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# Tibial marks in bare tibiae: relationship with robusticity indices

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## SUMMARY

In bare bones, transverse lines may have several origins. Defleshing of a prey generates cut-marks, which can also appear in relation with traumatic events, post-mortem changes such as marks of animal teeth, rodent gnawing, or impact of stones, or even bone decoration. We hypothesize that in some instances they may be due to hyperplastic vessels beating on the bone surface, as expression of increased blood flow demand imposed by hypertrophied muscles. We analyzed 140 well-preserved tibiae which belonged to pre-Hispanic individuals from El Hierro, in the Canary Archipelago, currently kept at the Department of Archaeology and Prehistory of the University of La Laguna, and determined robusticity indices. Tibial marks were found in 53 out of 140 cases. Epiphyseal and diaphyseal robusticity indices were significantly higher in the first case among those with marks than among those without marks (T=3.13; p=0.002), and nearly significantly in the latter case (T=1.88; p=0.063). Considering only men, similar differences were observed regarding epiphyseal robusticity index (T=2.90; p=0.005) and diaphyseal robusticity index (T=2.11; p=0.039). There were also differences regarding the depth of the tibial marks: a higher epiphyseal robusticity index was associated with a more marked depth of the lines (T=2.11; p=0.042). An association was also observed between depth of the marks and sex ($\chi^2$=4.12; p=0.042), more profound marks being observed among men. In conclusion, we here describe subtle bone marks in tibiae, which seem to correspond to vascular imprinting and are related to bone robustness. Whether or not they really represent an adaptation to an increased blood flow demand by hypertrophied muscles in relation with increased weight-bearing activity remains speculative, but this hypothesis may explain their presence.

**Key words:** Tibial marks – Bone marks – Robusticity indices – Prehispanic Canarians – Vascular imprints

## INTRODUCTION

Non-metric changes of bone shape may offer some difficulty in their detection and interpretation. In many cases they develop as a consequence of mechanical stress, such as repeated exercise of a given muscle; in this sense, bicipital tuberosity of the radius may indicate excessive and repetitive contraction of the biceps muscle, as, for instance, with the

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use of archs and arrows (Brothwell, 1982). Robust muscle contraction – something related to repetitive activity and training and with muscle mass and strength – may act on the bone at which this muscle is inserted, leading to local bone growth, by activating the canonical Wnt pathway (Liu et al., 2008), and to muscle hypertrophy. Muscle hypertrophy is usually accompanied by increased angiogenesis (Egginton et al., 2011) and vascular hypertrophy. Theoretically, these hypertrophied vessels may be involved in the pathogenesis of vascular imprints on bone. Indeed, this feature has been described in thalassemic individuals, in relation with the increased blood supply to the hyperplastic bone marrow (Lawson et al., 1984), but increased angiogenesis has been also described in a variety of diseases, especially leprosy (Paterson, 1965) haemophilia (Sejeant et al., 1973) and whenever a hyperplastic vessel contacts bone. Osteosclerotic reactions in response to other chronic infections, such as treponematosis, Hansen´s disease, or chronic pyogenic osteomyelitis, may also lead to increased vascularisation and to vascular imprints on bone surface, although, in these cases, bone sclerotic reaction is evident (Mays et al., 2003; Rissech et al., 2011). Paget´s disease is another condition in which hyperplastic, disordered angiogenesis take place, accompanying the formation of dense plaques of woven bone, although in this case angiogenesis usually leads to arteriovenous fistula formation rather than true arterial vessels.

Vascular imprints on bone are not only due to hyperplastic vessels beating on normal bone surfaces, but also to the effect of normal vessels acting on softer bones. This is what happens in osteomalacia, an entity defined by an impaired mineralization of osteoid. The so-called Milkmann-Looser pseudofractures are in fact vascular imprints on certain parts of the skeleton, which appear as transverse lines which span along a small part of a long bone diaphysis, or omoplatus, pelvis, and other bones (Lee and Lashari, 2007).

Therefore, several interpretations have been made regarding the presence of these vascular impressions on bone surface, almost always in relation with different kinds of illness. However, a detailed description and thorough analyses of their nature and relationships with other bone features in apparently normal bones are lacking. Based on these facts, in the present study we analyse the prevalence and anatomical characteristics of these lines, and also their relations with other alterations observed in bones, robusticity and other bone measures. If these lines truly represent vascular imprints, they must be related to vascular hypertrophy, and therefore must be in relation with robustness.

## Materials and methods

The total sample consisted of 140 tibiae (76 right and 64 left tibiae). They belonged to pre-Hispanic individuals from El Hierro, the smallest (273 km2) of the seven "big" islands of the Canary Archipelago, and they are currently kept at the Department of Archaeology and Prehistory of the University of La Laguna. The vast majority of them were buried in the volcanic cave Punta Azul. At the time of excavation of the cave, skeletons were not in anatomic position, so it was not possible to assign a given right tibia to a given left one. Therefore, the minimum number of individuals analysed was 76. Sex was assessed in 130 cases, applying the discriminant functions described some years ago for the prehispanic population of Gran Canaria (González-Reimers et al., 2000); in 10 cases only tibial fragments were available, and/or the bones presented erosions at the epiphyses which precluded accurate measurements, so accurate sex estimation was not possible. Of the 130 cases available, 75 were men and 55, women.

The presence or not of tibial marks was recorded by mere detailed inspection of the bones with bare eye, and further confirmation with a magnifying glass and photograph with a camera provided with a 10x magnification system. In addition, we also photographed the lines with a binocular magnifying glass, in order to disclose whether the section of the line was U- or V-shaped. We also obtained plain X-ray films from all the tibiae, in order to detect accompanying illness. Computed tomography (CT) was also performed in some cases with more marked lines, in order to show that neither osteitis nor endosteal bone reaction were present. We also recorded the number of lines observed on each bone.

Depth of the lines was semiquantitatively recorded in three degrees of intensity (from 1 to 3, grade 3 corresponding to faint marks, and grade 1 to marked, 2 to profound lines). Intermediate lines were difficult to differentiate from faint lines, and were detected in only 4 cases, so we grouped them together with grade 3 lines. Therefore, we finally had 2 groups of intensity: 26 tibiae with markedly profound lines, and 27 with faint marks. If several marks were present in a single tibia, we considered that the individual had deep marks if at least one mark was deep.

In a blinded manner, after having covered the shaft of the tibiae so that the evaluator could not know if there were marks or not, the size and aspect of the tibial tuberosity was graded by expert anatomists (ACP, MCR) in three degrees (1-3, this last corresponding to the more marked cases).

In order to evaluate the possible relationship between the tibial impressions and the robusticity of this anatomical element, some anthropometric parameters which describe the morphology of that bone have been measured following standard criteria (Martin, 1914; Martin and Saller, 1957; Olivier, 1960). Anthropometric parameters are the following:

1. Tibial length measurements, including: A) from the medial malleolus to the lateral condyle taken with an osteometric board; B) articular length, from the medial condyle to the centre of the distal articular surface and C) spino-malleolar length, from the tip of the intercondyloid eminence to the tip of the medial malleolus .
2. Circumference at the nutrient foramen level.
3. Minimum shaft circumference, usually located near the distal end of the tibia.
4. Anteroposterior and transverse diameters at the nutrient foramen level.
5. Proximal epiphyseal breadth, as the maximum distance between the condyles.
6. Distal epiphyseal breadth, as the distance between the medial malleolus and the centre of the fibular notch.

With these data, following methodologies used by other researchers in the study of the robusticity of tibia (Wood, 1920; Pearson, 2000; Pearson and Millones, 2005), we calculated several indices:

1. Diaphyseal robusticity index, as (midshaft posteroanterior diameter + midshaft medio-lateral diameter)/articular length
2. Epiphyseal robusticity index, as maximal epiphyseal breadth / tibial articular length 3.- Residual robusticity index, as (midshaft posteroanterior diameter + midshaft medio-lateral diameter)/ maximal epiphyseal breadth
4. Robusticity index, as minimum shaft circumference/tibial spino-malleolar length.

### *Statistics*

The Kolmogorov-Smirnov test was used to test normality of the quantitative variables, a condition not fulfilled by the number of lines per tibia. Therefore, a non parametric test, such as Mann-Whitney U test was used to analyse differences in this variable between 2 groups (i.e., two qualitative variables, such as men/women or deep or faint lines). Student's T test was used to analyse differences in the normally-distributed variables between 2 groups (for instance, tibial length among men/women). In order to test if there was an association between two qualitative variables (as, for instance, depth of the marks and sex), the $\chi^2$ test was used, always with Yates´s correction. If expected values in any of the cells of a contingency table were below 5, Fisher´s exact test was employed instead of $\chi^2$ test.

## RESULTS

### *Description and location of the tibial marks*

Tibial marks were observed with bare eye in 53 cases (37.85% of the total sample), although a detailed description requires the aid of magnifying devices. Some tibiae showed more than one mark. As seen in figures 1-4, obtained with a camera provided with a 10x magnifying system, these marks consist of horizontal grooves, always located in the anteroexternal aspect of the two proximal thirds of the shaft: indeed, the mean distance from the most proximal line to the proximal end of the tibia in relation to total tibial length was 0.400 ± 0.098, and the relation distance of the mark to the proximal end/ distance to the distal end was 0.774 ± 0.334. However, when only one mark was present, it was located approximately at the middle of the shaft (relation of distances to the proximal end/distal end= 0.926 ± 0.391).

Length of the marks usually spanned between 10 and 25 mm. Some of them showed a bifurcation, which always affected the anterior part of the mark (Fig. 5). With a binocular magnifying glass we clearly observed that the marks were U-shaped, suggesting that they were formed by vascular impingement, but not by the use of instru-

ments with cutting edges or trauma. (Figs. 5, 6).

In some cases, especially in those with profound marks, the groove was delimited, along its length, by a smooth, faint bone ridge, suggesting a reactive process of bone formation (Fig. 6). However, no gross osteosclerotic reaction or pathologic features were observed in any of the cases analysed, both with plain X-ray film and CT (Figs. 7a, b). Lines were not detectable with plain X-ray films.

*Prevalence and relationships to sex*

Overall prevalence was 37.85% of the tibiae analysed, but it is important to consider that 76 were right tibiae and 64 left tibiae. Considering only right tibiae, the prevalence of marks reached 30 cases (39.49%).

**Fig. 1.** Tibial marks in three different bones. In some cases, such as that shown in the left part of the illustration, bifurcation of the mark is fully evident.

**Fig. 2.** Another example of the tibial marks, in which the formation of a bone ridge is evident.

**Fig. 3.** In some cases, some marks are bended, such as that shown in this figure. This bended mark is also less profound than the others.

**Fig. 4.** New bone formation is evident also in this case.

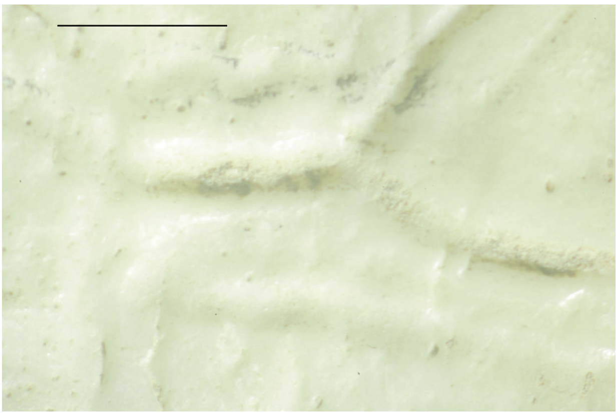

**Fig. 5.** Detailed photograph of one tibia with profound marks, illustrating that these marks are U-shaped. Bar = 3 mm.

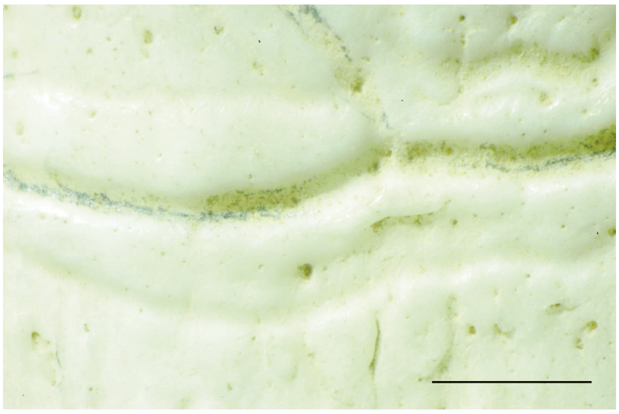

**Fig. 6.** Detailed photograph of another case, also showing the U-shaped characteristics of the tibial marks Bar =3 mm.

Considering only left tibiae, marks were observed in 23 cases (35.94%). In some tibiae more than 1 line was observed (Table 1).

Tibial marks were less frequently found among female tibiae (15 out of 55 cases, 27.27%) than among male ones (38 out of 75 cases, 50.67%) ($\chi^2$= 7.14; p=0.008). Considering only right tibiae, tibial marks were observed in 24 out of 44 male tibiae (54.55%) versus only 6 out of 27 female ones (22.22%, $\chi^2$= 7.06; p=0.008). Applying the discriminant functions (obtained from right tibiae [González-Reimers et al., 2000], and therefore, subjected to greater inaccuracy when applied to left tibiae) to the left tibiae, tibial marks were observed in 14 out of 31 male cases (45.16 %) and in 9 out of 28 female ones (32.15%, $\chi^2$= 1.03; NS).

The proportion of profound marks was higher among men than among women ($\chi^2$= 4. 12; p=0.042, Table 2), but no differences were observed between men and women with respect to the number of marks per bone (mean ± standard deviation= 2.16 ± 1.24; median and (interquartile range) = 2 (2-3), vs 1.87 ± 1.06; 2 (1-2), respectively; Z=0.82; p=0.41).

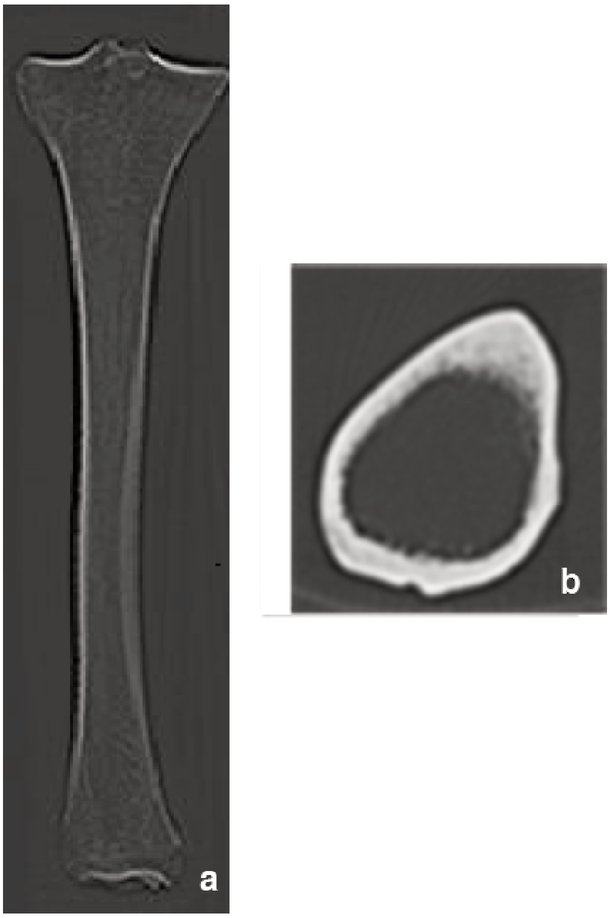

**Fig. 7.** CT images of one of the tibia with marks (**a**), which include a cross section of the bone at the level of nutrition foramen (**b**). In Fig. 7a, it is evident that no periostitis exists, whereas in figure 7b no endosteal bone growth is observable.

**Table 1.** Distribution of tibial marks.

| Number of lines | Total sample | | Right tibiae | | Left tibiae | |
|---|---|---|---|---|---|---|
| | Cases | Proportion | Cases | Proportion | Cases | Proportion |
| 1 | 20 | 37.7% | 9 | 30.0% | 11 | 47.8% |
| 2 | 20 | 37.7% | 13 | 43.3% | 7 | 30.4% |
| 3 | 5 | 9.4% | 3 | 10.0% | 2 | 8.7% |
| 4 | 6 | 11.3% | 4 | 13.3% | 2 | 8.7% |
| 5 | 1 | 1.9% | 0 | 0.0% | 1 | 4.3% |
| 6 | 1 | 1.9% | 1 | 3.3% | 0 | 0.0% |

**Table 2.** Depth of the marks, classified according to the bone analysed and sex.

| | Total | | Right tibia | | Left tibia | |
|---|---|---|---|---|---|---|
| | Depth | | Depth | | Depth | |
| | Marked | Faint | Marked | Faint | Marked | Faint |
| Men | 22 | 16 | 16 | 8 | 6 | 8 |
| Women | 4 | 11 | 1 | 5 | 3 | 6 |
| Total | 26 | 27 | 17 | 13 | 9 | 14 |
| | $\chi$2=4.12; p=0.042 | | $\chi$2=4.72; p=0.030<br>Fisher test: p=0.061 | | $\chi$2=0.20; NS<br>Fisher test: p=1.00 | |

Regarding the right tibiae, profound marks were more frequently observed among male cases (16 out of 24), than among female ones (1 out of 6). This association was nearly statistically significant ($\chi^2$= 4.72; p=0.030; unilateral significance using Fisher's exact test, p=0.040, but bilateral significance using Fisher´s test, p=0.061). However, no significant differences were observed regarding the number of marks in right tibiae (2.13 ± 1.23; 2 (1-2.75) among males and 2.5 ± 1.22; 2 (1.75-4) among females, and there was no association between sex and the presence or not of 2 or more or 3 or more marks per bone. No association was observed between depth of the marks or number of marks (Z=0.36; p=0.7).

No association between depth of the marks or number of marks and sex were observed when the left tibiae were analysed.

*Relationships with robusticity indices and anthropometric measurements.*

Anthropometric values and calculated indices are shown in Table 3. In Table 4 we show the values of the robusticity indices among individuals with or without marks. Epiphyseal robusticity index was significantly higher among those with marks than among those without marks (T=3.13; p=0.002), whereas diaphyseal robusticity index also showed a nearly significant trend in the same sense (T=1.88; p=0.063). Considering only right tibiae, epiphyseal robusticity index also showed higher values among those with marks (T=2.64; p=0.011), whereas no differences were observed in the case of left tibiae.

Considering only men, similar differences were observed regarding epiphyseal robusticity index (T=2.90; p=0.005) and diaphyseal

**Table 3.** Tibial measurements in men and women. Results are given as mean ± standard deviation. "n" means number of cases. Erosions of proximal or distal epiphysis, and, in some cases, loss of part of the bones explains that not all the measurements could be performed to all the cases. In the last column we show the value of Student´s T test (T) together with significance (p); *means p<0.05; **means p<0.01; ***means p<0.001.

| | Men | n | Women | n | T; p |
|---|---|---|---|---|---|
| Maximal tibial length | 344.17 ± 22.56 | 65 | 320.06 ± 14.11 | 33 | T=5.60; p<0.001*** |
| Proximal epiphyseal breadth | 72.75 ± 5.60 | 62 | 65.18 ± 3.75 | 31 | T=7.73; p<0.001*** |
| Distal epiphyseal breadth | 48.43 ± 4.97 | 66 | 45.37 ± 7.23 | 38 | T=2.55; p=0.012* |
| Minimum shaft perimeter | 81.23 ± 6.81 | 74 | 70.02 ± 3.72 | 51 | T=10.69; p<0.001*** |
| Transverse (medial-lateral) diameter (midshaft) | 20.94 ± 1.64 | 75 | 18.02 ± 1.30 | 54 | T=10.87; p<0.001*** |
| Perimeter at nutrient foramen | 92.80 ± 7.84 | 75 | 81.70 ± 4.14 | 54 | T=9.48; p<0.001*** |
| Anterposterior diameter (foramen) | 34.25 ± 3.27 | 75 | 30.19 ± 4.73 | 54 | T=8.75; p<0.001*** |
| Tibial articular length | 314.18 ± 11.38 | 67 | 302.33 ± 11.30 | 42 | T=5.30; p<0.001*** |
| Anterposterior diameter (midshaft) | 30.01 ± 3.40 | 75 | 25.83 ± 1.82 | 54 | T=8.21, p<0.001*** |
| Robusticity index | 24.15 ± 1.40 | 65 | 22.62 ± 1.15 | 33 | T=5.45; p<0.001*** |
| Diaphyseal robusticity index | 18.29 ± 1.18 | 67 | 16.98 ± 1.98 | 42 | T=4.35; p<0.001*** |
| Residual robusticity index | 7.08 ± 0.49 | 62 | 6.80 ± 0.42 | 31 | T=2.73; p=0.008** |
| Epiphyseal robusticity index | 23.07 ± 1.50 | 59 | 21.60 ± 1.19 | 28 | T=4.54; p<0.001*** |

**Table 4.** Robusticity indices and presence or not of tibial marks. Results are given as mean ± standard deviation. In the last column we show the value of Student´s T test (T) together with significance. NS means a p value >0.10; * means a p value >0.05, and **, a p value <0.01.

| Index | n | With marks | n | Without marks | T; p |
|---|---|---|---|---|---|
| **Total sample** | | | | | |
| Robusticity index | 41 | 23.95 ± 1.59 | 57 | 23.41 ± 1.41 | T=1.76; p=0.082 |
| Diaphyseal robusticity index | 45 | 18.14 ± 1.35 | 65 | 17.54 ± 1.80 | T=1.88; p=0.063 |
| Residual robusticity index | 41 | 6.98 ± 0.50 | 52 | 6.99 ± 0.48 | T=0.13; NS |
| Epiphyseal robusticity index | 40 | 23.12 ± 1.50 | 49 | 22.13 ± 1.46 | T=3.13; p=0.002** |
| **Right tibiae** | | | | | |
| Robusticity index | 26 | 24.02 ± 1.58 | 32 | 23.37 ± 1.22 | T= 1.77; p=0.083 |
| Diaphyseal robusticity index | 27 | 18.20 ± 1.21 | 34 | 17.64 ± 2.17 | T= 1.19; NS |
| Residual robusticity index | 25 | 7.03 ± 0.51 | 30 | 6.98 ± 0.50 | T= 0.34; NS |
| Epiphyseal robusticity index | 25 | 23. 16 ± 1.45 | 27 | 22.11 ± 1.42 | T= 2.64; p=0.011* |
| **Left tibiae** | | | | | |
| Robusticity index | 15 | 23.81 ± 1.64 | 25 | 23.46 ± 1.65 | T= 0.66; NS |
| Diaphyseal robusticity index | 18 | 18.05 ± 1.58 | 31 | 17.43 ± 1.31 | T= 1.47; NS |
| Residual robusticity index | 16 | 6.90 ± 0.47 | 22 | 7.01 ± 0.46 | T= 0.67; NS |
| Epiphyseal robusticity index | 15 | 23. 04 ± 1.62 | 22 | 22.16 ± 1.53 | T= 1.68; NS |

robusticity index (T=2.11; p=0.039). No differences were observed in these parameters when women with tibial marks were compared with those without tibial marks.

There were also differences in the epiphyseal robusticity index regarding the depth of the tibial marks: a higher index was associated with a more marked depth of the lines (T=2.11; p=0.042).

Well-developed, marked, tibial tuberosities were more frequently observed among male tibiae ($\chi^2=30.05$; $p<0.0001$). Similar, significant trends were observed when only right tibiae ($\chi^2=25.37$; $p<0.0001$) or left tibiae ($\chi^2=6.26$; $p=0.012$) were analysed. There was also a significant association between the size and shape of the anterior tibial tuberosity and the presence of marks: tibial marks were observed in 31 out of 63 with marked tibial tuberosity but only in 16 out of 52 individuals with less marked tuberosity ($\chi^2=4.05$; $p=0.044$). A tendency to a similar association was also observed when only right tibiae were considered, although without statistical significance ($\chi^2=2.96$; $p=0.085$), whereas no association was observed with the left tibiae ($\chi^2=1.14$; $p=0.3$). No relations were observed between depth of marks and prominent tibial tuberosities.

## Discussion

We observed transverse marks in nearly 40% of the cases included in this study. As commented before, vascular imprints are able to produce these marks, and their characteristics in the bones here analysed, as shown in Figs. 1-6, serve to rule out other possible etiologies. Indeed, in bare bones, transverse lines may also have other origins. For instance, defleshing of a prey generates cutmarks, which have been extensively analyzed (Bromage and Boyde, 1984), since they may inform about cannibalism and carcass processing behaviours, such as those described for early hominids (Shipman and Rose, 1983). Other possible sources include fissures due to traumatic events, post-mortem changes such as marks of animal teeth, rodent gnawing, or impact of stones, or, even bone decoration (Brothwell, 1972). Some authors also hypothesized that they may result as the action of plants roots. In this study, magnified images allow identification of the observed marks as possibly derived from vascular impressions. As shown in some cases, lines bifurcate and are surrounded by a bone ridge, suggesting a reactive process of bone formation. Even in some cases, bone growth led to the “tunnelization” of part of the line. The bone reaction implies that marks formed during life, so the hypothesis that the marks come from vegetal roots can be rejected. Also, post-mortem defleshing or marks of animal teeth can be ruled out. The shape of the marks makes it very unlikely that they correspond to wounds or cuts: as shown in Figs 5 and 6, the marks are clearly U-shaped, and not V-shaped, as would be the case if the marks would be due to wounds or defleshing.

In Figs. 5 and 6 smoothness of the bone surface is also noteworthy, a finding which does not support the presence of an underlying inflammatory process. The apparent normality of the bones with marks is also reinforced by the CT examination, in which neither osteosclerotic reaction nor endosteal bone growth was identifiable (Fig. 7). Moreover, bones in which lines were apparent did not show any different external aspect from bones without tibial marks. In the same sense, radiographical appearance did not differ. We did not detect any gross pathology in any of the 140 bones subjected to radiographic analysis, besides some Harris lines. Therefore, the probability of a chronic bone disease provoking an osteosclerotic reaction is unlikely.

Vascular impressions have been observed in situations such as osteomalacia, a condition in which the arterial pulse leads to a mark in the softened bone. However, this has nothing to do with what we here describe, in the sense that it seems that a robust bone response, with increased bone synthesis, was present, a feature which is not observed in osteomalacia, in which the lack of osteoid mineralization leads to softened bones. Moreover, in this study we found a good relation between the intensity of the marks and some robusticity indices. We hypothesize that these transverse marks are probably vascular marks, possibly related to the need of increased blood supply to hypertrophied muscle mass, in relation, for instance, with intense activity (loading or climbing). This may explain the relation between bone robustness and bone marks.

Bone mass results from an imbalance between synthesis and reabsorption, and in weight-bearing bones, such as tibiae, it may be related to increased bone apposition in response to a weight bearing effect, a feature mediated by the Wnt canonical pathway, a crucial regulator of bone formation and regeneration (Hoeppner et al., 2009). The Canary Islands were inhabited in pre-Hispanic times by a North African population, who arrived in the Islands during the first millennium BC. Mitochondrial DNA has revealed a parental relation with North African Berbers, although a unique mitochondrial haplotype U6B1 has been described solely for the inhabitants of the Islands (Maca-Meyer et al., 2004). Five out of the seven "big" islands of the Canary Archipelago are, in general, highly mountainous (for instance, La Palma reaches 2400 m altitude in only 700 Km$^2$; Tenerife, 3700 in less than 2000 Km$^2$; and El Hierro, 1500 m in only 273 Km$^2$), with profound ravines and marked slopes. Goatherding was the main activity, together with coastal fishing –more or less developed, depending on the island –, shellfishing, and some agriculture. In El Hierro, enormous amounts of limpets (mainly *Patella* sp) were consumed, but the shell middens are found quite away from the seashore. In addition, fresh water is (and was) scarce in this island , and some water springs are near the seashore, so water had also to be transported to the dwelling areas, relatively far away from the seashore. Perhaps continuous weight-bearing activity led to increased robustness, increased muscle mass and vascular marks on bone surface among the pre-Hispanic inhabitants of the Island.

In any case, as conclusion, we here describe subtle bone marks in tibiae, which seem to correspond to vascular impressions, and which keep a relation with bone robustness. Whether or not they really represent an adaptation to an increased blood flow demand by hypertrophied muscles in relation with increased weight-bearing activity remains speculative, but this hypothesis may explain their presence, and is consistent with the current knowledge about the style of life of the individuals in whom these marks are described.

## ACKNOWLEDGEMENTS

ATM, MAR, and ACO searched for the marks and measured the tibiae.

ATM and JMGT made detailed photographs of the marks.

MAR and EGR participated in the excavation of the anthropological material, designed the study, performed statistical analysis and the X-ray examinations of the bones, and wrote the manuscript.

MCR, ECC, and ACP analysed and assessed robusticity features of the bones and interpreted the nature of the marks as vascular imprinting.

All the authors approved the final version of the manuscript. There are no conflicts of interest.

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