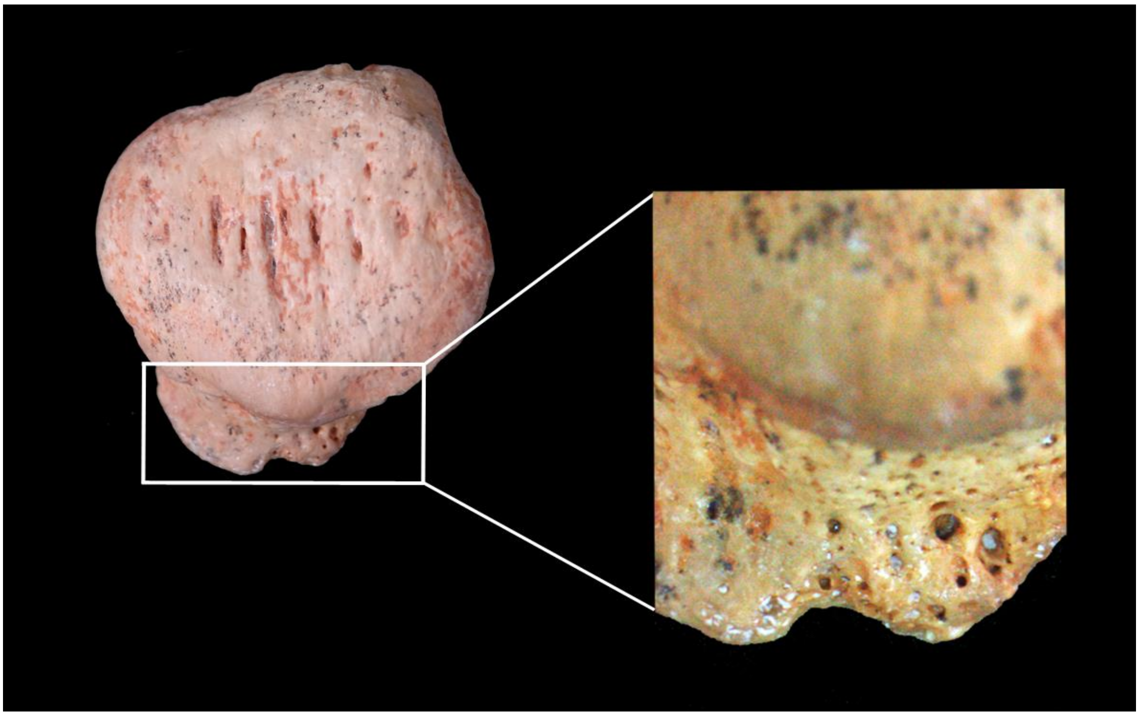

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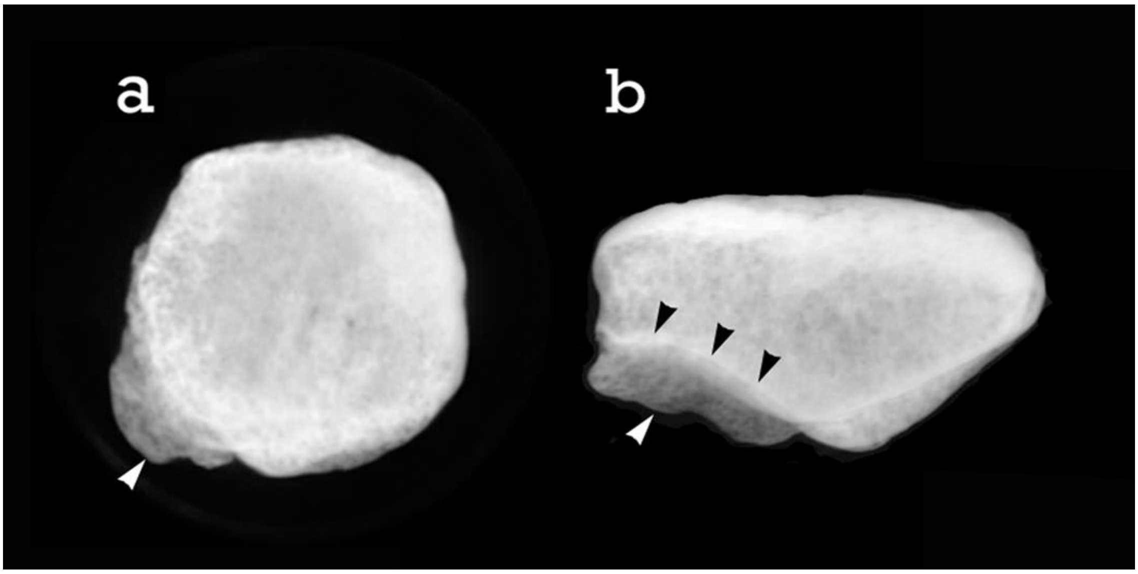
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