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Physical activity over 2,000 years in Milan: Using entheseal robusticity as indicator of occupational stress

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ABSTRACT

Entheseal changes have been traditionally considered as indicators of skeletal markers of activity and occupational stress in bioarchaeology, although many factors may influence their development including age, sex, body size, pathological conditions, and traumatic injuries. In the present study, we scored and examined entheseal robusticity of 46 entheseal sites (23 left and right) of 250 skeletons from the Anthropological Collection of the Laboratory of Forensic Anthropology and Odontology in Milan, Italy. The skeletons come from the same urban and socioeconomic context (low/middle classes in Milan) and were equally divided between males and females and archaeologically dated to five consecutive time periods spanning from Roman to contemporary era, traversing a total of about 2,000 years. Analysis of entheseal robusticity focused on three aspects: asymmetry, differences between sexes and diachronic trends. While results revealed no statistically significant disparities between left and right side, differences were found in sexes potentially related to gender division of labor. In addition, post-hoc comparisons demonstrated significant changes in mean individual scores across historical periods, with an overall increase in robusticity for both sexes. These changes are consistent with historically documented activities performed by males and females over time in Milan. Through the analysis of the degree of robusticity of entheseal sites and by engaging with historical sources, the study explores physical activity in a major European metropolis and reveals its evolution in females and males over time.

1. Introduction

Musculoskeletal stress markers or entheseal changes (EC) have a long history of being used as indicators of occupational or recreational activities in bioarchaeology (Larsen, 2015; Sheridan and Gregoricka, 2020; Weiss, 2004). EC are defined as the degree of development of entheses and the presence of bone changes at entheseal sites (Henderson et al., 2010; Mariotti et al., 2004). The term "enthesis", which is derived from the ancient Greek word for "insertion", indicates the site of attachment of muscles on the bone surface, whereas the site of attachment of ligaments is called "syndesmosis". These sites of insertions allow the dispersion of the force exerted by mechanical movements from the muscles and into the bone through the interface provided by the entheses (Benjamin et al., 2002). The different collagens and proteoglycans present in the tissue of entheses guarantees the optimal mechanical properties to reduce the stress exerted on bones and on the entheses themselves (Cardoso and Henderson, 2010). EC are interpreted as indicators of prolonged and repeated muscular loading, which is why their pattern on the skeleton has been used to provide information regarding physical activity involving specific muscles or groups of muscles and reconstruct lifestyles of ancient individuals (Larsen, 2015; Sheridan and Gregoricka, 2020; Weiss, 2004). Nonetheless, EC may be influenced by various factors including age, body size, sex, anatomy of the attachment site, metabolic, genetic, and pathological conditions (Milella et al., 2012), which is why the terms "entheseal changes" are preferred to "musculoskeletal stress markers" (Jurmain et al., 2011).

Morphologically, EC are characterized by the presence of areas of bone hypertrophy with mounds, exostosis, ridges, and/or crests,

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although pitting and furrows may also be observed (Wilczak, 1998). Stress at the site of attachment of muscles increases blood flow, which stimulates the activity of osteoblasts and results in bone hypertrophy and therefore increases the robusticity of the entheseal site (Benjamin et al., 2009; Weiss, 2003). Enthesophytes are the product of the endochondral ossification of enthesis fibrocartilage and does not involve hyaline cartilage (Benjamin et al., 2000). Interpretations of EC as indicators of physical activity are based on the assumption that bone always answers to stress (functional adaptation) and therefore keeps remodeling in a specific site (entheseal insertions) to cope with the pressure of the muscles (Turcotte et al., 2020). The common approach is therefore to correlate activity with entheseal changes, but some works on macerated bones found that entheseal changes did not show any significantly association with occupation (Cardoso and Henderson, 2010; Milella et al., 2012). These contradictory results may be partly explained by the differences in observation and recording methods of EC, inter- and intra-observer errors, as well as biological variability (Santana-Cabrera et al., 2015).

Entheses can be classified into fibrous (or direct entheses) or fibrocartilaginous entheses depending on the type of tissue that links the bone surface with the tendon (Benjamin et al., 2002; Claudepierre and Voisin, 2005).

Fibrous entheses are sites of attachment of muscles to metaphyseal or diaphyseal bone. They are so named because the connective tissue that links the tendon to the periosteum is fibrous, constituted of the so-called Sharpey's fibres (Benjamin et al., 2002; Claudepierre and Voisin, 2005). Tendons can attach directly or indirectly to the bone, but in both cases the interface is a fibrous enthesis (Benjamin et al., 2002). The fibers of periosteally-mediated fibrous entheses are not in direct contact with the bone but with the periosteum, while the tendon fibers of the "unmediated" entheses attach directly into the bone (Turcotte et al., 2020). Fibrous entheses display as rough area, and they can appear poorly ("areal") or highly ("circumscribed") delimited; this morphological variability can be attributed to the large surface of diaphyseal bone areas in which the tendon attaches (Benjamin et al., 2002; Cardoso and Henderson, 2010; Henderson and Cardoso, 2012). One example of fibrous entheses is the deltoid tendon of the humerus (Claudepierre and Voisin, 2005).

Fibrocartilagenous entheses attach tendons on the epiphyseal surface of long bones or on small bones (such as carpal and tarsal bones), in areas poor of compact bone where the trabecular architecture is greatly involved in mechanical function (Benjamin et al., 2002; Claudepierre and Voisin, 2005). In fact, fibrocartilaginous entheses seem to suffer more from overuse injuries than fibrous attachments and therefore could be more representative of the mechanical activities performed by the individual (Jurmain et al., 2011). EC related to pathological conditions such as DISH and the spondyloarthropathies are more common in fibrocartilaginous than fibrous entheses. The development of fibrocartilaginous entheses involves the endochondral ossification of hyaline cartilage and the metaplasia of the end of the tendon into cartilage cells, resulting in the deposition of a layer of fibrocartilage (Claudepierre and Voisin, 2005; Niepel and Sit'aj, 1979). Although endochondral ossification is stopped in adulthood, the process of differentiation of tendons into fibrocartilage tissue can be reactivated, leading to a major development of the entheses, especially to contrast the force impresses by muscles (Claudepierre and Voisin, 2005). The tissue of fibrocartilaginous entheses is constituted of four zones, including dense fibrous connective tissue, uncalcified fibrocartilage tissue, calcified fibrocartilage, and bone, allowing to balance the elasticity of bones and tendons (Benjamin et al., 2002; Turcotte et al., 2020). On dry bones these entheses are recognizable as well-delimited and smooth areas (Cardoso and Henderson, 2010). An example of fibrocartilaginous entheses is the distal attachment of the *biceps brachii* tendon (Villotte et al., 2010).

Different portions of the same entheses could show the co-existence of fibrocartilaginous and fibrous tissues, underling the presence of a spectrum between these two categories and reflecting the complexity of human anatomy (Benjamin et al., 2002; Cardoso and Henderson, 2010).

In bioarcheology, the study of EC has been used to provide information about movements, tasks, and overall individual physical activity, as well as biomechanical patterns in past populations (Milella et al., 2012). EC, along with supernumerary facets, fractures and Schmorl's nodes, can be grouped into markers of occupational stress, as they represent skeletal responses that reflect habitual movements perpetuated by muscles (Mariotti et al., 2004; Mattei and Rehman, 2014; Wilczak, 1998). Although discussion exists in the literature, studies have demonstrated a relationship between EC and physical activity (Karakostis et al., 2019; Milella et al., 2015; Niinimäki, 2011; Schrader, 2015; Villotte et al., 2010).

However, despite the supposed link between EC and physical activity, other factors may influence the development of these bone alterations including hormonal imbalance, bone remodeling, trauma, body conformation, genetic predisposition, and pathological conditions that affect the musculoskeletal apparatus (Jurmain et al., 2011; Mariotti et al., 2004). Pathological conditions associated with EC include DISH, the spondylarthropathies, and traumatic lesions. This shows that EC should be interpreted with caution, as a direct correlation between physical activity and EC could be hazardous without a complete understanding of the pathological status of the individual (Villotte et al., 2010). The degree of development of EC is also influenced by biological sex and age. Specifically, older individuals usually show a higher robusticity than younger individuals; similarly, EC typically appear more pronounced in males than in females (Weiss, 2004). Moreover, EC in fibrous entheses tend to become more developed in adulthood, when the attachment zone passes from periosteal to bony (Jurmain et al., 2011). The variables that appear the present the strongest association with the development of EC are age, body mass, and size, especially for fibrous entheses (Villotte et al., 2010).

Although various may play a role in their development, EC remain a valuable tool to examine biomechanical patterns from bones, but their interpretation must be cautious. Recent studies tried to clarify this relationship with conflicting results: for instance, Mariotti et al. (2007, 2004) did not find any statistical correlation between known occupation and EC, whereas Villotte et al. (2010) found a statistical difference between skeletons of workers and non-workers from the analysis of EC.

This is not a methodological paper validating the use of EC as marker of mechanical stress. The objective of this paper is to analyze entheseal robusticity, used as a proxy for physical activity, in a sample of 250 skeletons from Milan, spanning five historical periods from the Roman to the contemporary era, to investigate patterns of physical activity and occupational stress over time. Specifically, the study aims to assess three key aspects: asymmetry between left and right entheseal sites, differences in robusticity between males and females, and diachronic trends in entheseal development across historical periods. By integrating bioarchaeological data with historical context, the research seeks to explore the evolution of physical activity within its gendered socio-cultural context over the past 2,000 years.

2. Materials and methods

The study was conducted on 250 skeletons of the Anthropological Collection of the LABANOF (CAL – *Collezione Antropologica LABANOF*), housed in the Laboratory of Forensic Anthropology and Odontology (LABANOF) of the University of Milan. The CAL is a large osteological collection constituted of over 7,000 skeletons, including about 5,000 from archaeological sites in Lombardy and in particular the urban center of Milan, and 2,127 unclaimed contemporary skeletal remains from the CAL Milano Cemetery Skeletal Collection available for research and didactic purposes in accordance with Italian law (Cattaneo et al., 2018; Viero et al., 2021). The study sample is part of an ongoing research project aiming to reconstruct the lifestyle of the inhabitants of Milan over the last 2,000 years (Biehler-Gomez et al., 2024, 2023b, 2023a, 2022; Giordano et al., 2023; Mattia et al., 2021) and were selected from the collection based on several criteria: fusion of the coxal bones for a reliable estimation of sex, equal distribution among the five historical periods established for the study (50 skeletons per period) and same number of male and female individuals (125 females and 125 males). As a result, the sample is composed of 50 skeletons per historical period (25 females and 25 males), defined as follows: Roman era (2nd-5th century CE) from the necropolis below the *Università Cattolica* (dated 3rd-5th century CE), Early Middle Ages (6th-10th century CE) and Late Middle Ages (11th-15th century CE) from the emergency excavations of *Sant'Ambrogio* and *Via Necchi* (with stratigraphic units spanning from the 1st century CE to the 15th century CE), Modern era (16th-19th century CE) from the mass grave burials in *Via Sabotino* (dated to the half of the 17th century) and Contemporary era from unclaimed cemetery individuals who died in the second half of the 20th century (Table 1). Analysis of topography of the necropolis, associated cultural material and structure of the burials suggest that the sites were necropolises for the poor/middle classes of the Milanese society. All necropolises and cemeteries used in this study come from the same urban context, allowing for a diachronic perspective.

Bioarchaeological analyses encompassed the estimation of biological sex and age-at-death. Specifically, biological sex was determined based on sexually dimorphic morphological traits of the pelvis and cranium, supplemented by metric analysis (Phenice, 1969; Spradley and Jantz, 2011; Walker, 2008, 2005). Age-at-death was estimated using a combination of dental eruption patterns, epiphyseal fusion, and degenerative changes observed in the pubic symphysis, auricular surface, acetabulum, first rib, and sternal end of the fourth rib (AlQahtani et al., 2010; Brooks and Suchey, 1990; Iscan and Loth, 1986; Kunos et al., 1999; Lovejoy et al., 1985; Rougé-Maillart et al., 2009; Scheuer and Black, 2004). These age estimations were subsequently categorized into the following age groups: 16–20, 21–30, 31–45, 46–60, 61–80, and > 80 years. Demographic distribution of the study sample is presented in Fig. 1.

To ensure consistency when comparing results across historical periods and to avoid terminological biases, this study adopts the standard proposed by Mariotti et al. (2004), and the term "enthesis" will be used throughout the text to refer to the site of attachment of ligaments and muscles. Although alternative methods for examining entheseal changes (Henderson et al., 2017; Mariotti et al., 2007; Villotte et al., 2010) are available, no universally accepted standard exists in the literature, and researchers often vary in their use of one method over another. In this study, the Mariotti et al. method was selected due to the research team's familiarity with its application and its straightforward, practical implementation, which facilitated systematic data collection and analysis. Consequently, a total of 23 post-cranial entheses were recorded (both left and right, Fig. 2) according to the scoring system developed by Mariotti on all 250 skeletons of the sample. Degree of robusticity was evaluated for each enthesis with three possible scores (1, 2, or 3) (Mariotti et al., 2007, 2004). Osteophytes and porosity were not recorded in the present sample (contrary to other research, e.g. Schrader (2015) and Palmer and Waters-Rist (2019)). This choice allowed for an easier and clearer interpretation of ECs and comparability with the literature (Havelková et al., 2013; Hawkey and Merbs, 1995; Palmer et al., 2016).

In particular, three aspects were investigated: asymmetry, differences between sexes, and changes across historical periods. Statistical analyses were performed using JASP software® (version 0.19.1). Values were considered significant at $p < 0.05$.

To investigate potential asymmetry in entheseal robusticity, scores were collected on both the left and right sides for each individual. As asymmetry analysis involves paired data, Wilcoxon signed rank tests were selected because they are well-suited for non-parametric paired comparisons, allowing robust analysis of ordinal data such as entheseal scores.

To assess differences in entheseal robusticity between males and females for each historical period, Mann-Whitney U tests were used. This test is appropriate for comparing two independent groups with ordinal data, making it a suitable choice for evaluating scores between sexes. In instances where the variance was equal to zero, Pearson's Chi-square tests were performed to evaluate differences, as they allow comparison of categorical distributions when continuous or ordinal statistical methods are not applicable. Together, these methods provided reliable tools to identify potential sex-related patterns in entheseal robusticity while accounting for the structure of the data.

To examine diachronic trends in entheseal robusticity, three mean scores per individual were calculated: a "mean individual score" representing the average score across all 23 entheseal sites for each skeleton, a "mean upper limbs score" based on the average of scores for upper limb entheseal sites, and a "mean lower limbs score" derived from lower limb entheseal sites. These mean scores were selected to provide composite measures of robusticity for individuals, upper limbs, and lower limbs, enabling focused diachronic analysis. Kruskal-Wallis tests were chosen for this analysis because they are ideal for comparing multiple independent groups (in this case, historical periods) with ordinal data. When significant differences were identified, Dunn's post-hoc comparisons with Bonferroni correction were conducted to pinpoint specific period-to-period changes while controlling for multiple comparisons. This approach ensured accurate identification of significant diachronic trends.

This approach allowed for a comprehensive analysis of entheseal robusticity, addressing asymmetry, sex differences, and diachronic changes while appropriately handling variance issues in the data and ensuring statistical rigor and reliability. The raw data is available as Supplementary Material.

Table 1
Description of the study sample.

Historical period	Site	*n* individuals	*n* males	*n* females
Roman era	Cattolica	50	25	25
Early Middle Ages	Sant'Ambrogio	39	18	21
	Via Necchi	11	7	4
Late Middle Ages	Sant'Ambrogio	49	24	25
	Via Necchi	1	1	0
Modern era	Sabotino	50	25	25
Contemporary era	CAL Milano Cemetery Skeletal Collection	50	25	25

3. Results

3.1. Asymmetry

Investigation of the difference in robusticity between right and left limbs revealed no statistically significant result for none of the 23 entheseal sites examined across all five historical periods, as shown in Table 2.

3.2. Differences between sexes

As analysis of asymmetry revealed no significant differences in the entire sample, a unique score was utilized. Specifically, scores from the left side were used; in cases of missing values, they were substituted with right-side scores to ensure completeness.

Analysis of sexual dimorphism in the study sample showed statistically significant results in 10 of the 23 entheseal sites recorded in this study (43 %), regardless of historical period (Table 3). Significant variations between sexes were found in the entheseal sites of most bones investigated (clavicle, humerus, radius, femur, and tibia) except for the ulna, calcaneus and patella. In total, males showed higher mean values than females in 94 entheseal sites across all five historical periods (82 % of the total 115 sites = 5 x 23), whereas females revealed higher values

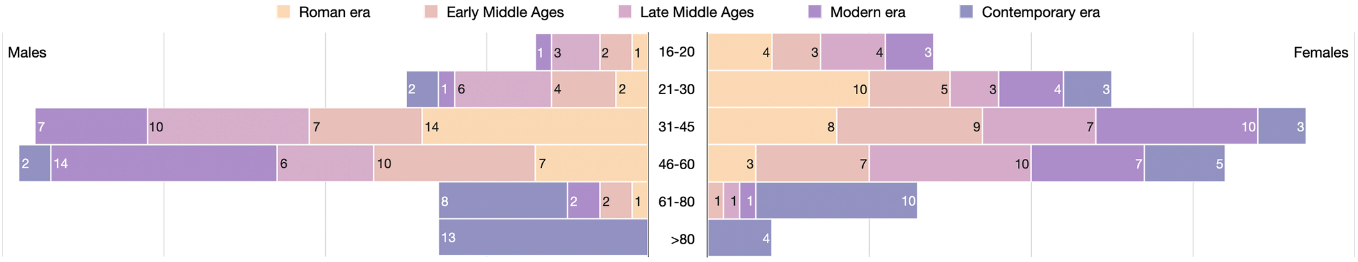

Fig. 1. Pyramid chart showing the distribution of the sample by age-at-death and sex.

than males in only 18 % or 21 instances.

3.3. Diachronic trends

Kruskal-Wallis tests and Dunn's post-hoc comparisons with Bonferroni correction were performed to evaluate potential changes in entheseal robusticity scores for both male and female samples. To do so, three mean scores evaluated: a mean individual score, to allow for comparison of entheseal robusticity between individuals, and mean upper and lower limbs scores, to examine whether degrees of robusticity differed in distribution on the skeletal remains (Table 4). In both samples, the analyses revealed a statistically significant difference in mean robusticity scores across historical periods ($p < 0.001$). These results were seen in both upper ($p < 0.001$) and lower limbs ($p < 0.001$), showing a systemic change in entheseal robusticity. For both males and females, Dunn's post-hoc comparisons revealed statistically significant changes between the two extreme periods ($p < 0.001$), as well as between the late medieval and modern periods ($p < 0.05$). Interestingly, while in females these changes were significant in all three mean scores (i.e., individual, upper, and lower limbs), in males the modern era did not a statistically significant difference in mean upper limbs robusticity scores ($p > 0.05$).

4. Discussion

4.1. Asymmetry

In total, 13 entheseal sites showed higher scores on the right side (56.5 %), compared to nine on the left side (39.1 %), whereas one site, the insertion of the *pronator teres* muscle on the radius, exhibited the exact same mean score on both sides. Interestingly, while upper limbs EC appeared more marked on the right side (10 out of 16 entheseal sites, or 62.5 %), the opposite was observed in the lower limbs, favoring the left side (4 out of 7 entheseal sites, or 57.1 %). Although scores of robusticity showed some asymmetry between right and left entheseal sites, the results were not statistically significant and are therefore not strong enough to support valid interpretations (Table 2). Though this lack of asymmetry is not unprecedented (al-Oumaoui et al., 2004), most archeological studies show a righthandedness (Hughes et al., 1996; Santana-Cabrera et al., 2015; Sperduti, 1997).

Despite the lack of statistical difference, a disproportion of intensity of usage between limbs must have existed. For instance, a dominant side between left and right limbs must have been present for each individual, even if this was not reflected in the EC recorded. Alternatively, limb dominance may have been expressed over finer actions, which, by their less intense nature, may not have provoked major EC in the entheseal sites examined, contrary to what can be appreciated in movements with greater muscle loading, such as lifting heavy objects (Karakostis et al., 2017; Wilczak, 1998). Indeed, EC in dominant limbs may not show any dichotomy if the movements are characterized by low intensity. Additionally, heavy work involving the upper limbs usually require both arms, which participate equally. In fact, the non-dominant side can handle half of the total mechanical stress, thus masking the EC of the favored limb (al-Oumaoui et al., 2004; Santana-Cabrera et al., 2015). Furthermore, asymmetry between limbs, especially the upper ones, might be genetically controlled or related to body size, and therefore may not always reflect activity pattern (Stirland, 1993).

4.2. Difference between sexes

The analysis of the difference in EC between females and males is based on the following assumption: if historical sources bring to light a clear division of work between sexes, then the skeletons should reflect this dimorphism. Consequently, analysis of physical activity patterns can prove a valuable information to reconstruct past ways of life, even though such interpretations should be taken with precautions. Indeed, EC only give us the tools to recognize and interpret divisions of labor within past societies and cannot be used to reliably identify punctual changes by themselves.

This approach has found major applications in archeological samples, in which the comparison between EC, historical sources, and artifacts has provided a global overview of labor dynamics in the past (Havelková et al., 2011). Usually, men evidence a greater robusticity of entheseal sites, which is typically linked to strenuous physical activity; however, it is necessary to consider other variables that may play a role in this trend, such as hormonal factors (Mariotti et al., 2007; Villotte et al., 2010) and differences in growth of muscles (Ruff, 2003). Moreover, estrogens and androgens influence both endosteal and periosteal bone deposition (Foster et al., 2014), and estrogens may weaken tendons in women (Kjær and Hansen, 2008; Westh et al., 2008). The increase of testosterone levels during adolescence in males lead to significant growth of muscles size, which could impact the degree of robusticity of entheseal sites in young men (Round et al., 1999).

In the present study, EC, evaluated through the degree of robusticity of the entheseal site, showed statistically significant differences between sexes in 10 of the 23 entheses examined in the total sample (43 %), present in both upper and lower limbs and in most bones except for the ulna, calcaneus, and patella (Table 3). In addition, robusticity scores were higher in males than in females in 82 % of instances (94 out of 115 sites for all five periods). This difference could reflect a division of occupations between sexes, which assumed a different pattern in each historical period. Better understanding of the correlation between EC and physical activity is necessary to further interpretations.

4.2.1. Roman sample

Robusticity scores of entheseal attachments showed no statistical difference between males and females. Mean EC scores ranged between 1.10 and 1.39 (excluding the outlier value of 1.77 at the level of the Achilles tendon in males), revealing generally low scores.

Overall, the distribution of entheseal development within the Roman population showed a greater robusticity among males with respect to females. Mean robusticity scores were higher in females than males at the entheseal sites of the *costoclavicular ligament* (clavicle), *conoid ligament* (clavicle), *deltoid muscle* (clavicle), *biceps brachii muscle* (radius), *interosseous membrane* (radius) *vastus medialis muscle* (femur), and *quadriceps tendon* (tibiae), but the differences were negligeable and did

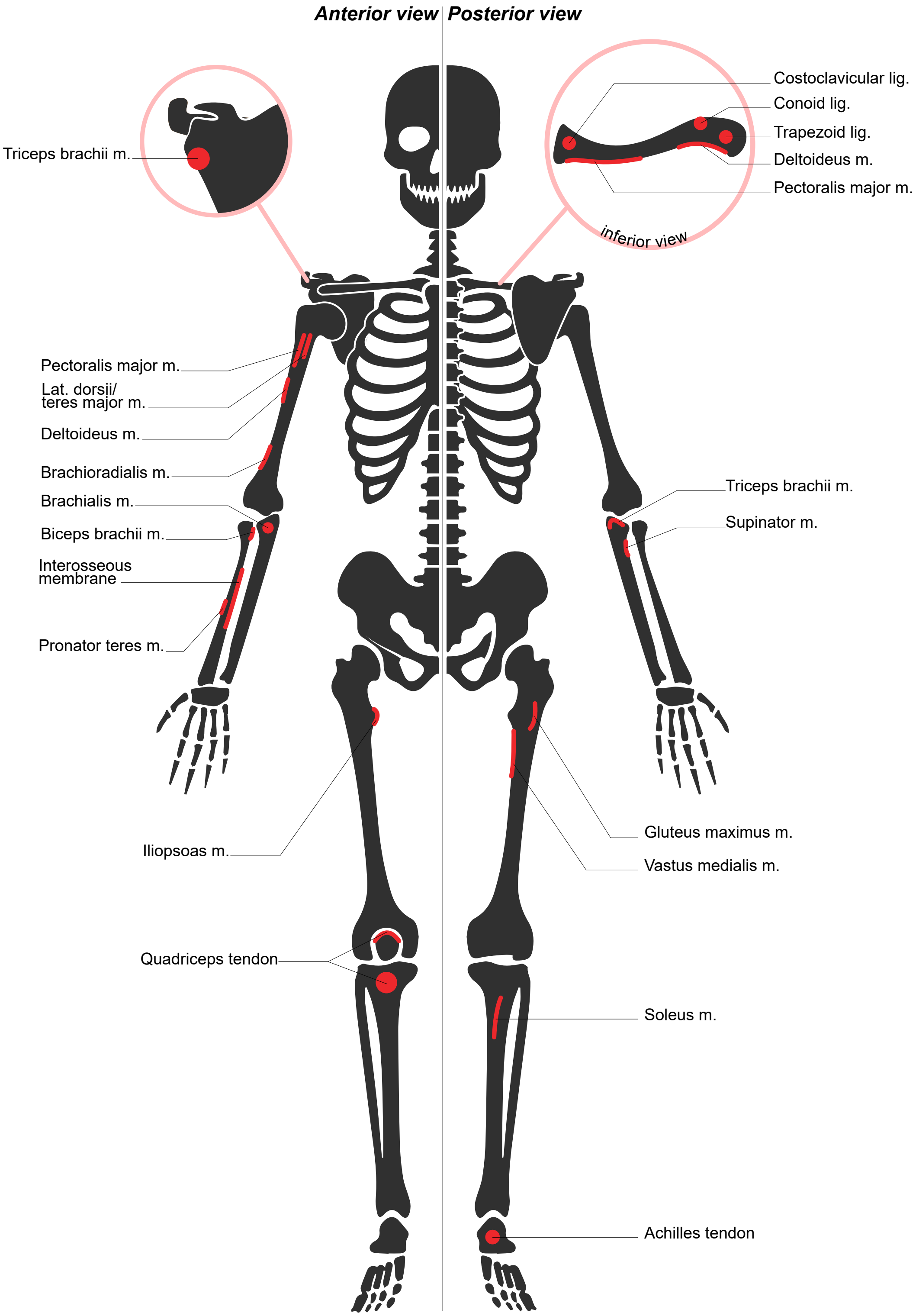

Fig. 2. Distribution of the entheseal sites considered in this study.

not reveal any statistically significance. Compared to the Roman sample form Anatolia (Üstündağ, 2020), our results showed a slightly different pattern of distribution as, in their study, males were characterized by significantly higher EC at the level of the supraspinatus and infraspinatus insertion, whereas females exhibited higher scores at the origin insertion of the common extensor muscles.

Mean values showed a slightly higher degree of robusticity among the sites in the lower limbs over those on the upper limbs. In fact, the second highest value (after the *Achilles tendon*) was 1.39 in the femoral entheseal site of the *gluteus maximus muscle*, which is also the site with the highest robusticity score in other Italian necropolises in the Roman age (Catalano et al., 2010). The trend is dissimilar from the results of other Roman necropolises (Catalano et al., 2010).

In fact, the highest mean scores were observed in males at the attachments of the *Achilles tendon*, *gluteus maximus*, and *brachioradialis muscles*, and those of the *Achilles tendon*, *conoid ligament* and *quadriceps*

Table 2
Asymmetry of entheseal robustness per historical period with number of observations (*n*), W-statistic, *p* value, and effect size with matched rank biserial correlation (R: right, L: left, significant values in bold).

Bone	Entheseal site	*n*	W	*p*	Rank-Biserial Correlation
Scapola	*Triceps brachii m.*	107	19.50	0.050	−0.571
Clavicle	*Costoclavicular lig.*	122	120.00	0.344	−0.200
	Conoid lig.	126	172.00	0.796	0.058
	Trapezoid lig.	115	68.00	0.674	−0.111
	Pectoralis major m.	138	39.00	0.644	−0.143
	Deltoideus m.	134	54.00	0.236	−0.294
Humerus	*Pectoralis major m.*	128	48.00	0.021	−0.543
	Lat. dorsi/Teres major m.	129	90.50	0.860	−0.047
	Deltoideus m.	163	72.00	0.458	0.200
	Brachioradialis m.	126	74.50	0.397	0.242
Radius	*Biceps brachii m.*	137	54.50	0.523	0.198
	Pronator teres m.	130	28.00	1.000	0.018
	Interosseous membrane	148	30.00	0.824	0.091
Ulna	*Triceps brachii m.*	127	49.00	0.307	−0.279
	Brachialis m.	139	49.00	0.835	−0.067
	Supinator m.	153	49.50	0.551	−0.175
Femur	*Gluteus maximus m.*	178	169.50	0.613	−0.103
	Iliopsoas m.	138	49.00	0.842	−0.067
	Vastus medialis m.	162	80.50	0.857	0.052
Patella	*Quadriceps tendon*	65	15.00	0.374	0.429
Tibia	*Quadriceps tendon*	107	35.00	0.437	0.273
	Soleus m.	135	99.00	0.881	0.042
Calcaneus	*Achilles tendon*	100	33.00	0.644	−0.154

tendon of the tibia in females. These may be related to a specific biomechanical set of movements: extension of the foot, erect posture, thigh flexion, extension of the forearm and bending of the elbow. All of these actions were probably commonplace in the daily life of roman citizens in Milan. Indeed, they are compatible with the majority of occupations at the time, which are also associated with limb symmetry (Santana-Cabrera et al., 2015). In an urban context such as this one, manual works consisted principally in manufactured articles and building industry. Epigraphic sources testified that women worked in (almost) the same fields as men, but with different occupations. Among middle-lower class females, the most common activities were (Treggiari, 1979): *obstetrices, medicae, nutrices* (midwives, doctors (Codex Justinianus 7.7.1.5a), nurses), entertainers (singers, mime-actresses), domestic slaves, workshop owners (*officina*), and *brattiaria*, who worked gold-leaves to make jewels (which probably consisted in the artisan work and the production of gold-leaves, leaving the hammering process to men). Women were particularly involved in selling goods, such as stones (raw, cut, incised), cameos, pearls, gold, clothes, bottles (*lagunaria*), perfumes, and lotions (*unguentariae*; probably made by women themselves), aliments, and coloring fabric purple (*purpuraria*) (Treggiari, 1979). The majority of roman women participated in the clothes-production industry, which comprehends a vast category of activities, such as spinning wool, sewing, and selling the finished product. The term *vestificae* indicates all female tailors working for the elite and living in their house, while common women used to sew clothes in their own home to sell them to other women. There are also reports of *sarcinatrices* (menders) who worked exclusively on the materials of their clients, and probably some of their duties were shared with the *vestificae*. A specialized figure in this branch were the *lanificae*, namely the women who spin wool. A comment in Apuleius' Metamorphosis shows the fatigue and misery behind this occupation, when a *lanificae* says "*at ego misera pernox et per diem lanificio nervos meos contorqueo*" ("I wretchedly strain my nerves by spinning all night and day") (Met. 9.5). Women who sold the woven linen made by themselves were called *lintearia*. Other professions held by women include *sutrix* or shoemakers, *clavaria* who ran nail salons (CIL V.7023), *meretrix* who were prostitutes and waitresses in taverns as documented in Pompeian graffiti and written sources (Ulpian Dig. 23.2.43 pr.), *ornatrices* or hairdressers, and waitresses serving food and drink in *popinae*, which was considered an "extension" of women's domestic duties (Becker, 2016). Women do not appear to have been involved in building and woodworking, which presupposed strenuous physical activity as well as remarkable physical force (Becker, 2016). This overview of typical middle-low class female occupations is compatible with our osteological results, as their skeletons do not show any particularly marked entheseal activity in long bones. In fact, the highest mean value was of 1.33, representing medium entheseal development in the calcaneus, probably reflecting quotidian actions with no specific occupational meaning. Additionally, there was no evidence of significant differences between sexes regarding the entheseal sites of the quadriceps and calf muscles, which are involved in walking. This may suggest that lifestyle for both males and females was equally characterized by moving on foot (Battistini et al., 2022).

4.2.2. *Early medieval sample*

Like Havelková et al. (2013), no significant asymmetry was found between limbs in the early medieval sample.

In their study, Havelková et al. (2013) found EC in the wrists of women of different social classes, indicating that in the Early Middle Ages women practiced the same activities regardless of social status. In addition, women presented more EC than men in the area of the elbow (Havelková et al., 2011), though was not observed in the present study. Like the author, we found that the insertion of the *biceps brachii muscle* was more developed in males, though this was not significant (p = 0.211). Only one entheseal site showed statistically significant differences in robusticity between males and females, namely the *soleus muscle* insertion in the tibia, more pronounced in males. As one of the calf muscles, the soleus muscle is a powerful lower limb muscle involved in flexion and extension of the foot (Battistini et al., 2022). This may suggest that male activities included more walking than for females and, perhaps, more involvement in transporting heavy loads, as suggested by the higher robusticity of EC of the upper limbs (although non statistically significant) (Havelková et al., 2011). During the Early Middle Ages, in the cities of central-northern Italy, the recorded trades included "goldsmiths, coppersmiths, cobblers, tailors, soap makers, painters (…) merchants, jewelers, money changers, and doctors (…) bakers, cauldron makers" (Azzara, 2017, pp. 129, 140)). In Milan, at the time, women worked both at home, where they performed "professional" tasks, such as spinning, sewing, and weaving, as well as outside the domestic sphere.

Mean values of robusticity were higher or equal in men with respect to women, except for the entheses of the *triceps brachii muscle* of the scapula and *pectoralis major muscle* of the clavicle, though only by a small margin (0.08 and 0.06, respectively). With respect to the previous period, mean EC scores not only increased (ranging from 1.04 to 1.67) – albeit not significantly – but the gap between male and female values also deepened, resulting in high mean male EC scores for both upper and lower limbs. This is consistent with the literature which says that both men and women were engaged in activities involving the arms (for instance, pottery making (Havelková et al., 2011)). The highest robusticity values in men corresponded to the *gluteus maximus muscle* (femur), *Achilles tendon* (calcaneus) and *quadriceps muscle* (patella) insertions, involved in movements related to walking and standing; whereas the entheseal sites of the *Achilles tendon*, *gluteus maximus muscle*, and *costoclavicular ligament* of the clavicle where the most marked in females. Havelková et al. (2013) found that individuals buried with warrior equipment presented marked EC at the insertion of the *gluteus maximus muscle*, which they suggested may be connected with horse riding, based on the literature. In the present study, males showed a much higher degree of robusticity of this insertion than women, hence, this may potentially be related to the fact men were more likely to ride horses than women. Given the social background of the individuals of the sample and the context of early medieval Milan, the development of lower limb musculature in males potentially from riding activities may

Table 3

Differences between sexes in entheseal robustness per historical period, showing the number of observations (*n*), mean values per sex (M: male, F: female), and the results of statistical analyses (W-value for Mann-Whitney *U* test and Chi square X^2 statistic when variance was equal to 0, significant values in bold).

Bone	Entheseal site	Roman era			Early Middle Ages			Late Middle Ages			Modern era			Contemporary era		
		n	mean	comparison	*n*	mean	comparison	*n*	mean	comparison	*n*	mean	comparison	*n*	mean	comparison
Scapola	*M Triceps brachii m.*	21	1.05	$X^2 = 0.831$	12	1.08	W = 117	14	1.07	$X^2 = 1.327$	14	1.50	W = 121	23	1.65	W = 163.5
	F Triceps brachii m.	17	1.00	$p = 0.362$	19	1.16	$p = 0.843$	18	1.00	$p = 0.249$	15	1.73	$p = 0.455$	21	1.14	$p =$ **0.023**
Clavicle	*M Costoclavicular lig.*	19	1.10	W = 155	14	1.57	W = 121	15	1.27	$X^2 = 4.899$	16	1.50	W = 108	22	1.64	W = 231.5
	F Costoclavicular lig.	16	1.12	$p = 0.881$	19	1.42	$p = 0.628$	16	1.00	$p =$ **0.027**	15	1.47	$p = 0.592$	21	1.67	$p = 1.00$
	M Conoid lig.	17	1.18	W = 176.5	14	1.29	W = 120	20	1.30	W = 200	19	1.47	W = 237	24	1.75	W = 216
	F Conoid lig.	19	1.32	$p = 0.479$	17	1.29	$p = 0.980$	21	1.29	$p = 0.748$	19	1.95	$p = 0.075$*	23	1.39	$p = 0.153$
	M Trapezoid lig.	18	1.33	W = 160	13	1.38	W = 77.5	19	1.37	W = 212	17	1.47	W = 154.5	25	1.69	W = 244
	F Trapezoid lig.	18	1.28	$p = 0.948$	13	1.23	$p = 0.627$	23	1.26	$p = 0.843$	16	1.69	$p = 0.468$	24	1.33	$p = 0.180$
	M Pectoralis major m.	19	1.10	$X^2 = 2.003$	17	1.06	W = 145	22	1.14	W = 264	17	1.23	W = 169	23	1.48	W = 223
	F Pectoralis major m.	18	1.00	$p = 0.157$	17	1.12	$p = 1.00$	22	1.23	$p = 0.450$	18	1.39	$p = 0.485$	22	1.32	$p = 0.400$
	M Deltoideus m.	19	1.05	W = 177.5	14	1.29	W = 84	20	1.25	W = 175	18	1.50	W = 232	24	1.38	W = 279.5
	F Deltoideus m.	21	1.16	$p = 0.263$	14	1.14	$p = 0.383$	22	1.04	$p = 0.065$*	18	2.11	$p =$ **0.018**	23	1.39	$p = 0.937$
Humerus	*M Pectoralis major m.*	21	1.24	$X^2 = 3.231$	19	1.26	W = 163.5	16	1.25	W = 140	16	1.62	W = 118	25	2.12	W = 246.5
	F Pectoralis major m.	21	1.00	$p = 0.199$	22	1.04	$p = 0.055$*	19	1.05	$p = 0.433$	16	1.50	$p = 0.684$	25	1.80	$p = 0.170$
	M Lat. dorsi/Teres major m.	21	1.09	$X^2 = 2.002$	20	1.30	W = 182	17	1.12	W = 173.5	16	1.75	W = 99	25	1.60	W = 210
	F Lat. dorsi/Teres major m.	20	1.00	$p = 0.157$	23	1.04	$p = 0.054$*	22	1.04	$p = 0.425$	17	1.41	$p = 0.132$	24	1.17	$p =$ **0.027**
	M Deltoideus m.	22	1.18	W = 201.5	20	1.35	W = 162	21	1.24	W = 223.5	18	1.54	W = 184	24	1.71	W = 260
	F Deltoideus m.	19	1.10	$p = 0.747$	20	1.15	$p = 0.145$	24	1.12	$p = 0.336$	18	1.39	$p = 0.664$	25	1.48	$p = 0.370$
	M Brachioradialis m.	22	1.36	W = 145.5	19	1.47	W = 134.5	21	1.43	W = 180	19	1.79	W = 148.5	25	1.64	W = 226
	F Brachioradialis m.	16	1.06	$p = 0.162$	19	1.16	$p = 0.074$*	20	1.20	$p = 0.287$	15	1.87	$p = 0.838$	25	1.20	$p =$ **0.030**
Radius	*M Biceps brachii m.*	23	1.13	W = 204.5	19	1.26	W = 168.5	19	1.16	W = 197.5	20	1.65	W = 97	25	1.56	W = 293
	F Biceps brachii m.	18	1.17	$p = 0.926$	21	1.14	$p = 0.211$	21	1.14	$p = 0.938$	15	1.20	$p =$ **0.037**	23	1.56	$p = 0.908$
	M Pronator teres m.	22	1.18	$X^2 = 2.511$	20	1.15	W = 181.5	18	1.22	W = 191	20	1.70	W = 127.5	20	1.20	$X^2 = 3.399$
	F Pronator teres m.	17	1.00	$p = 0.285$	20	1.10	$p = 0.349$	23	1.13	$p = 0.474$	17	1.35	$p = 0.149$	21	1.00	$p = 0.183$
	M Interosseous membrane	22	1.00	$X^2 = 1.254$	21	1.19	W = 172	19	1.10	W = 234	20	1.45	W = 146	23	1.43	W = 223.5
	F Interosseous membrane	18	1.06	$p = 0.263$	18	1.06	$p = 0.377$	24	1.08	$p = 0.761$	18	1.22	$p = 0.227$	24	1.25	$p = 0.135$
Ulna	*M Triceps brachii m.*	21	1.19	$X^2 = 2.338$	21	1.19	W = 174	20	1.15	W = 205.5	20	1.30	W = 151	24	1.46	W = 260.5
	F Triceps brachii m.	15	1.00	$p = 0.311$	81	1.11	$p = 0.513$	23	1.04	$p = 0.246$	15	1.33	$p = 0.981$	22	1.36	$p = 0.935$
	M Brachialis m.	23	1.17	$X^2 = 1.712$	23	1.26	W = 187.5	21	1.14	W = 220	20	1.45	W = 195.5	24	1.71	W = 205.5
	F Brachialis m.	12	1.00	$p = 0.425$	19	1.16	$p = 0.258$	22	1.09	$p = 0.563$	16	1.75	$p = 0.212$	23	1.30	$p = 0.076$*
	M Supinator m.	23	1.09	$X^2 = 0.758$	23	1.22	W = 187.5	20	1.10	$X^2 = 2.310$	21	1.43	W = 202.5	24	1.71	W = 234.5
	F Supinator m.	17	1.00	$p = 0.384$	18	1.17	$p = 0.445$	22	1.00	$p = 0.129$	17	1.65	$p = 0.411$	25	1.40	$p = 0.135$
Femur	*M Gluteus maximus m.*	23	1.39	W = 150	24	1.87	W = 212.5	21	1.43	W = 202.5	22	1.77	W = 192	24	2.12	W = 226
	F Gluteus maximus m.	17	1.12	$p = 0.077$*	22	1.54	$p = 0.219$	23	1.17	$p = 0.198$	20	1.60	$p = 0.447$	24	1.79	$p = 0.178$
	M Iliopsoas m.	21	1.24	W = 137.5	23	1.52	W = 187	18	1.22	W = 135	14	1.43	W = 99	25	2.12	W = 180.5
	F Iliopsoas m.	15	1.07	$p = 0.297$	21	1.19	$p = 0.112$	18	1.06	$p = 0.162$	15	1.27	$p = 0.759$	23	1.52	$p =$ **0.018**
	M Vastus medialis m.	23	1.17	W = 163.5	24	1.33	W = 196.5	22	1.09	W = 241	20	1.25	W = 182	24	1.92	W = 180
	F Vastus medialis m.	14	1.21	$p = 0.916$	20	1.15	$p = 0.149$	23	1.04	$p = 0.546$	18	1.22	$p = 0.951$	22	1.32	$p =$ **0.035**
Patella	*M Quadriceps tendon*	13	1.31	$X^2 = 2.154$	13	1.61	W = 78.5	14	1.29	W = 105.5	17	1.41	W = 126	9	2.00	W = 70.5
	F Quadriceps tendon	8	1.00	$p = 0.341$	15	1.20	$p = 0.233$	18	1.06	$p = 0.186$	16	1.37	$p = 0.672$	19	1.68	$p = 0.416$
Tibia	*M Quadriceps tendon*	19	1.16	W = 164	18	1.28	W = 151.5	16	1.31	$X^2 = 3.770$	10	1.60	W = 46	25	1.92	W = 156
	F Quadriceps tendon	16	1.25	$p = 0.531$	18	1.17	$p = 0.645$	13	1.00	$p = 0.152$	10	1.50	$p = 0.754$	24	1.12	$p <$ **0.001**
	M Soleus m.	21	1.19	W = 163	19	1.53	W = 151.5	18	1.39	W = 136	14	1.43	W = 93.5	24	1.37	W = 295
	F Soleus m.	17	1.06	$p = 0.408$	22	1.14	$p =$ **0.039**	16	1.25	$p = 0.737$	13	1.46	$p = 0.909$	25	1.32	$p = 0.898$
Calcaneus	*M Achilles tendon*	13	1.77	W = 58.5	13	1.69	W = 108.5	15	1.47	W = 110	11	2.09	W = 72	19	2.10	W = 80
	F Achilles tendon	12	1.33	$p = 0.225$	17	1.65	$p = 0.945$	16	1.37	$p = 0.655$	15	1.87	$p = 0.568$	11	1.73	$p = 0.270$

Table 4
Kruskal-Wallis tests and Dunn's post-hoc comparisons with Bonferroni correction for both male and female samples (significant values in bold).

		Mean individual score			**Mean upper limbs score**			**Mean lower limbs score**		
Females	**Kruskal-Wallis**	Statistic = 28.926			Statistic = 23.347			Statistic = 28.665		
		p **< 0.001**			*p* **< 0.001**			*p* **< 0.001**		
	Dunn's Post Hoc	Mean	z	*p*	Mean	z	*p*	Mean	z	*p*
	Roman vs Early medieval	1.09–1.22	1.953	0.509	1.12–1.27	1.790	0.735	1.09–1.20	1.729	0.837
	Early vs Late medieval	1.22–1.14	1.258	1.000	1.27–1.13	1.609	1.000	1.20–1.12	1.246	1.000
	Late medieval vs Modern	1.14–1.49	−3.245	**0.012**	1.13–1.45	−2.838	**0.045**	1.12–1.55	−3.649	**0.003**
	Modern vs Contemporary	1.49–1.40	0.293	1.000	1.45–1.47	0.827	1.000	1.55–1.36	−0.385	1.000
	Roman vs Contemporary	1.09–1.40	4.269	**<0.001**	1.12–1.47	3.856	**0.001**	1.09–1.36	4.122	**<0.001**
Males	**Kruskal-Wallis**	Statistic = 29.637			Statistic = 20.123			Statistic = 30.558		
		p **< 0.001**			*p* **< 0.001**			*p* **< 0.001**		
	Dunn's Post Hoc	Mean	z	*p*	Mean	z	*p*	Mean	z	*p*
	Roman vs Early medieval	1.20–1.38	2.124	0.337	1.28–1.56	1.820	0.688	1.16–1.27	−2.400	0.164
	Early vs Late medieval	1.38–1.23	1.662	0.965	1.56–1.27	1.766	0.774	1.27–1.20	1.160	1.000
	Late medieval vs Modern	1.23–1.60	−3.265	**0.011**	1.27–1.59	−1.764	0.777	1.20–1.60	−3.534	**0.004**
	Modern vs Contemporary	1.60–1.69	0.593	1.000	1.59–1.92	1.969	0.490	1.60–1.61	−0.117	1.000
	Roman vs Contemporary	1.20–1.69	4.353	**<0.001**	1.28–1.92	3.846	**0.001**	1.16–1.61	4.176	**<0.001**

be attributed to the use of donkeys and mules, rather than horses, which were reserved for the wealthier segment of the population for military activities or transportation. In our case, the use of equids (e.g., donkeys, mules) was almost exclusively practiced by men, including farmers, transporters, and artisans, who moved and transported goods on the backs of mules and donkeys. Additionally, from the end of the 3rd century, a significant portion of the Roman army was composed of barbarians (Grillo, 2008, pp. 5, 9, 24), to the extent that it led to the "Germanization" of the army. During the Lombard era, all free men were required to contribute to the military (6th-7th centuries). The higher development of upper limb musculature in males compared to females is consistent with the actions performed during combat, even by infantrymen. In Milan, throughout much of the Middle Ages and until the 13th century, all men (aged 18 to 60) were obligated to take turns fighting – using not only weapons like swords, shields, pikes, and lances, but also tools typically used in their daily work such as axes, cleavers, sickles, etc. (Grillo, 2008, pp. 118–119). However, from that date onwards, due to a "disaffection towards arms" (Grillo, 2008, p. 141), they were largely replaced by professional soldiers, mostly foreign mercenaries of low social status, hired in mercenary companies and then serving under *condottieri* (Grillo, 2008, pp. 141–166, 2003, pp. 38–41). In the Lombard era, the lower strata of the population consisted of free men who used bows and arrows (*exercitales*: (Grillo, 2008, p. 32), while knights who fought with swords and lances were almost always part of the socioeconomic elite. However, the *milites* of northern Italy mentioned in an 11th-century source, were not nobles and were positioned in the social hierarchy midway between the common population and state officials (Bishop Atto of Vercelli; (Grillo, 2008, pp. 95–96). During the Carolingian period (8th-9th centuries), there was compulsory conscription for all free adult males, but with distinctions for peasants and small landowners, who, due to their occupational needs, were allowed to serve in turns by paying a monetary substitute instead of joining the army (Grillo, 2008, pp. 41–43). In the cities of central-northern Italy, from the 11th century onwards, knights were those who could afford to buy a horse, armor, and weapons, meaning their status was determined solely by financial capability and not by social requirements or proximity to power (Grillo, 2008, p. 98).

4.2.3. Late medieval sample

Analysis of EC in the sample attributed to the Late Middle Ages showed one entheseal site with statistically significant different scores between males and females, in favor of males: the *costoclavicular ligament* of the clavicle. This ligament is particularly stressed during rotary movements (Hawkey and Merbs, 1995). Although not significant (except for the *costoclavicular ligament*), values of entheseal robusticity were systematically higher in males than in females, except for the *pectoralis major muscle* enthesis where the female mean score was slightly higher (by 0.09). The amplitude of scores was less important than in the previous period (though this was not significant, see Table 4), with mean values per site ranging from 1.00 to 1.47 and indicating overall lower scores.

Both males and females showed their highest scores at the level of the *Achilles tendon* (calcaneus) insertion, although they represent only medium entheseal development. Indeed, on average, after the *Achilles tendon*, the highest scores were found at the attachments of the *gluteus maximus* (femur) and *brachioradialis* (humerus) muscles in males, and *trapezoid ligament* (clavicle) and *soleus muscle* (tibia) in females. Results do not show major differences in scores between upper and lower limbs. In Milan, the sectors where most of the active population, both male and female, were engaged included textiles, leather processing, metalworking, and construction-related activities (Zanoboni, 2014), which is consistent with the skeletal evidence provided in the analysis of EC. In late medieval Milan, the majority of urban workers were shoemakers, leather workers, blacksmiths, carpenters, barbers, *ritaglieri* and *sellai* which in some cases were counted among the poorest (Balestracci, 1982). Written sources state that women were also involved in urban construction activity: they performed ancillary duties, e.g., assistant-bricklayer, yet they received half the wages given to men and often worked outside the established trade guilds (Zanoboni, 2014). Clearly, these tasks were less physically tiring than those performed by men but entheseal robusticity scores indicate relatively low entheseal development in this period. In the Lombard metropolis, thousands of people were employed as weavers, fullers, spinners, and dyers. From the 12th century onwards, a significant change occurred in weaving, where female labor was prevalent, with the introduction of foot-powered looms. This innovation increased production, labor, and physical activity, impacting not only the upper limbs but also the leg operating the pedal. Additionally, there was no evidence of robusticity patterns that could be associated with the activity of horse riding (Belcastro and Facchini, 2001; Berthon et al., 2018; Fornaciari et al., 2007; Józsa et al., 1991), a typical scenario within our common imaginary about the Late Middle Ages.

4.2.4. Modern sample

The modern era is the only period in which statistically significant differences in EC between sexes were noted with both male and female samples showing higher values. Indeed, males presented EC significantly more marked than females at the *biceps brachii muscle* (radius) insertion, whereas women had significantly more robust entheseal attachments of the *deltoideus muscle* on the clavicle. For men, this insertion can be related to the flexion, extension, and supination of the forearm, while for women, the deltoideus muscle is involved in the abduction and rotation of the shoulder (Hawkey and Merbs, 1995).

In this sample, mean values presented a greater scoring amplitude, ranging from 1.2 or slight robusticity to 2.11, corresponding to high development, and were more sparsely distributed among sexes. In fact, higher scores were recorded in men for 13 entheseal sites and in women for 10, though differences were statistically significant for only two in total. Interestingly, almost all of the entheseal sites in women with a higher mean value of robusticity than in men were located on the upper limbs (except for the *soleus muscle* insertion on the tibia). In fact, the highest average score was found in the female sample for the clavicular insertion of the *deltoid muscle* (score 2.11). The most robust entheseal sites appear to be the *Achilles tendon* (average score 2.09), *gluteus maximus* (average score 1.77) and *latissimus dorsi/teres major muscles* (average score 1.75) in males, and in females the aforementioned *deltoid muscle* on the clavicle (average score 2.11), *conoid ligament* (average score 1.95), *brachioradialis muscle* (average score 1.87), and *Achilles tendon* (average score 1.87), showing higher scores in females. Because of these values in the bones of the arm for both males and females, the upper limbs seem to show higher overall scores than the lower limbs, which may be a result of their occupational activity. The prevalence of more robust entheses in the upper limbs among modern males is also common in research sites far distant to that of the present study. Indeed, Cook and Dougherty (2001) identified occupational activities typical of northern Europe in the pattern of male EC, especially in the upper limbs. Similar to our study, Palmer et al. (2016) saw sexual dimorphism on the *biceps brachii muscle* in his Dutch sample in favor of males. The advancements in machinery used in the silk sector, starting from the mid-14th century with the introduction of silk mills replacing twisting machines, created true “industrial plants” predominantly employing male labor (Poni, 1996, pp. 270–271), although large Bolognese-style silk mills only became widespread from the second half of the 17th century (Poni, 1996, pp. 280–281). In Milan, from the 15th century and throughout the modern era, one of the most common occupations for women was weaving silk and gold-thread fabrics, brocades, and damasks, where they could achieve the status of master weavers (Poni, 1996, pp. 271, 288–289; Zanoboni, 2016, pp. 80–86, 1997). In fact, as the Italian modern historian Bellavitis writes “the textile sector has traditionally been dominated by female labor, although some tasks like sewing and tailoring, which are assumed to have always been performed by women, only became feminized in the modern era” (Bellavitis, 2016, p. 127). Similar to Venice, from the 16th-17th centuries, they worked both *“alla piana”* and *“in opera”*, in tasks such as winding, doubling, warping, and spinning precious metals for producing aurous fabrics (Bellavitis, 2016, p. 107). In 1585, Tommaso Garzoni, known for his notorious misogyny, wrote that women could be “sibyls, witches, court women, housekeepers, prostitutes, pimps, wool spinners, laundresses, midwives, wet nurses, and nannies” (Garzoni, 1996, pp. 790–791). This list suggests that although laundresses were present during the medieval period, their numbers increased from the 16th century onwards, often working alongside family members. This labor, arduous and conducted outdoors, became feminized because it was tied not only to textile manufacturing but also to domestic needs expressed by the bourgeoisie (Bellavitis, 2016, pp. 15–16; Lilli, 2008). The greater participation of women in textile production, the introduction of specific machinery in the sector, and the rise of the laundering profession, all of which heavily engaged the upper limbs, may explain the development of entheseal changes observed in the modern era.

4.2.5. Contemporary sample

In the contemporary sample, six entheseal sites were significantly more robust in men with respect to women, namely the insertions of the *triceps brachii* (scapula), *latissimus dorsi/teres major* (humerus), *brachioradialis* (ulna), *iliopsoas* (femur), and *vastus medialis muscles* (femur), as well as *quadriceps tendon* (tibia), involved in the extension and flexion of the forearm, adduction and rotation of the arm at the shoulder, flexion and rotation of the thigh at the hip, extension of the knee, and flexion of the trunk (Hawkey and Merbs, 1995). While these may be related to gender division of occupational activities, two other factors may play a role. First, entheseal development has been shown to be more pronounced in males than in females in the literature, a result that has also been observed throughout the present study. In addition, the contemporary sample is constituted of much older individuals with respect to the other historical periods (known ages – mean age of 67 years, median 71 years) with 66 % of individuals over 60 years (Cattaneo et al., 2018). The results obtained are therefore consistent with the literature and expected given the known association between EC and age (Weiss, 2004).

In the present sample, mean scores were almost always higher or equal in males than in females, except for the attachments of the *deltoideus muscle* and *costoclavicular ligament* (clavicle), though this difference was negligeable and not significant. Similarly, the sample studied by Mariotti and colleagues (2004), dated between 19th and the 20th century, shows that males presented more marked EC, with the exception of the *brachialis muscle* (ulna) insertion. Amplitude of EC ranged from 1.00 (representing low development) to 2.12 (or high development) with generally much higher scores in the male sample. Interestingly, EC with high entheseal development (mean score 2 and above) were mainly concentrated in the lower limbs, specifically the *gluteus maximus* and *iliopsoas muscles* (femur), *Achilles tendon* (calcaneus) and the patellar attachment of the *quadriceps tendon*, with the exception of the *m. pectoralis major* insertion on the humerus; whereas for females these high mean scores were not reached, amounting at the most to 1.80 at the *pectoralis major muscle* (humerus) insertion. Although this may be explained by a higher muscular loading due to physical activity, age-at-death may have played a significant role. Indeed, Milella et al. (2012), observed a similar trend in their 20th century sample and identified a statistically significant correlation between the robusticity of the entheseal attachment and age-at-death.

4.2.6. Diachronic trends

When examining differences across historical periods, we note an overall increase in robusticity scores from the Roman age to the Contemporary age for both males and females (Table 3). This is consistent with the literature as the contemporary sample is characterized by a distribution of ages-at-death towards the older age groups (mean age of 67 years) and EC have an established association with age. The same reasoning may be applied to the other historical periods (individuals over 45 years per historical period: 22 % for the Roman era, 36 % for the Early Middle Ages, 34 % for the Late Middle Ages, 48 % for the modern era, and 84 % for the contemporary era): as the percentage of older individuals increased over periods, it is not surprising that robusticity scores augmented. However, this explanation is only applicable to a certain extent. Indeed, age is not the only factor playing an important role in entheseal development and age group distribution was comparable between the various historical periods, with few elderly individuals (2–6 % of individuals over 60 years) except for the contemporary era. Consequently, the overall increase in robusticity scores observed in the present study may be the results of more physically strenuous occupational activities requiring repeated muscular loading.

Investigation of the evolution of entheseal development over time (Fig. 3) shows a common and statistically significant trend ($p < 0.001$) (Table 4): low scores in Roman times (mean female individual score: 1.09; male mean: 1.20), an increase of entheseal robusticity scores in the Early Middle Ages (female mean: 1.22; male mean: 1.38), that decrease in the Late Middle Ages (female mean: 1.14; male mean: 1.23), a sharp escalation in the modern era (female mean: 1.49; male mean: 1.60), which slightly declines in females (mean 1.40) and continues increasing in males (mean 1.69) in the contemporary era. Comparisons of the samples evidenced a marked increase in entheseal robusticity in Milan between Roman and contemporary eras ($p < 0.001$). Additionally, a significant increase in mean individual scores for both sexes ($p < 0.05$)

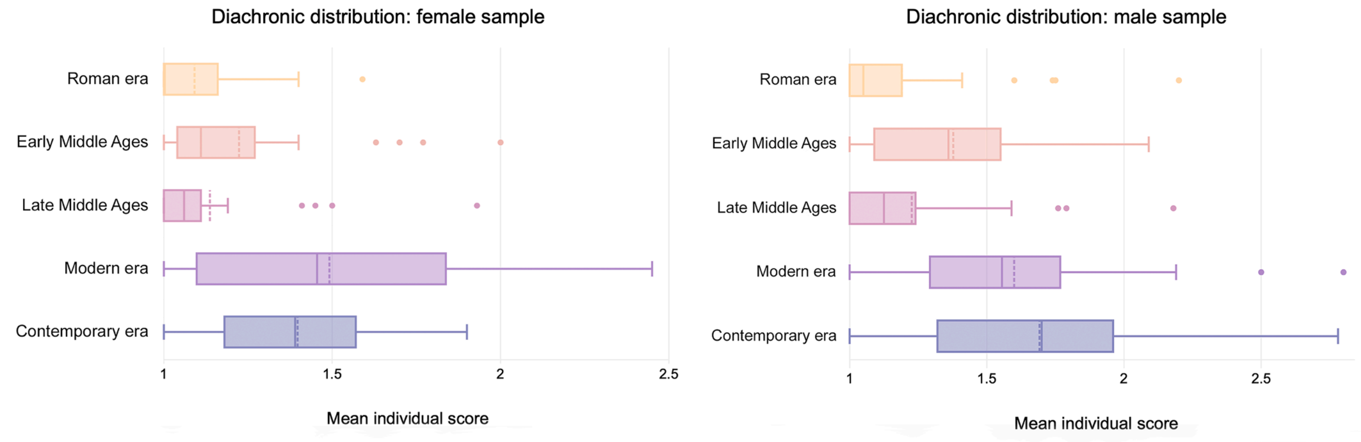

Fig. 3. Box plots showing the diachronic distribution of mean individual scores of entheseal robusticity for females and males (solid line: median; dashed line: mean).

was found between the early (Roman and medieval) and late historical periods (modern and contemporary) ($p < 0.05$) which can be pinpointed to the transition between the late medieval and modern eras. Consequently, the assessment of the robusticity of entheses reflected the variation in the types of work and activities performed in Milan over the last 2,000 years, following the different social and economic changes that impacted its inhabitants. For example, there is an observed increase in male entheseal robusticity from the Roman era to the Early Middle Ages, which coincides with the arrival of the Lombards, overall changes in lifestyle in the transformation of the Western Roman Empire, and the integration of new practices, such as mandatory conscription.

The modern period showed particularly interesting results. Significant differences in sexes were always greater in males and male mean values were almost systematically higher in males with respect to females (82 % of instances); this is not surprising *per se*, as EC have shown to be more developed in males than females in the literature (Weiss, 2004). Yet, the modern sample is the only one that does not conform to this trend. Indeed, in this period, females showed significantly more robust attachments of the *deltoid muscle* on the clavicle, and a total of ten entheseal insertions (43 % – almost half of them) reported higher mean values of EC in females. Furthermore, this is the only period in which entheseal sites of the upper limbs appear more developed than in the lower limbs (Table 3). This osteological evidence may be the reflection of the massive intensification of the textile industry in modern era Milan, which particularly impacted women. Therefore, even in the case of women, the assessment of the robusticity of entheses revealed their changing lifestyle over time, adding a new puzzle piece for the reconstruction of women’s history.

4.3. Considerations and interpretative limitations

EC have long been used in the bioarchaeological literature to reconstruct pattern of physical activity and investigate divisions of labor in the past. In this perspective, we evaluated the degree of robusticity of 23 entheseal sites (both right and left) of 250 skeletons to explore occupational stress in males and females in Milan over 2,000 years. However, there are several elements intrinsic and extrinsic to the study that influence EC and thus limit the interpretations that may be drawn from the present study.

First, the state of the preservation of the skeletal remains of the study sample. Preservation is a major contender in bioarchaeological studies, especially when dealing with archaeological remains. Here, it implies that not all skeletons had all left and right entheseal sites present or sufficiently well-preserved to be evaluated. In fact, only in five skeletons out of the total sample of 250 individuals were all 46 entheseal sites observed: all were males, three were Roman, one contemporary and one late medieval. Out of 11,500 entries in the dataset (46 entheseal sites x 250 individuals), 4,072 could not be scored (35 %) because of taphonomic preservation. The majority of these (52 % – 2,141) were from female individuals. This is not surprising given that females tend to be less well-preserved than males (Biehler-Gomez et al., 2022). As expected, only a minority of entheseal changes could not be recorded on the contemporary skeletons (8 % of the total sample – 347), known to be well-preserved (Biehler-Gomez et al., 2022), while that percentage varied between 21 % and 28 % for the other historical periods (Roman, 866 – 21 %; early medieval, 893 – 22 %; late medieval, 843 – 21 %; modern, 1123 – 28 %). This is an unavoidable limitation inherent to the nature of archaeological material.

Second, the different ages-at-death among individuals could present a limitation of the research, as EC are cumulative with age (Mariotti et al., 2004; Milella et al., 2012; Weiss, 2003). However, the aim of this study was not to compare activity patterns between younger and older individuals. Instead, the primary objective was to examine differences in entheseal robusticity between males and females across each necropolis/site and diachronic analysis was conducted to assess overall trends across time periods. Consequently, both young and old individuals were considered equally important, and no direct comparison was made between these two age groups. Moreover, all subsamples exhibited a similar age-at-death distribution: the Roman era (n = 32), Early Middle Ages (n = 33), Late Middle Ages (n = 35), and Modern era (n = 38) all showed a peak frequency in the 21–45 years age range. This consistency enabled comparisons between these subsamples while minimizing the bias associated with age-at-death. The sole exception is the Contemporary era sample, which includes a significantly higher proportion of older individuals (n > 46 years: 35). This discrepancy presents a limitation when comparing this period with earlier historical phases.

Third, the methodology implemented. In this paper, we examined all entheseal sites for EC following the same methodology, i.e., that developed by Mariotti et al. (2007). However, scoring was limited to entheseal robusticity and we did not consider enthesophytes or porosities. Evaluation of entheseal changes by visual scoring may be more or less subjective (Mariotti et al., 2004). In fact, Mariotti and colleagues themselves observed high interobserver error between adjacent scores and recommended grouping the three subgroups of score 1 to avoid sample fragmentation, which we applied in this study. Additionally, bioarchaeological studies on EC use different methods that employ various number of stages, thus complicating comparison of the data acquired.

Fourth, the choice of EC as indicators of occupational stress. The postulate in using EC to reconstruct the past is that, as entheses are sites of interface between muscles and bones, they are sensitive to mechanical loading which may lead to bone remodeling. As such, EC are used as indicators of repeated and prolonged muscular activity and can thus allow to explore biomechanical patterns and physical activity in the past. However, some entheses are naturally smooth (Cardoso and Henderson, 2013) and the robusticity of the entheseal site also depends on the gracility of the bone (Wilczak, 1998). Moreover, as already mentioned, EC may be influence by a vast array of factors including age, body size, sex, anatomy of the attachment site, metabolic, genetic, and pathological conditions, as well as traumatic bone injuries (Milella et al., 2012). To get a clearer picture of physical activity, other skeletal markers should be considered in a multifactorial approach including osteoarthrosis of synovial articulations, vertebral degenerative changes, and antemortem traumatic lesions. Additionally, as Jurmain and colleagues explained: "the major issue for many of the supposed "markers [of activity]" is the near-total lack of contemporary reference samples to permit accurate estimation of their specificity relative to particular activities" (Grauer, 2012, p. 538; Jurmain et al., 2011). Consequently, given their lack of specificity, EC cannot reliably identify specific activities. Our suggestions of activities are therefore just that, possibilities of activities based on the entheseal sites involved and historical documentation, aimed only at examining consistency of findings between the present study and written sources.

5. Conclusion

Several factors may participate in the development of EC and the literature has demonstrated physical activity to be one of them. Hence, as markers of repeated muscular loading, EC can serve as indicators of physical stress in the past. In this paper, we tried to provide a new lens through which we could reconstruct, at least partially, the toll of mechanical stress among Milanese men and women over the last 2,000 years, focusing on three aspects of entheseal robusticity: asymmetry, differences between sexes, and diachronic trends. While limited in their interpretative power and multifactorial in etiology, analysis of entheseal robusticity showed no significant asymmetry, an overall higher development in males with respect to females, and a similar temporal trend for both sexes. This potentially indicates a gender division of labor as well as a general increase and cultural change in physically strenuous activities. In particular, females were found to evidence high entheseal robusticity scores in the upper arms in the modern era which may be associated to activities related to textile production. Some activities typically performed by males such as military involvement and the use of donkeys, mules, and horses may have led to muscular loading in the upper and lower limbs which could explain the EC reported. Conversely, the high scores observed in the contemporary era may be explained in part by the advanced age-at-death of the individuals of this sample.

Interestingly, the results revealed not only a general increase in female physical activity over time but also a dynamic perception of the female body, which can be seen as an economic instrument reflecting the socio-historical context of women. Indeed, entheseal changes demonstrate that women have become increasingly involved in occupational activities, underscoring their entry into and growing importance within the workforce. In contrast, for males, entheseal changes reflected a more static role over time, consistently engaged in strenuous physical activities throughout all historical periods.

CRediT authorship contribution statement

Lucie Biehler-Gomez: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Conceptualization. **Claudia Moro:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Conceptualization. **Beatrice del Bo:** Writing – review & editing, Writing – original draft, Resources, Conceptualization. **Mirko Mattia:** Data curation. **Lucrezia Rodella:** Visualization. **Giorgio Manzi:** Supervision. **Cristina Cattaneo:** Supervision.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jasrep.2024.104966.

Data availability

Data supporting the findings of this study are available within the article. Raw data that support of the findings of the study are available as Supplementary Material.

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