Variation in the intertrochanteric line in a modern human population from southwestern China (19th–20th centuries)

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Abstract The intertrochanteric line on the proximal human femur has been the focus of paleoanthropological study for several decades, as it is thought to be a defining characteristic of bipedalism. Expression of this trait is highly variable in human fossils. However, the relatively narrow range of modern human groups in which its expression has been documented limits understanding of its variability and interpretation of its meaning. Our study analyzed variation in the expression of the intertrochanteric line in a population comprising young, middle and old age groups living in the 19th–20th centuries in Kunming city, southwestern China. Results showed that this trait was not equally present in all age groups. Statistical analyses revealed significant differences in frequencies of absence between the age groups, and also highlighted strong correlations between age and the degree of expression of the intertrochanteric line. It was more frequently absent or subtly expressed in young individuals, while individuals in the middle and old age groups tended to exhibit a more pronounced expression of this feature. The degree of expression of the intertrochanteric line also differed significantly between sexes, and it was significantly positively correlated with body size. Interestingly, the degree of expression of the intertrochanteric line rarely exhibited significant correlations with magnitudes of cross-sectional geometric properties of the femoral diaphysis, used as proxy measurements for physical activity patterns.

Key words: bipedalism, age, sex, body size, cross-sectional geometric properties

Introduction

As a distinct characteristic of the hominin lineage, bipedality has played a key role in human evolution (Prost, 1980; McHenry, 1986; Hunt, 1994; Wood and Richmond, 2000; Richmond and Jungers, 2008; Wood and Harrison, 2011). The hominin femur exhibits several traits that are indicators of bipedalism (e.g. the bicondylar angle and a deep patellar groove), and have been used extensively in reconstructions of locomotor patterns (Heiple and Lovejoy, 1971; Aiello and Dean, 1990; Pickford et al., 2002). The intertrochanteric line has been proposed to be one such functional indicator of bipedalism (Lovejoy and Heiple, 1972; Aiello and Dean, 1990; Pickford et al., 2002).

The intertrochanteric line is a roughened region on the anterior aspect of the proximal femur, extending from the greater trochanter to the lesser trochanter (Gray et al., 2005; White and Folkens, 2005; Schünke et al., 2006). It serves as an attachment point for the iliofemoral ligament (i.e. the enthesis). Because the ligament is integral to maintaining bipedal posture and locomotion, paleoanthropologists have long focused on the presence of the intertrochanteric line in non-human primates and hominin fossils (Stern and Susman, 1983; Grine et al., 1995; Lovejoy et al., 2002; Pickford et al., 2002; Curnoe et al., 2015). In modern humans, an extremely strong iliofemoral ligament facilitates stability of the trunk on the hip joint by limiting primarily extension, but also some rotation and adduction. Tension generated in this ligament elicits the skeletal indicator of the intertrochanteric line at its distal attachment site (Aiello and Dean, 1990; Hewitt et al., 2001, 2002; Platzer, 2014; Hidaka et al., 2014). For these reasons, the presence of the intertrochanteric line was con-
sidered a skeleton indicator of upright posture and bipedal locomotion, and thus a unique characteristic among hominins, capable of distinguishing human remains from those of non-human primates (Aiello and Dean, 1990; Pickford et al., 2002). In contrast, the intertrochanteric line was once believed to be absent in apes, owing to their different trunk stability requirements with regard to the hip joint during their quadrupedal locomotor kinematics. Nonetheless, there is some evidence that an intertrochanteric line is not exclusive to hominins. Lovejoy et al. (2002) found subtle or moderate intertrochanteric lines in 18.9% of gorilla femora \((n = 95)\) and 5% of chimpanzee femora \((n = 60)\). Thus, what distinguishes humans from non-human apes is not the complete absence of this trait in the latter, but rather a relatively higher prevalence of its presence and a more pronounced expression in the former.

Despite a generally higher frequency of expression of the intertrochanteric line in hominins, it is still highly variable in its form of expression, ranging from complete absence to an extremely pronounced expression. For instance, a number of ausstralopiths and Homo proximal femora have been found without evidence of this trait. Day (1969) noted that an intertrochanteric line is absent on the *Australopithecus* OH-20 femur. Similarly, Marchi et al. (2017) describe the absence or weak expression of this trait in *Homo naledi* femora (e.g. U.W. 101-002, U.W. 101-938, U.W. 101-1000/1098).

Weidenreich (1941) described the absence of this trait in the femora of Zhoukoudian *Homo erectus*, and regarded it as one of the peculiarities of these hominins. In contrast, other hominin femora, such as the *Orrorin tugenensis* femur, the AL 333-3 femur (*Australopithecus afarensis*), and the Trinil femur I, exhibit pronounced or well-marked intertrochanteric lines (Hepburn, 1896; Stern and Susman, 1983; Pickford et al., 2002; Richmond and Jungers, 2008). Among modern human populations, the intertrochanteric line is absent in 18% of the 92 native American femora and 5% of the 100 Zulu femora, especially those of adolescents, analyzed by Lovejoy and Heiple (1972). However, the expression of this trait has not been widely documented across other human populations.

The causes of variation in the expression of an intertrochanteric line are poorly known (Lovejoy et al., 2002). It can be questioned whether bipedalism is certain to produce this trait, and whether its absence always reflects a lack of bipedal locomotion. Furthermore, when a femur exhibits this trait, the degree of its expression can vary widely among modern humans. Thus, we argue that more investigation of factors influencing the degree of the trait’s expression is warranted, especially assessment of frequency and degree of expression in additional human populations. Such information will shed further light on the central question that needs to be discussed: is development of an intertrochanteric line an exclusive reflection of intensity of bipedal activities, or is it a manifestation of multifactorial causes?

Considering that the intertrochanteric line is a kind of enthesis, factors related to morphological changes occurring at other entheseal sites may have similar impacts on this trait. Previous studies have observed that age is a primary determinant of entheseal changes, regardless of the histological tissue category (i.e. the fibrous enthesis or fibrocartilaginous enthesis) of the tissue (Robb, 1998; Villotte et al., 2010a; Niinimäki, 2011; Henderson et al., 2012; Milella et al., 2012; Niinimäki and Baiges Sotos, 2013). These findings bolster support for the hypothesis proposed by Lovejoy and Heiple (1972), who attributed variation in the intertrochanteric line to ageing, as they found this trait frequently absent in adolescents. However, their work investigated a relatively narrow range of human groups. Documentation of this trait in additional human groups would be useful for understanding how widespread this phenomenon may be.

Sex is another factor considered to impact entheseal changes (Villotte et al., 2010b; Weiss et al., 2012; Milella et al., 2012; Santana-Cabrera et al., 2015). Sex differences in the expression of the intertrochanteric line to sex, on the other hand, has to our knowledge not yet been systematically analyzed in a human group. Even if sexual dimorphism exists in one group, a further investigation would be necessary to assess whether this phenomenon can be explained by hormonal and genetic differences between sexes, or whether it is truly attributable to sex differences in activity patterns (Murdock and Provost, 1973; Symons, 1979; Ruff, 1987; Wilczak, 1998; Geary, 2010). Although the effects of activity patterns and body size have been examined in previous studies of muscle attachment sites and a few ligament insertions, the associations between these factors and the intertrochanteric line are still poorly understood (Monson Chapman, 1997; Peterson, 1998; Wilczak, 1998; Weiss, 2004; Villotte et al., 2010b; Havelková et al., 2011; Rabey et al., 2015).

Here, we document variation in the expression of the intertrochanteric line in a Chinese modern human population. The aim of this study is to investigate whether the frequency of the trait’s absence and the degree of its expression vary with age, sex, body size, and/or activity. The null hypothesis being tested states that there is no effect of these factors on the morphological expression of the intertrochanteric line. Understanding the extent of these potential influences will contribute to a better understanding of the significance of the intertrochanteric line in paleoanthropology and human skeletal biology.

### Materials and Methods

#### Materials

The skeletal assemblage used here was excavated from a cemetery located in Kunming city, Yunnan province in southwestern China. The assemblage is currently housed in the Institute of Vertebrate Paleontology and Paleoanthropology, Chinese Academy of Sciences. The cemetery opened in the 1820s and was excavated in 1938 because the adjacent Yunnan University planned to build a new campus there. According to epitaphs and documents from the time when the cemetery was active, individuals buried in the cemetery were poor local residents.

A total of 147 individuals were selected for analysis (Table 1). Three selection criteria were used: no visible evidence of pathology, completed epiphyseal fusion, and good state of preservation. The sample consisted of 102 males and 45 females. The entire sample was divided into four age groups: young (estimated as 18–29 years), middle (estimated as 30–45 years), old (estimated as >46 years of age), and
unknown age. Estimations of age and sex were based on protocols described in Standards for Data Collection from Human Skeletal Remains (Buikstra and Ubelaker, 1994), especially those emphasizing pubic symphyseal surfaces, auricular surfaces, and epiphyseal fusion.

**Methods**

Several scoring systems for entheseal changes have been proposed in recent decades (Hawkey and Merbs, 1995; Mariotti et al., 2004; Villotte, 2006; Villotte et al., 2010a; Henderson et al., 2016). Most of these systems emphasize morphological changes of muscle attachment sites rather than osteoligamentous junctions. We found the protocols of these scoring systems ineffective when describing morphological changes of the intertrochanteric line. The only graded visual reference system created specifically for the intertrochanteric line was a four-grade scale developed by Lovejoy and Heiple (1972). However, this method does not consider variation in expression between different parts of the intertrochanteric line. The iliofemoral ligament can diverge distally before its attachment to the intertrochanteric line, effectively separating into two arms: a lateral arm and a medial arm (Figure 1). This distal separation results in the iliofemoral ligament also being referred to as the Y-ligament, because of its resemblance in shape to the letter ‘Y’ (Hewitt et al., 2002; Platzer, 2014; Telleria et al., 2014). Thus, we assess the intertrochanteric line considering both parts of the iliofemoral ligament, namely the superior intertrochanteric line and the inferior intertrochanteric line. Given that functions and mechanical properties have been reported to differ between these two arms of the iliofemoral ligament, morphological expression of the superior and inferior intertrochanteric line may differ as well (Martin et al., 2008; Van Arkel et al., 2015).

In our study, we modified the graded visual reference system of Lovejoy and Heiple (1972) to reflect these two parts of the intertrochanteric line. The degrees of expression of the intertrochanteric line were classified into four grades: 0 = absence; 1 = trace to slight; 2 = moderate; and 3 = pronounced (Figure 2). To minimize inter-observer error, all femora were scored by one trained observer. In order to evaluate intra-observer error, 70 femora were selected randomly and scored a second time approximately six months after the earliest scoring. Cohen kappa coefficients ranged from 0.86 to 0.90, showing substantial agreement between the two sets of measurements (Landis and Koch, 1977).

### Table 1. Sample sizes and demographic information

| Age groups | Males | Females | Total |
|------------|-------|---------|-------|
| Young      | 26    | 14      | 40    |
| Middle     | 34    | 23      | 57    |
| Old        | 25    | 6       | 31    |
| Unknown    | 17    | 2       | 19    |
| Total      | 102   | 45      | 147   |

Figure 1. Illustration of the iliofemoral ligament (Y-ligament), which extends from the anterior inferior iliac spine to the proximal femur. The superior intertrochanteric line anchors the superior arm of this ligament, and the inferior intertrochanteric line anchors the inferior arm.

Figure 2. Morphological variation in the intertrochanteric line. Grade 0 (absence): the surface of the osteoligamentous junction is smooth with no evidence of expression. Grade 1 (trace to slight): the trait can be distinguished by physical touching and visual inspection, but the degree of expression is faint. Grade 2 (moderate): the trait is well defined and exhibits a moderate degree of rugosity. Grade 3 (pronounced): the trait is very developed, exhibiting a highly roughened and raised surface.
Thus, intra-observer error was considered to be negligible. Additionally, body size (i.e. represented by body mass) and activity patterns were estimated. Since femoral head size is correlated to body mass, we used femoral head superoinferior height (FHSI) as a proxy measure of body mass (Ruff et al., 2012; Niinimäki and Baiges Sotos, 2013). To estimate activity, we calculated cross-sectional geometric (CSG) properties of the femur, including TA (total subperiosteal area), and ratios including $I_{\text{max}}/I_{\text{min}}$ and $I_x/I_y$. These properties are considered to be the indicators of robusticity and ratios of bending rigidity, presumably modified by daily repetitive mechanical loading during life (Ruff and Hayes, 1983a, b; Stock and Pfeiffer, 2001; Lieberman et al., 2004; Shaw and Stock, 2009; Niinimäki et al., 2017). To acquire these data, femora with intact epiphyses were examined by computed tomography (CT) scanning with a SOMATOM Definition Flash scanner (Siemens, Erlangen, Germany) in Peking University Third Hospital. The kilovolt peak was 120 kV, and the reconstructed slice thickness was 1.0 mm. Following the methods developed by Ruff (2000), 3-D models of the femora were oriented with respect to the standardized axes. Briefly, the standardized coronal plane of the femur was set as a plane parallel to the posterior surfaces of condyles. When establishing this plane, the femur was initially laid flat on the posterior surfaces of the condyles and the lesser trochanter, after which the proximal end was raised off the table until the anteroposterior point of the middle-shaft was approximately in the same horizontal plane as the proximal and distal diaphysis. The deepest point of the intercondylar notch and the mediolateral midpoint of the shaft were aligned in a sagittal plane. After that, we prepared CT images of sections taken at 50% biomechanical length and calculated cross-sectional geometric properties using the MomentMacroJ plugin for ImageJ (www.hopkinsmedicine.org/fae/mmacro.htm). Of the 147 individuals originally identified from the sample, we were able to collect femoral head dimensions from 133 individuals with well-preserved femoral heads, and we also collected CSG properties from 56 individuals with well-preserved epiphyses.

Since expression of the intertrochanteric line was assessed as an ordinal variable, non-parametric statistics were required. Specifically, we used Wilcoxon signed-rank tests, Kruskal–Wallis tests, and Mann–Whitney U-tests for evaluating comparisons between groups and sides, and Spearman’s rho tests were used to undertake correlation analyses. A significance level of 0.05 was used for all statistical analyses, and data were analyzed with SPSS version 22.0.

### Results

Table 2 displays the distribution of different grades in the entire sample. Generally, expression of the intertrochanteric line varied from completely absent to strongly developed. Absence of the intertrochanteric line was not rare (only if

| Grades              | Males                     | Females                   |
|---------------------|----------------------------|----------------------------|
|                     | Young | Middle | Old | Unknown | Young | Middle | Old | Unknown |
| Superior intertrochanteric line (L) |       |        |     |         |       |        |     |         |
| 0                   | 0.61  | 0.00   | 0.00| 0.00    | 0.57  | 0.00   | 0.00| 0.00    |
| 1                   | 0.26  | 0.20   | 0.09| 0.42    | 0.29  | 0.35   | 0.33| 0.00    |
| 2                   | 0.13  | 0.68   | 0.35| 0.58    | 0.07  | 0.65   | 0.50| 1.00    |
| 3                   | 0.00  | 0.12   | 0.57| 0.00    | 0.07  | 0.00   | 0.17| 0.00    |
| Total               | 1.00  | 1.00   | 1.00| 1.00    | 1.00  | 1.00   | 1.00| 1.00    |
|                     | (23)  | (25)   | (23)|(12)     | (14)  | (20)   | (6) | (1)     |
| Superior intertrochanteric line (R) |       |        |     |         |       |        |     |         |
| 0                   | 0.56  | 0.07   | 0.00| 0.00    | 0.62  | 0.00   | 0.00| 0.00    |
| 1                   | 0.28  | 0.07   | 0.09| 0.36    | 0.23  | 0.43   | 0.25| 1.00    |
| 2                   | 0.16  | 0.75   | 0.45| 0.50    | 0.15  | 0.57   | 0.25| 0.00    |
| 3                   | 0.00  | 0.11   | 0.45| 0.14    | 0.00  | 0.00   | 0.50| 0.00    |
| Total               | 1.00  | 1.00   | 1.00| 1.00    | 1.00  | 1.00   | 1.00| 1.00    |
|                     | (25)  | (28)   | (22)|(14)     | (13)  | (21)   | (4) | (2)     |
| Inferior intertrochanteric line (L) |       |        |     |         |       |        |     |         |
| 0                   | 0.48  | 0.04   | 0.00| 0.00    | 0.50  | 0.05   | 0.17| 0.00    |
| 1                   | 0.26  | 0.20   | 0.04| 0.33    | 0.36  | 0.45   | 0.17| 1.00    |
| 2                   | 0.22  | 0.52   | 0.17| 0.58    | 0.14  | 0.45   | 0.50| 0.00    |
| 3                   | 0.04  | 0.24   | 0.78| 0.08    | 0.00  | 0.05   | 0.17| 0.00    |
| Total               | 1.00  | 1.00   | 1.00| 1.00    | 1.00  | 1.00   | 1.00| 1.00    |
|                     | (23)  | (25)   | (23)|(12)     | (14)  | (20)   | (6) | (1)     |
| Inferior intertrochanteric line (R) |       |        |     |         |       |        |     |         |
| 0                   | 0.56  | 0.00   | 0.00| 0.00    | 0.46  | 0.05   | 0.00| 0.00    |
| 1                   | 0.16  | 0.25   | 0.05| 0.36    | 0.46  | 0.43   | 0.50| 1.00    |
| 2                   | 0.20  | 0.54   | 0.27| 0.50    | 0.08  | 0.48   | 0.50| 0.00    |
| 3                   | 0.08  | 0.21   | 0.68| 0.14    | 0.00  | 0.05   | 0.00| 0.00    |
| Total               | 1.00  | 1.00   | 1.00| 1.00    | 1.00  | 1.00   | 1.00| 1.00    |
|                     | (25)  | (28)   | (22)|(14)     | (13)  | (21)   | (4) | (2)     |

Numbers of individuals are shown in parentheses below the rows reporting totals.
scores of both the superior and inferior parts are zero can this trait be considered absent). Specifically, 22 of 147 individuals (14.97%) in the sample exhibited no intertrochanteric line on at least one side of their femora. Apart from that, the other three classes were also observed on femora, while the frequencies differed between different age and sex groups. A Wilcoxon signed-rank test indicated that there were no significant differences between the degree of expression of intertrochanteric lines on the two sides (i.e. non-significant bilateral asymmetry in expression) (Table 3), allowing pooling of data from left and right femora in subsequent analyses.

When investigating sexes separately, correlation analyses and comparisons between age groups revealed significant associations or differences, respectively (Table 4). In both superior and inferior parts of the intertrochanteric line, Kruskal–Wallis tests showed significant differences between age groups \((P < 0.001)\), regardless of sex. Similarly, the Spearman’s rho also indicated that there were strong positive correlations between age and the expression of the intertrochanteric line \((P < 0.001; \text{ Spearman’s rho} = 0.60–0.73)\). All cases of absence appeared among young males and females, whereas more pronounced intertrochanteric lines were more common in middle and old groups of both sexes.

When controlling for age, significant differences between sexes were observed (Table 5). In young samples, there were no significant sex differences in the expression of the superior and inferior intertrochanteric line. By contrast, sex differences were statistically significant in the inferior intertrochanteric line of the middle age group \((P < 0.003)\) and the old age group \((P < 0.001)\), while the superior part only displayed significant differences in the middle age group \((P < 0.006)\). In each case males demonstrated more pronounced intertrochanteric lines with higher frequencies than females.

Table 6 reports the relationship between the expression of the intertrochanteric line and CSG properties and FHSI, which represent proxy measures of physical activity and body mass, respectively. There were statistically significant, positive, but weak correlations between \(I/I\) and expression of the inferior intertrochanteric line, while the other properties did not exhibit a significant correlation with the expression. However, with regard to body mass, FHSI showed a statistically significant (but low strength) positive association with expression of the intertrochanteric line \((P < 0.001; \text{ Spearman’s rho} = 0.24–0.41)\).

**Discussion**

In this investigation, more than 14% of the individuals exhibited no intertrochanteric line on at least one femur; all of these individuals lacking an intertrochanteric line belonged to the young age group, and even though they were habitually bipedal, exhibit typical bicondylar angles and deep patellar grooves. Thus, the presence of an intertrochanteric line is not a characteristic shared by all humans in this group, nor does bipedal locomotion necessarily produce this trait in all age groups. In other words, in our view, the absence of an intertrochanteric line is not a characteristic shared by all humans in this group, nor does bipedal locomotion necessarily produce this trait in all age groups. In other words, in our view, the absence of an intertrochanteric line of the middle age group \((P < 0.003)\) and the old age group \((P < 0.001)\), while the superior part only displayed significant differences in the middle age group \((P < 0.006)\). In each case males demonstrated more pronounced intertrochanteric lines with higher frequencies than females.

Table 3. Bilateral asymmetry analyses of the intertrochanteric line

|                     | Males |            |            | Females |            |            |
|---------------------|-------|------------|------------|---------|------------|------------|
|                     | Youngest | Middle | Oldest | Youngest | Middle | Oldest |
| Superior            |        | 20       | 21       | 22      |          |         |
| Intertrochanteric    |        | 0.083    | 1.00     | 0.317   |          |         |
| Inferior            |        | 20       | 21       | 22      |          |         |
| Intertrochanteric    |        | 0.739    | 0.705    | 0.655   |          |         |

\(n\), number of individuals; \(P\), \(P\)-value of Wilcoxon signed-rank test; —, no data available, as the number of observed cases is not enough for rigorous statistical testing.

Table 4. Correlations of expression of the intertrochanteric line with age and comparisons between age groups

|                     | Males |            |            | Females |            |            |
|---------------------|-------|------------|------------|---------|------------|------------|
|                     |        |            |            |         |            |            |
| Superior Intertrochanteric | 85    | \(<0.001\) | 0.728      | \(<0.001\) |         |     |
| Inferior Intertrochanteric | 85    | \(<0.001\) | 0.697      | \(<0.001\) |         |     |

\(n\), number of individuals; \(P\), \(P\)-value of Kruskal-Wallis test or Spearman’s rho test; \(r_s\), Spearman’s correlation coefficient. \(P\)-values in bold are \(<0.05\).

Table 5. Results of comparisons between different sex groups (Mann–Whitney \(U\)-test)

|                     | Males vs. females | Males vs. females | Males vs. females |
|---------------------|-------------------|-------------------|-------------------|
|                     | \(n\) | \(P\) | \(n\) | \(P\) | \(n\) | \(P\) |
| Superior Intertrochanteric |        |        | 40    | 0.990 | 57    | \(0.006\) |
| Inferior Intertrochanteric |        |        | 40    | 0.670 | 57    | \(0.003\) |

\(n\), number of individuals; \(P\), \(P\)-value of Mann–Whitney \(U\)-test. \(P\)-values in bold are \(<0.05\).
The presence of an intertrochanteric line was universal in middle and old age groups. Over the course of aging, the tendency for an individual to exhibit a more pronounced intertrochanteric line appears to increase. As demonstrated by the statistical analyses, there were significant differences between age groups, and the positive correlations between age and expression of the intertrochanteric line were strong as well. Thus, age should be considered as an important predictor for variation in the expression of the intertrochanteric line. Considering that the intertrochanteric line is a kind of enthesis, this result is not surprising. Other studies have shown that age is the primary predictor for morphological changes in muscle attachments (Wilczak, 1998; Benjamin et al., 2009; Alves Cardoso and Henderson, 2010; Milella et al., 2012; Michopoulou et al., 2015, 2017). In this respect, the intertrochanteric line responds similarly to age as do other entheses on limb bones.

Other studies also have highlighted the effect sex has on entheseal changes (Villotte et al., 2010b; Milella et al., 2012; Santana-Cabrera et al., 2015). In our investigation into the intertrochanteric line, the effect of sex (i.e. sexual dimorphism) varied with age. For the middle and old age groups, the difference between sexes reached a significant level, with more pronounced expression in men. Within younger samples, significant sexual dimorphism in the expression of an intertrochanteric line was not observed. In fact, in studies of other attachment sites (e.g. the attachments of m. pectoralis major and m. deltoideus), Milella et al. (2012) also noticed that sex differences varied between different age classes. We believe that sex is a more complex factor, since it is related to genetic, hormonal, body size, and sociocultural factors such as gender-based physical activities (Murdock and Provost, 1973; Symons, 1979; Ruff, 1987; Wilczak, 1998; Geary, 2010). While it is beyond the scope of the present study to parse the individual contributions of each of these factors in determining sex differences, we can comment further on why age may have differential effects on sexes during non-adulthood and adulthood. Specifically, this may be a reflection of the change in hormonal differences between sexes during ageing, and it may result from the accentuation or cumulative effect of sex differences in body size and activity patterns in the older age groups (Edén, 1979; Ho et al., 1987; Donahue et al., 2006).

In the old age group, a sex difference was observed in the inferior intertrochanteric line, but not in the superior part. Compared with other factors we considered as potentially influencing entheseal morphology, activity pattern is probably one of the most relevant factors explaining why differences did not appear in both parts of the intertrochanteric line simultaneously, since the ligament arms attaching to the respective parts have different functions in locomotion. While both arms of the iliofemoral ligament limit hip extension, the lateral arm of the iliofemoral ligament (i.e. the part attaching to the superior intertrochanteric line) also limits adduction and external rotation of femur, whereas the medial arm (i.e. the part attaching to the inferior intertrochanteric line) also limits internal rotation (Platzer, 2014; Martin et al., 2008). The observed differences in the expression of the two parts of the intertrochanteric line of the old age group implies that there might be a division between sexes in this age group with regard to physical activities, especially activities that incorporate internal rotation of the hip. Nevertheless, we cannot exclude the possibility that the sex difference found here may be related to sexual dimorphism in pelvic morphology. Females usually have broader pelves and more oblique femora than males (Heiple and Lovejoy, 1971; Van Gerven, 1972). This difference may contribute to male and female differences in hip biomechanics and the mechanical properties of the iliofemoral ligament, which may ultimately influence the expression of intertrochanteric line.

However, the potential impact of physical activities on the intertrochanteric line lacks support from other indicators of limb use, specifically CSG properties. No statistically significant correlations were observed between ratios of CSG properties and variation in the expression of an intertrochanteric line, except for one instance. This result accords with those of previous studies on animal and human muscle at-

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### Table 6. Correlations of expression of the intertrochanteric line with CSG properties (TA, I_x/I_y, I_{max}/I_{min}) and FHSI

|                           | Superior intertrochanteric line | Inferior intertrochanteric line |
|---------------------------|---------------------------------|---------------------------------|
|                           | n  | r_s | P    | n  | r_s | P    |
| TA                        | 56 | 0.081 | 0.528 | 56 | 0.008 | 0.949 |
| I_x/I_y                   | 56 | 0.096 | 0.427 | 56 | 0.267 | 0.026 |
| I_{max}/I_{min}           | 56 | −0.034 | 0.782 | 56 | −0.198 | 0.101 |
| FHSI                      | 133 | 0.237 | <0.001 | 133 | 0.410 | <0.001 |

TA, total subperiosteal area; I_x, second moment of area (anteroposterior rigidity, or about the x-axis); I_y, second moment of area (mediolateral rigidity, or about the y-axis); I_{max}, maximum second moment of area; I_{min}, minimum second moment of area; CSG, cross-section geometric; FHSI, femoral head supero inferior height; n, number of individuals; P, P-value of Spearman’s rho test; r_s, Spearman correlation coefficient. P-values in bold are <0.05.
tachments (entheses). Although entheses are often considered to be theoretical markers of activity patterns, several studies have shown that the relationship between enthesis rugosity and activity may not be so simple (Weiss, 2004; Weiss et al., 2012; Michopoulos et al., 2015, 2017; Rabey et al., 2015; Wallace et al., 2017). Others have argued that CSG properties and ratios have limits when being applied as proxies for physical activity patterns, which prevents them from capturing more subtle differences in activities that may influence enthesal morphology (Michopoulos et al., 2017). If this ultimately would be the case, it is inappropriate to exclude the possibility that activity patterns may cause variation in the presence or expression of an intertrochanteric line. Further work is required to investigate these possibilities.

Unlike CSG properties, femoral head SI height (i.e. a proxy measure of body mass) was a significant predictor of the presence and degree of expression of an intertrochanteric line, even though Spearman’s correlation coefficients were relatively low, indicating a small-to-modest degree of strength in this association. Individuals with presumably larger body masses were more likely to exhibit more pronounced intertrochanteric lines. This implies a positive association between body size and biomechanical properties of the iliofemoral ligament (e.g. tensile strain at failure). In larger individuals, lower limbs are correspondingly heavier in an absolute sense. As a result, their iliofemoral ligaments are required to be relatively stronger to restrict hip extension, as well as rotation and adduction of the lower limbs. Similarly, larger individuals also tend to have absolutely heavier thighs. When the cumulative centre of mass of the head, trunk, and upper limbs is located behind a coronal plane through the hips, the iliofemoral ligaments must resist backwards rotation of the torso, preventing it from toppling backwards over the hips. Finally, in this manner, this elevated tension has been suggested to elicit a more pronounced intertrochanteric line in bipedal humans (Aiello and Dean, 1990).

In conclusion, similar to what has been shown elsewhere for two modern human populations (Lovejoy and Heiple, 1972), the intertrochanteric line is not a characteristic shared by all modern humans, especially young individuals, meaning bipedal locomotion does not definitively cause the occurrence of this trait. Rather, our current analysis of a modern human population underscores that variation in the presence and expression of an intertrochanteric line should be considered as reflecting multifactorial causes. This variation is related to age, sex, and body size, whereas expression of this trait does not appear to exhibit a significant correlation with activity levels. Moreover, these same factors also appear to be implicated in differential expression of the different parts of the intertrochanteric line. It would be unreliable to base reconstructions of locomotor patterns (i.e. presence or absence of bipedalism) on the expression of an intertrochanteric line without considering background information about age-at-death, body size, and sex. The significance of the intertrochanteric line feature should be considered more cautiously in future paleoanthropological studies.

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