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Entheseal changes of the Achilles tendon in the Samnitic population of Opi, Val Fondillo (VII-VI century BCE; Abruzzo, central Italy): A preliminary study

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Abstract. Entheseal changes are an important feature in anthropological studies for reconstruction of life-styles in ancient populations. This study examined Achilles tendon enthesis in a Samnitic population of Opi (VII-VI century BCE; central Italy), to investigate differences in work activities between females and males through life. Fifty-one individuals provided 35 usable heel bones that were examined using a standardized scoring method for entheseal changes (grades 0-4). Different distribution patterns of enthesopathies between females and males were seen. Females showed physiological changes in Achilles tendon enthesis linked to age-group. Males showed overall higher entheseal change distributions linked to earlier death, with some reaching the highest grade 4 in the 25-35 years age-group (8.3%). These data are consistent with different work activities between these females and males, and suggest more static and less-demanding female roles, with some males involved in harder/ more dynamic and dangerous activities, compared to females.

Key words: enthesopathies, hell bone, Achilles tendon, paleopathology, Italy

Introduction

Entheses are the insertion sites of tendons on bones, and their function is to transmit the muscle force to the skeleton. They are considered to result from adaptation to muscular loading (Niinimäki & Baiges Sotos, 2013). When the osteotendinous junctions are diseased or inflamed, the entheses are said to manifest enthesopathies (Capasso, 2015), and these can be seen on the bone as spurs or *fossae* (depending which muscle is involved). Enthesopathies are due to continual functional overload of the osteotendinous junctions, and they can be used in physical anthropology to reconstruct the general level of occupational stress or specific work activities of individuals in past populations.

According to the histological type of the tissue in the insertion zone, it is possible to differentiate entheses into two kinds: fibrous entheses, which are characterized by fibrous connective tissue between tendons and bones; and fibrocartilaginous entheses, which are characterized by fibrocartilage between tendons and bones. Fibrous entheses are usually seen for bones of the appendicular skeleton with a thick layer of compact bone (e.g., diaphysis of long bones), while fibrocartilaginous entheses are seen for bones with a thin layer of compact bone (e.g., epiphyses of long bones and apophyses) (Benjamin et al., 1986; Benjamin et al., 2002). There are several factors that can influence the appearance of enthesopathies, which are mainly defined by the age and gender of an individual, and also by their work activities.

Many studies have demonstrated how people show sexual dimorphism related to enthesopathies (Steen & Lane, 1998; Weiss, 2003; Weiss, 2004). Males show a higher frequency of enthesopathies than females, and this will be linked not only to different work activities and lifestyle, but also to the physiological view, in terms of the greater muscle volume and body size of males.

Mariotti et al. (2004) demonstrated effects of age on the form and degree of development of enthesopathies. These were related to long-term activities that resulted in changes in the entheses, with the development of enthesopathies. However, in the older age-groups, enthesopathies cannot develop further, due to reduced osteoblast activity and thus decreased levels of cortical bone, with the subsequent weakening of the skeletal structure and increased tendon stiffness (Nagy, 1998), which can then no longer transmit the muscular pulse well. Another relevant factor that is age related is the decrease in muscle mass and the changes in the locomotor patterns on reaching old age (Evans, 1995). For these reasons, the functional interpretations of data on enthesopathies in osteoarchaeological series must be interpreted in a critical manner, taking into account their multifactorial aetiology and their irreversible nature.

The Achilles tendon is located at the back of the lower leg, and it connects the gastrocnemius and the soleus muscles to the calcaneal tuberosity. Microtrauma of the tendon can result from repetitive plantar hyperflexion, or from overpronation after knee extension has begun (Capasso et al., 1999). The presence of mechanical stress can strongly induce the formation of new fibrocartilage at the enthesis, and increase osteoblast activity at the same time (Benjamin et al., 2000). Benjamin et al. (2009) described the formation of a bony spur at the Achilles tendon enthesis, primarily as the result of endochondral, intramembranous, and condroidal ossification. Achilles tendon enthesopathies have been described for long-distance runners of the Neolithic in Nigeria (Dutuor, 1986), for modern joggers (Clement at al., 1984), and for a medieval population in Spain that was characterized by various habitual activities that related to carrying heavy loads, agriculture, cattle breeding, and hunting (Galera & Garralda, 1993).

Here, we present the results from a preliminary study on the patterns of Achilles tendon enthesopathies from an ancient Samnitic population from Italy, which were dated to the VII-VI century BCE. The aim was to investigate the hypothesis of a division of labour according to age-groups and gender, and more in general, towards a reconstruct the style and quality of life of this pre-Roman population in their particular natural environment in central Italy (Cilli, 2021).

Materials and methods

The materials were from the Samnitic necropolis of Opi, Val Fondillo (province of L'Aquila, region of Abruzzo, central Italy). The necropolis dates from the VII-V century BCE, and it lies on the slopes of Mount Marsicano, at an altitude of 1,450 m a.s.l. (Figure 1). This study focused on the most ancient burials that have been recovered from the necropolis, which were dated to the VII-VI century BCE. The full sample consisted of the skeletal remains of 89 individuals, which are housed in the Anthropolgy Operetative Unit of "G. d'Annunzio" State University in Chieti, Italy. The skeletons belonged to 39 male and 18 female adults (>18 years), plus 13 infants, 4 *juvenes*, and 15 indeterminate individuals.

The individuals for this analysis were selected according to the following criteria: (a) age of death >18 years, to avoid any entheseal changes due to immaturity of the musculoskeletal system; (b) absence of any pathological condition that might have influenced the body biomechanics; and (c) well defined age and gender, according to Ferembach et al. (1980), Brothwell (1981), and Todd (1920), as indeterminate individuals cannot be used in statistical analysis. The selected individuals were divided into four age-groups: 18-25 years (young adults); 25-35 years (adults); 35-45 years (mature adults); and 45+ years (old adults). The final sample consisted of 51 individuals: 15 females and 36 males, as those with defined age of death and gender.

From these 51 individuals, is was possible to analyse the entheseal changes of the Achilles tendon of 6 heel bone samples from the females and 29 from

Figure 1. Location of the town of Opi in central Italy (Source: Google Maps).

the males. The entheseal changes for these 35 samples were measured according to the classification proposed by Mariotti et al. (2004) and Donatelli (2004). These changes can be described as follows:

Grade 0: Absence of modification of the bone surface.

Grade 1: The inferior half of the posterior surface of the calcaneus slightly protruded with respect to the superior half, with a rounded crest and few longitudinal *striae*.

Grade 2: Slight modification of the posterior surface of the calcaneus, with more evident crest and *striae*, or enthesophytes up to 1 mm in length.

Grade 3: Large modification where the crest protrudes a lot, with vertical ridges and enthesophytes from 1 mm to 3 mm in length.

Grade 4: Very large modification of the posterior surface of the calcaneus, which is characterized by a very protruding crest and enthesophytes of more than 3 mm in length. This stage represents the true enthesopathy of the Achilles tendon, as known as "*calcar Achilleo*".

For each of the age-groups, the frequency of each enthesopathic grade was calculated considering the female and male samples independently, choosing indifferently one calcaneus between the right and left sides per person, as all individuals showed no differences between the two sides for entheseal lesions. The number of calcanei of each specific enthesopathic grade was divided by the total number of usable individuals (leaving out cases where scoring was not possible; Table 1), to transform the data into percentages. This method was used because of the small numbers of individuals in the full sample. In this way, a clearer idea of the enthesopathic frequencies was obtained for the given population, regardless of the size of the sample.

Results

This analysis provides some data of particular interest. First, most of all of the individuals were affected by some degree of entheseal changes of the Achilles tendon. The gender-related differences reflected the greater development of the Achilles tendon entheseal changes in the males than the females (Table 1). Furthermore, these enthesopathic lesions showed complex distributional patterns among the age-groups.

Females

The distributional pattern of the entheseal changes of the heel bone across the females showed an increasing trend with increasing age. Among these females, the young adult age-group (i.e., 18-25 years) was not affected by any large entheseal changes (i.e., all grades 0/1; Table 1; Figure 2A). The individuals in the adult age-group (i.e., 25-35 years) were characterized by grade 1 entheseal changes of the calcaneus (Figure 2B). In the mature adult age-group (i.e., 35-45 years) this shifted to higher grade 1 and 2 entheseal changes, while all of the old age-group (i.e., 45+ years) showed grade 3 entheseal changes of the Achilles tendon (Table 1). No female individuals showed enthesopathic changes (i.e., grade 4). This distribution of the increasing grades for the females reflects the physiological development of the enthesis of the Achilles tendon through the years.

Males

The distributional pattern of the entheseal changes of the heel bone across the males was more irregular. The 18-25 age-group showed entheseal changes from grade 0 to grade 2, with most already showing grade 1 (57.1%; Table 1). The following age-group (i.e., 25-35 years) included all grades of entheseal changes, as well as the true enthesopathic change (i.e., grade 4; 8.3%; Table 1; Figure 3), with the main distribution into grade 3 (33.3%; Table 1). Compared to the females in these early age-groups, this thus indicates the more rapid development of these changes for the males. However, the 35-45 age-group showed no true enthesopathic changes (i.e., grade 4), and equal numbers of individuals who were affected by grade 2 and 3 entheseal changes. For the old adults (i.e., 45+ years), this decrease appears to have continued, as they were affected by entheseal changes from grade 0 to grade 3, with grades 1 and 3 predominating (33.3%; Table 1).

Females versus males

As indicated above, unlike the females, the males did not show any linear development of Achilles

Table 1. Age, gender and entheseal score distribution of the 35 individuals of the Samnitic population of Opi, Val Fondillo (VII-VI century BCE; central Italy).

Age-group (years)	Gender	Samples	Entheseal score distribution (% usable heel bones)				
		Total usable individuals (n)	0	1	2	3	4
18-25	Female	2	50.0	50.0	0	0	0
	Male	7	28.6	57.1	14.3	0	0
25-35	Female	1	0	100	0	0	0
	Male	12	8.3	25.0	25.0	33.3	8.3
35-45	Female	2	0	50.0	50.0	0	0
	Male	4	0	0	50.0	50.0	0
45+	Female	1	0	0	0	100	0
	Male	9	16.7	33.3	16.7	33.3	0
Total	**Female**	**6**	**16.7**	**50.0**	**16.7**	**16.7**	**0**
	Male	**29**	**13.8**	**31.0**	**24.1**	**27.6**	**3.5**
Total	**All**	**35**	**14.3**	**34.3**	**22.8**	**25.7**	**2.9**

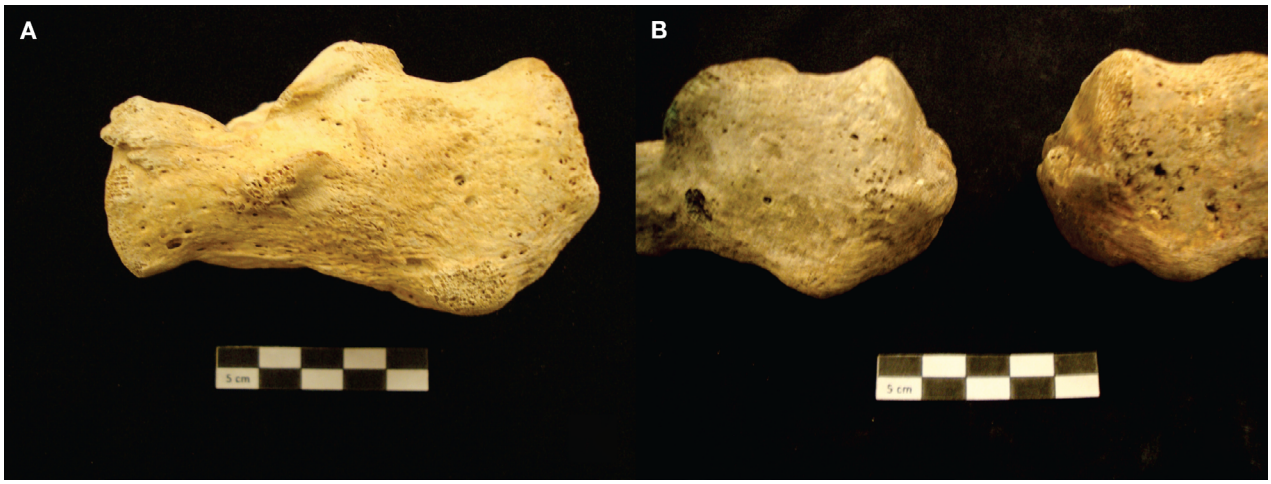

Figure 2. (A) Entheseal changes of Grade 0 for sample T47. (B) Entheseal changes of Grade 1 for sample T107.

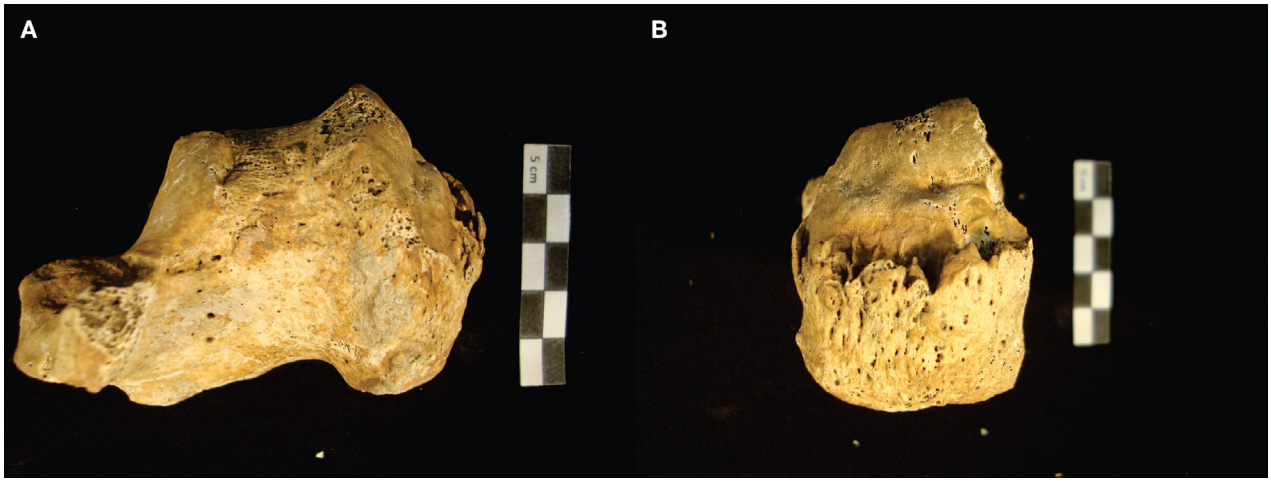

Figure 3. Enthesopatic form (grade 4) of the Achilles tendon for sample T55. (A) Lateral view. (B) Posterior view.

tendon enthesis with age; indeed, for the males, the most affected group with the largest changes was the adult age-group (i.e., 25-35 years). Although the numbers available here for this analysis remain relatively small, this male age series takes on added meaning with the consideration of the irreversible nature of these entheseal changes and the development of true enthesopathic changes (Sudol-Szopińska et al., 2015).

Discussion

This analysis needs be considered taking into account the activities of a VI century BCE population, as reconstructed by the archaeological data, to better understand the relationships between age, gender, work activities, and enthesopathic changes. From historical and archaeological data (Di Marino, 2002), we would hypothesize that the main work activities of this Opi, Val Fondillo population can be ascribed to animal breeding and crop farming.

The anthropological data defined here support the hypothesis of labour differentiation between the sexes. The effects of age on enthesopathies can be linked to an accumulation of microtraumatic stress on entheseal surfaces due to daily, 'normal' biomechanical loading patterns (Milella et al., 2012). This continuous stress is responsible for bone growth at the site of the enthesis,

which can continue up to the mature adult age-group (to *ca*. 45 years), as seen for the female age series here. Afterwards, there is no further increase in the entheseal changes, which will be due to decreased bone reaction to strain (Robb, 1998) or to decreased muscle mass due to changes in lifestyle during advanced (old) age (Evans, 1995).

Thus, this physiological age-related development of enthesis was observed only in the females, although these never reached the enthesopathic form of grade 4. This suggests that the females did not deal with the heavier physical activities, such as animal breeding and crop farming, and thus that their activities were probably limited to 'housework', handcrafts, and child rearing. There was no evidence of heavy loads on the heel bones, and the development of enthesopathic lesions for the females were linked directly to age, which will probably be aggravated by skeletal weakness in old age (Nagy, 1998; Evans, 1995).

For the males of Opi, Val Fondillo, the picture appears more complex. There was no overall linear development of entheseal changes with age such as that seen for the females. The young adult males (i.e., 18-25 years) were affected by grade 1 and grade 2 enthesis, while the adult group (i.e., 25-35 years) already showed the full range to grade 4 entheseal changes. In the mature adult group (i.e., 35-45 years), the entheseal changes were focused on grades 2 and 3 enthesis, initially implying that those who had reached grade 4 had already died at the younger age. This was further evident with the males over 45 years of age, indicating that those males who had survived were those with lower grade enthesis.

This nonlinear development of Achilles tendon enthesis was therefore influenced less by the normal aging process, and more by external factors, such as a heavy work activity load. Indeed, the younger males (i.e., 18-35 years) were more affected by rapid entheseal development (which included enthesopathic grade 4). For those males who survived to 35 to 45 years of age, they only showed grades 2 and 3 enthesis. This means that males took on a heavier work load at a younger age, as they were more exposed to the development of Achilles tendon enthesopathy before the age of 35 years. From 35 years on, the entheseal changes followed the normal aging process. The finding of grade 4 enthesopathy only in the males aged between 25 and 35 years must thus be linked to a high mortality rate for this age group.

The data for the men who survived to the old age-group (i.e., 45+) reflects two large groups of these people of Opi: a "nonworking" group, which is characterized primarily by grade 1 enthesis; and the working males who were still dedicated to hard labour, and who showed grade 3 enthesis. This means that a part of the male population would have carried out work activities in which the Achilles tendon was overloaded. On the basis of the palaeodemographic data (D'Anastasio & Vitullo, 2008), it appears reasonable to conclude that while some of the demanding work increased the risk of death, part of the male population carried out generally less demanding work, which did not overload the Achilles tendon.

There was thus clear differentiation between males and females here. The males showed the higher entheseal scores, which means that they were involved in tasks with higher levels of musculoskeletal stress of the Achilles tendon, compared with the females, who were involved in less physically demanding activities. These data from the males enable some interesting interpretations. The strong and rapid development of enthesis in the younger males would imply that the males started working at a young age, which probably started in childhood, and continued until they were 25 years to 35 years old, an age at which there was known to be high mortality (D'Anastasio & Vitullo, 2008). Afterwards there was a change in the workload and activities, which as a consequence, stopped any further Achilles tendon entheseal changes.

Through the archaeological records from other populations of the same historical period, we can try to reconstruct the different work activities of the males and females of Opi. As stated above, we can now confirm that the females will have been involved in the less strenuous activities, and so they did not have much stress on the Achilles tendon, which thus followed the normal age-related development. The males instead were much more influenced by external factors, such as the work activities, for their normal development of the Achilles tendon. This reflect also the conclusion drawn by the palaeopathological analysis of Opi population (Icaro et al., 2021).

Some epidemiologic studies on musculoskeletal disease factors of feet and ankles in modern populations have linked the development of enthesis to some features of daily work activities and anatomical characteristics (Dawson et al., 2002; De Zwart et al., 1997; D'Souza et al., 2005; Merlino et al., 2003). These included long periods of standing/walking, awkward positions, high physical workloads (e.g., lifting, pushing, kneeling), and high body mass index. As our materials are skeletal remains, it is impossible to define the body mass index of these individuals, so this variable was not taken into consideration in the present analysis, even if it cannot be excluded as a possible contributory factor.

The activities of this population would have mainly involved animal breeding and crop farming. However, dental analysis of these ancient people of Opi have shown that their nutrition was based on nonabrasive, simple and soft foods (D'Anastasio & Vitullo, 2008). Therefore, we can exclude vegetables as main food and crop farming as the primary activity. This hypothesis is supported also by an analysis of the enthesopathies of the upper limbs, which focused on the sindesmopathies of the costoclavicular ligament (D'Anastasio & Capasso, 2004). Crop farming implies the use of a plough, which requires it to be pushed and guided through the hard soil, and this can result in strong stress on the Achilles tendons, and also, in particular, on arm and shoulder enthesis. However, only 29.9% of these people of Opi showed changes of their costoclavicular ligament, as mainly males from 35 years to 45 years old (D'Anastasio & Capasso, 2004). This low percentage in comparison with similar populations, such as for Ercolano or Alfedena (D'Anastasio & Vitullo, 2008), suggests that crop farming was not the main activity, and food was supplied through other means.

As the water supply and faunistic and botanical richness of the Sangro River Valley has been demonstrated by a large literature on the biodiversity and richness of this area (Cianficconi et al., 2002; Pannunzio & Colella, 2006; Ferri et al., 2007), it would appear that animal breeding and hunting provided the main food supplies. The breeding of sheep and goats and other domestic animals also involved their transfer between their summer and winter pastures, which was known as the "Transhumance" (a characteristic of the Abruzzo region since the III millennium BCE) (D'Ercole, 1998). Also, when hunting, there would have been the need for long-distance travel over the rough land of mountain areas. These primary dynamic activities involved continuous travel, long periods of walking, and high physical workloads. Thus, this would appear to be the cause of the rapid development of Achilles tendon enthesopathies, due also to the particular positioning that the feet can have in climbing and descending slopes, without any changes seen for upper limb enthesis.

The young males were also designated to carry out this harder work. This would again explain the enthesopathic cases that afflicted these young males before 35 years of age, instead of the older males, with the risk of death for these young males as the highest for the whole population.

Conclusions

Studies of entheseal changes are important not only because they can provide an understanding of the growth and aging of the musculoskeletal system, but also because they can define biocultural, demographic, and life history reconstructions. Usually, the development of enthesis is caused by aging and other physiological patterns. This analysis of the entheseal alterations of the Achilles tendon is important, as it provides new information (though partial and not definitive) about the Samnitic population of Opi, Val Fondillo.

Once formed, this bony spur associated with the Achilles tendon (which results from bone metaplasia of the tendinous fibres of the Achilles tendon) does not undergo bone remodelling or re-absorption. Indeed, in the most difficult cases, it can only be removed by surgery. According to the data in the present study, we can conclude first that as the females of the population showed entheseal development linked only with age, they would have been largely involved in housework, handcrafts and child rearing. In contrast, the males were affected by the most serious entheseal changes of the Achilles tendon, which did not gradually develop with age, but which developed rapidly in some males (who also died at a relatively early age) and showed

some variations across the later age-groups. These data show the higher frequency of serious entheseal changes in males compared to females, which supports the hypothesis of different work activities between the two sexes. As the true enthesopathic form (i.e., grade 4 entheseal changes) was seen for only a few of the male population of Opi, this would imply that only these few males carried out those activities where the Achilles tendon was continuously overloaded, such as animal breeding, hunting, and, secondarily, crop farming.

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