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Osteoarthritis – a problematic skeletal trait in past human populations. Osteoarthritic changes vs. entheseal changes in the late medieval and early modern population form Łekno

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ABSTRACT: According to medical knowledge, physical activity plays a role in osteoarthritic changes formation. The impact of occupation on osteoarthritic changes development in past human populations is not clear enough, causing problems with interpretation. The aim of the current study is to examine the relationship between osteoarthritis and entheseal changes. Skeletal material comes from the late medieval, early modern population from Łekno (Poland). The sample consists of 110 males and 56 females (adults only). Osteophytes, porosity and eburnation were analyzed in the shoulder, elbow, wrist, hip, knee, and ankle. Entheses on the humerus, radius, femur, and tibia were examined. Standard ranked categorical scoring systems were used for the osteoarthritic and entheseal changes examination.

Males with more developed osteophytes in the shoulder have more "muscular" upper limbs (higher values of muscle markers). Males with more developed osteophytes in the hip and knee are predicted to have more "muscular" lower limbs. Males with more developed osteoarthritis in the shoulder, wrist, hip, and knee exhibit more developed entheseal changes. Males with more developed entheses tend to yield more developed osteophytes (all joints taken together) and general osteoarthritis (all changes and all joints taken together). Females with more developed entheses have more developed osteoarthritis in the elbow, wrist, and hip. Individuals with more developed entheses have much more developed osteophytes. When all the three types of changes are taken together, more "muscular" females exhibit more developed osteoarthritis. The lack of uniformity of the results, wild discussions on the usage of entheses in activity patterns reconstruction and other limitations do not allow to draw unambiguous conclusions about the impact of physical activity on the osteoarthritis in past populations and further studies are needed.

KEY WORDS: osteophytes, porosity, eburnation, physical activity, skeletal population

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Introduction

Osteoarthritis (OA) is an ubiquitous pathological condition in skeletal populations (Rogers and Waldron 1995, Lieverse et al. 2007, Weiss and Jurmain 2007, Calce et al. 2018). It is also a common joint disorder observed today (Arden and Nevitt 2006, Rothschild and Woods 1993). Research on osteoarthritis has been hugely popular in both medical science and bioarchaeology. The reason for this has been the insufficiently known etiology of OA changes, as well as the great prevalence of the disorder in past and contemporary humans.

Medical science is aimed at improving knowledge of the reasons of OA appearance and progression (Hunter and Spector 2003, Valdes and Spector 2010), the response of cells, tissues, and organs to etiological factors (Abramson and Attur 2009), the epidemiology of the disorder (see Arden and Nevitt 2006, Johnson and Hunter 2014), methods of osteoarthritic changes diagnosing (O'Reilly and Doherty 2003, Moskowitz 2007), its prevention and treatment (Felson et al. 2000, Sarzi-Puttini et al. 2005, Fakhari and Berkland 2013, Jevsevar 2013).

The etiology of osteoarthritis is multifactorial (Felson 2003, Martel-Pelletier 2004, Teichtahl et al. 2005, Arden and Nevitt 2006, Roach and Tilley 2007, Gabay et al. 2008). Age, sex, obesity, genes, metabolic factors, articular cartilage nutrition, endocrine factors, bone density, overloading of the musculoskeletal system, joint injuries, joint infection, congenital defects, joint instability, congenital and/or developmental joint deformities, physical activity and occupation, or even muscle weakness are given as etiological factors (Anderson and Loeser 2010, Arden and Nevitt 2006, Felson 2003, Gabay et al. 2008, Teichtahl et al. 2005).

On the basis of medical knowledge about OA, bioarchaeologists have used osteoarthritic changes to describe the biology of past human groups, especially with regard to health status and habitual behavior (*see* Weiss and Jurmain 2007, Rothschild and Woods 1993). Despite its high incidence, for biological anthropologists, osteoarthritis is still a problematic in terms of etiology and interpretation. The relationship between OA changes and some etiological factors (e.g. age, sex, body size, physical activity) in skeletal populations are not unanimous, and in many cases these data do not coincide with clinical views. Osteoarthritic changes as skeletal traits with not well understood etiology and progression (Felson 2003, Teichtahl et al. 2005, Arden and Nevitt 2006, Roach and Tilley 2007, Weiss and Jurmain 2007, Gabay et al. 2008) raise a number of problems for researchers of past human populations.

Biological anthropologists have tried to find out what osteoarthritic changes tell about skeletal populations, if osteoarthritic changes can be treated as health and socioeconomic status indicators, if these changes are reliable markers of physical activity, and therefore if they can be used for past human lifestyle reconstruction (Weiss and Jurmain 2007). Finding out the answer for these questions is crucial for reliable evaluation and interpretation of osteoarthritic changes in skeletal populations, for proper interpretation of their ecology, biology and behavior. Finding out an answer to these questions could also be useful for clinician in preventing and treating osteoarthritic changes.

According to medical knowledge, physical activity and occupation are given as etiological factors in OA formation (Anderson and Loeser 2010, Arden and Nevitt 2006, Felson 2003, Gabay et al. 2008, Teichtahl et al. 2005). Muscles are the biggest contributors to the mechanical loading of joints, which is thought to provide crucial mechanical stimuli for cartilage nutrition, disorders which lead to OA progression (Herzog and Longino 2007). Some data confirm that stronger muscle contraction forces increase joint loads and therefore increase the risk of OA development (Chaisson et al. 1999). There are studies showing the opposite results, the protective role of strong muscles against osteoarthritis (strong quadriceps decreases OA progression) (Slemenda et al. 1997, 1998, Sharma et al. 2003). Although muscle weakness is postulated as a risk factor in OA etiology, this influence is not clear yet. This inconsistency is not clear. It is postulated that other local factors can influence load distribution and contribute to safe muscle force distribution over the menisci, articular cartilage, and other tissues (e.g. joint tissues laxity) (Sharma et al. 2003, Arden and Nevitt 2006).

Similarly to clinicians, which are not unanimous on the impact of physical activity on the osteoarthritis development, bioarchaeologists are also cautious when they interpret this impact. A group of studies examine the relationship between osteoarthritis and entheseal changes (ECs) which are treated, though with caution, as physical activity markers. Entheses define the area where a capsule, a tendon or a ligament attaches to bone and covers non-pathological changes in the attachment site (Benjamin *et al.* 2002, Villotte and Knüsel, 2013). Taking the assumption that bone tissue changes in response to environmental stress (biomechanical stimuli connected with physical activity) to protect itself against breakage (Ruff at al. 2006, Schoenau and Frost 2002) or to prevent a ligament/tendon rupture (Hawkey 1998), entheseal changes are treated by some authors as physical activity markers (Eshed et al., 2004; Henderson and Alves Cardoso 2013). The etiology of entheseal changes is multifactorial. A role of genes, age, physical activity, sex, hormones, or body mass is underlined in ECs formation (Milella et al. 2012, Niinimäki, 2011, Schlecht 2012, Villotte and Knüsel 2013).

Some authors hypothesized that if positive relationships between OA and entheses exist, it is possible that osteoarthritic changes have similar etiology as entheses and therefore they could be activity indicators, and therefore they can be used in activity patterns reconstruction (Rojas-Sepúlveda and Dutour 2014, Woo and Pak 2013, Schrader 2012, Palmer at al. 2016). The anthropological studies results do not unequivocally confirm this thesis.

Rojas-Sepúlveda and Dutour (2014), who examined entheseal changes and osteoarthritis in Pre-Hispanic skeletal collections, obtained a mismatch between results from OA and ECs, attributing the the lack of associations with their independent etiology. Similar results and conclusions were drawn by Woo and Pak (2013) for the Korean population. These researchers tried to explain it suggesting that osteoarthritic changes and attachment sites have different levels of vulnerability to various causes (Woo and Pak 2013). In the Tombos population of New Kingdom Period Nubia (1550–1069 BC) Schrader (2012) found a significant correlation between lipping and entheseal changes in the wrist and hip, while no such relationship was found for lipping, porosity and eburnation in other joints. The author does not draw any firm conclusions about etiological relationships between these two groups of skeletal markers, although she indirectly points to their dependence (Schrader 2012). Palmer and colleagues (2016), who found a very low correlation between OA and ECs in post-medieval Dutch, argued that the result may illustrate the variable and complex etiology of these two groups of traits. Also Myszka (2015), who examined a medieval population from Cedynia and medieval and early modern populations from Słaboszewo, found that the strength and direction of the ECs and OA dependencies was not always significant, and was different according to joint and/or the type of osteoarthritic changes. Calce et al. (2018), who examined the relationship between osteoarthritic changes and femoral torsional strength (as another proxy for activity) in the modern European skeletal collections, found no significant impact of activity on OA formation, although the negative correlation between pelvic OA and femoral torsional strength authors refer to protective role of physical work capacity in childhood.

As seen above, the previous study results are not homogenous; they do not speak clearly for or against the existence of a relationship between osteoarthritis and entheses, and do not allow for drawing any final conclusions about dependent or independent etiology of these skeletal traits. This ambiguity of the results does not allow for any final conclusions and indicates a need to continue the research.

The present study is an attempt to increase knowledge about osteoarthritis to improve the usage of osteoarthritic changes in the analyses of skeletal collections. This knowledge is essential for proper, reliable interpretation of past human biology, ecology and behavior. In order to complete this knowledge, the relationship between osteoarthritis and entheseal changes on the basis of skeletal material from Łekno (Poland) is analyzed here.

Materials and methods

The skeletal material used in the study came from the late medieval, early modern (14th to 16th century) (Wyrwa 2003) population from Łekno. The bone material comes from the collection of the Department of Human Evolutionary Anthropology, Adam Mickiewicz University in Poznań. The sample under analysis consists of 110 males, 56 females.

Only adult remains were included in this study. Standard anthropological methods were applied to determine the sex and age of the individuals (Buikstra and Ubelaker, 1994). Features of the cranium and pelvis were assessed for sex estimation. Age was estimated through the analysis of pubic symphysis changes. The age categories used in the study followed the standards by Buikstra and Ubelaker (1994): Young Adult (20–34 years), Middle Adult (35–49 years), Old Adult (50+ years). The exact number of male and

Table 1. Age and sex distribution of Łekno sample

Age category	N	
	Males	Females
Young Adult	28	23
Middle Adult	57	22
Old Adult	25	11
All group	110	56

N – number of individuals.

female individuals in each age category examined in this study are presented in Table 1. The group of skeletons examined here includes individuals without any observable skeletal changes (illnesses, traumas, fractures or bone deformities) except osteoarthritic changes.

Łekno was a part of settlement complex where in historical times settlements and architectural structures of considerable political, administrative, socio-economic and religious significance were located (Wyrwa 1989). But the examined population is not well documented in terms of lifestyle and occupation, which additionally hinders the interpretation of the dependency between physical activity and analysed skeletal traits.

Osteoarthritic changes were examined in accordance with standard methods proposed by Buikstra and Ubelaker (1994). Three types of osteoarthritic changes were examined: osteophytic lipping (OP), porosity (POR) and eburnation (EB) (Buikstra and Ubelaker 1994). OA or a combination of osteophytic lipping, porosity or eburnation, if any, was scored in: (a) shoulder (articular surface of scapula, humeral head); (b) elbow (articular surfaces of distal end of humerus, articular surfaces of proximal end of ulna); (c) wrist (articular surfaces of distal end of ulna, articular surfaces of proximal and distal end of radius); (d) hip (acetabulum (pelvic bone), articular surface of femoral head); (e) knee (articular surface of distal end of femur, articular surfaces of proximal end of tibia); (f) ankle (distal end of tibia). Data were recorded using the four-point rating scale developed by Buikstra and Ubelaker (1994). Osteophytes (OP): (0) no observable change; (1) barely discernible; (2) sharp ridge, sometimes curled with spicules; (3) extensive spicule formation. Porosity (POR): 0) no observable change; (1) pinpoint; (2) coalesced; (3) both pinpoint and coalesced present. Eburnation (EB): (0) no observable change; (1) barely discernible; (2) polish only; (3) polish with groove (s).

According to the tissue type present at the attachment site two types of entheses can be distinguished: fibrocartilaginous and fibrous. Fibrocartilaginous entheses occur on long bone epiphyses, short bones, and some part of vertebrae. This type of EC changes does not attach to bone via periosteum. Fibrous entheseal changes occur on long bone diaphyses and attach to bone directly, or indirectly – by periosteum (Benjamin et al. 2002, Jurmain and Villotte 2010). In spite of some limitations resulting from a different anatomy of types of ECs, a slightly different response to the impact of environmental factors (Molnar 2010, Villotte 2009), both types of entheseal changes are used in the current study. to analyse a general relationships between entheseal and osteoarthritic changes. When selecting which entheseal changes to examine, the following factors were taken into account: (a) usage of muscle in “daily activity”, (b) repetitive occurrence of ECs in studies by various authors, (c) entheseal changes variability, (d) degree of bone material preservation. Considering the above, seven entheseal changes are examined here. The details of the changes under analysis are presented in Table 2. Only robusticity type of entheses are analyzed here. Four grades of robusticity are analyzed according to Hawkey (1998), Hawkey and Merbs (1995): (0) no observable changes in tendon attachment site, (1) weakly expressed robusticity, (2) moderate grade of robusticity, and (3) strong robusticity at the attachment site.

Table 2. Entheseal changes (EC) analyzed in the present study

EC	Bone structure (insertion site)	Muscle
H1	Bicipital groove	*Pectoralis major*
H2	Deltoid tuberosity	*Deltoid*
R1	Bicipital tuberosity	*Biceps*
R2	Midshaft of radius	*Pronator teres*
F1	Gluteal tuberosity	*Gluteus maximus*
F2	Linea aspera	*Adductor brevis, Adductor longus, Adductor magnus, Biceps femoris (short head), Vastus lateralis*
T	Soleal crest	*Soleus*

Statistical analyses were made using aggregate mean value of OA calculated as a mean value of OA. The analyses were made for each type of osteoarthritic change in each joint, for each type of OA change from all joints taken together, and for each type of OA changes and each joint taken together.

Statistical analyses were made using the aggregate mean value of entheseal changes as a mean value calculated from observable entheseal changes. Differences between males and females in osteoarthritic changes and entheseal changes were examined using U Mann-Whitney statistics. Correlations of osteoarthritic changes and entheseal changes with age were examined using Spearman's correlation.

The relationship between osteoarthritic changes and entheseal changes was tested using Spearman's correlation. The following relationships were examined: (a) entheseal changes of the upper limb bones (mean value of H1, H2, R1, R2) and upper limb joints osteoarthritic changes (osteophytes, porosity separately for shoulder, elbow, wrist); (b) entheseal changes of the lower limb bones (mean value of F1, F2, T) and lower limb joints osteoarthritic changes (osteophytes, porosity separately for hip, knee, ankle). Eburnation could not be included in these analyzes; (c) osteoarthritic changes in each joint (osteophytosis, porosity, eburnation taken together) and all entheseal changes (mean value of all the observable entheses); (d) all the entheseal changes (mean value of all the observable entheses) and OP (means of all observable osteophytes), POR (means of all observable porosity), EB (means of all observable eburnation), OA all (means of all observable types of osteoarthritic changes). The statistical significance was determined at the probability level of 0.05. Statistical analyzes were carried out using the Statistica 10.0 PL software.

Results

Table 3 contains the mean (x), standard deviation (SD), sample size (n) for osteoarthritic changes (osteophytes, porosity, eburnation) according to joint noted in the Łekno material. In males, the mean of osteophytes is 0.38, porosity is 0.30, eburnation is 0.002. When all joints and osteoarthiritic changes are taken together, the mean is 0.22. In the female group, the mean of osteophytes is 0.30, porosity is 0.34, eburnation is 0.009. When all joints and osteoarthritic changes are taken together, the mean is 0.22. The differences in osteoarthritic changes between males and females are not statistically significant (Table 3).

Table 4 contains the mean (x), standard deviation (SD), sample size (n) for entheseal changes in the Łekno material. In males, when all entheses are taken together, the mean is 1.62, in females it is 1.37. In males, the mean is higher for linea aspera (F2; x=2.07), the lowest for deltoid tuberosity (H2; x=1.07). In the female group, the mean is higher for gluteal tuberosity (F1; x=2.11), the lowest for pronator teres origin (R2; x=0.87). Statistically significant differences between males and females were obtained for pronator teres origin (R2).

When the correlations of osteoarthritic changes with age are analyzed, the results are not homogeneous. In some samples there is significant increase with age in males (OP in the shoulder, knee, and when osteophytes of all joints are taken together; POR in the wrist and hip; all OA changes taken together in the hip and knee). In females knee osteoarthritis (all changes taken together) similarly increases with age. Correlation with age is obtained also for osteophytosis (all joints taken together), porosity (all joints taken together), and when all osteoarthritic changes and all joints are taken together (Tab. 5).

When the impact of age on entheses formation is examined in males from the

Table 3. The means (x), number of cases (n), and standard deviations (SD) for osteoarthritic changes (OP – ostophytes, POR – porosity, EB- eburnation) and U Mann-Whitney test (Z) results in the Łekno material

Joint		Males			Females				
		n	x	SD	n	x	SD	Z	p
Shoulder	OP	105	0.408	0.635	41	0.365	0.667	−0.903	0.366
	POR	109	0.403	0.896	40	0.449	0.999	0.181	0.856
	EB	104	0.009	0.047	46	0.024	0.109	0.106	0.915
Elbow	OP	107	0.535	0.641	33	0.577	0.781	0.197	0.843
	POR	117	0.046	0.291	41	0.162	0.506	0.766	0.444
	EB	125	0.000	0.000	41	0.000	0.000	−0.004	0.997
Wrist	OP	104	0.243	0.509	32	0.249	0.503	0.036	0.971
	POR	104	0.141	0.597	32	0.094	0.376	−0.293	0.770
	EB	109	0.000	0.000	32	0.000	0.000	−0.005	0.996
Hip	OP	105	0.434	0.629	44	0.303	0.503	−0.958	0.338
	POR	109	0.402	0.832	48	0.818	1.189	0.985	0.325
	EB	108	0.000	0.000	48	0.049	0.209	0.246	0.806
Knee	OP	82	0.408	0.670	28	0.631	1.046	0.007	0.994
	POR	86	0.283	0.753	35	0.314	0.759	−0.179	0.858
	EB	97	0.000	0.000	35	0.000	0.000	−0.005	0.996
Ankle	OP	80	0.072	0.261	40	0.024	0.109	−0.403	0.687
	POR	83	0.199	0.719	38	0.074	0.334	−0.488	0.626
	EB	82	0.000	0.000	37	0.000	0.000	−0.005	0.996
Total	OP	583	0.377	0.461	216	0.303	0.504	−1.910	0.056
	POR	606	0.289	0.617	234	0.339	0.695	−0.025	0.980
	EB	625	0.002	0.014	239	0.009	0.055	0.220	0.826
	All	1818	0.219	0.283	689	0.222	0.360	−1.343	0.179

n – number of available joint surfaces.

Table 4. The means (x), number of cases (n) and standard deviations (SD) for entheseal changes and U Mann-Whitney test (Z) results for entheseal changes in the Łekno material

EC	Males			Females				
	n	x	SD	n	x	SD	Z	*p*
H1	104	1.71	0.934	46	1.46	0.650	–1.790	0.073
H2	109	1.07	0.743	46	1.20	0.859	0.840	0.401
R1	79	1.71	0.667	31	1.77	0.706	–0.217	0.828
R2	84	1.30	0.760	41	0.87	0.653	–2.463	0.014
F1	94	2.02	0.617	37	2.11	0.727	0.384	0.701
F2	99	2.07	0.807	51	1.84	0.593	–1.650	0.099
T	88	1.62	0.803	38	1.13	0.760	–1.807	0.071
Total	657	1.62	0.608	290	1.37	0.612	–2.470	0.01

x – means, n – number of available entheses , H1 – bicipital groove, H2 – deltoid tuberosity, R1 – bicipital tuberosity, R2 – midshaft of radius, pronator teres origin, F1 – gluteal tuberosity, F2 – linea aspera, T – soleal crest.

Table 5. The Spearman correlation coefficient (R) table of osteoarthritic changes and age in the in the males from Łekno

Joint	OA change	Males		Females	
		R	*p*	R	*p*
Shoulder	OP	0.24	0.048*	0.18	0.393
	POR	–0.01	0.922	0.28	0.182
	EB	0.14	0.250	–0.26	0.213
Elbow	OP	0.13	0.315	0.24	0.321
	POR	–0.02	0.869	0.24	0.243
	EB	–	–	–	–
Wrist	OP	0.11	0.392	0.16	0.511
	POR	–0.29	0.023*	0.28	0.218
	EB	–	–	–	–
Hip	OP	0.22	0.098	0.05	0.782
	POR	0.306	0.014*	0.25	0.176
	EB	–	–	0.01	0.953
Knee	OP	0.39	0.007*	0.44	0.775
	POR	0.12	0.378	0.15	0.495
	EB	–	–	–	–
Ankle	OP	0.24	0.104	–0.07	0.745
	POR	–0.15	0.294	0.24	0.284
	EB	–	–	–	–
All joints	OP	0.30	0.006*	0.31	0.046
	POR	0.07	0.534	0.43	0.005
	EB	0.11	0.305	–0.11	0.469
	All	0.20	0.072	0.33	0.029

OP – osteophytes, POR – porosity, EB – eburnation.

Łekno sample, the bicipital tuberosity (R1), midshaft of radius, pronator teres origin (R2), gluteal tuberosity (F1), linea aspera (F2) are positively correlated with age. In females, all the correlations are not statistically significant (Tab. 6).

Table 6. The Spearman correlation coefficient (R) table of entheseal variables changes and age

EC	Males		Females	
	R	*p*	R	*p*
H1	−0.23	0.126	0.40	0.052
H2	−0.21	0.137	0.23	0.312
R1	−0.46	0.003*	0.21	0.343
R2	−0.31	0.049*	0.44	0.053
F1	−0.32	0.028*	0.21	0.283
F2	−0.32	0.024*	0.28	0.185
T1	0.31	0.157	0.18	0.484

H1 – bicipital groove, H2 – deltoid tuberosity, R1 – bicipital tuberosity, R2 – midshaft of radius, pronator teres origin, F1 – gluteal tuberosity, F2 – linea aspera, T1 – soleal crest.

Table 7 shows the correlation coefficient values of upper limbs joints osteoarthritic changes (osteophytes – OP, porosity – POR) and entheseal changes of the upper limb bones (mean value of H1, H2, R1, R2). Table 7 contains also the correlation coefficient values of entheseal changes of the lower limb bones (mean value of F1, F2, T), and osteoarthritis variables from lower limbs joints. In the Łekno material, males with more developed ECs have more developed osteophytes in the shoulder, wrist, hip, knee, and ankle. Females with more developed ECs have more developed ostephytes, and more pronounced porosity in the hip (Tab. 7).

When we correlate osteoarthritic changes in a joint (osteophytosis, porosity, eburnation taken together) and all entheseal changes (mean value of all the observable entheses), the males with more affected shoulder (R=0.35),

Table 7. The Spearman correlation coefficient (R) table of entheseal changes and osteoarthritis variables (OP – osteophytes, POR – porosity) in the Łekno material

OA	Joint	Males			Females		
		n	R	*p*	n	R	*p*
OP	EC upper lilimblimbs						
	Shoulder	56	0.506	0.011*	23	0.418	0.047
	Elbow	50	0.203	0.535	20	0.399	0.082
	Wrist	49	0.449	0.001*	15	0.507	0.054
	EC lower						
	Hip	51	0.308	0.028*	22	0.140	0.533
	Knee	51	0.498	0.001*	18	−0.113	0.714
	Ankle	38	0.419	0.009*	13	0.304	0.219
POR	EC upper						
	Shoulder	59	0.111	0.403	25	0.038	0.714
	Elbow	54	−0.115	0.407	21	0.495	0.856
	Wrist	51	0.012	0.935	16	–	–
	EC lower						
	Hip	53	0.244	0.078	24	0.378	0.023
	Knee	41	0.046	0.774	16	−0.211	0.069
	Ankle	40	−0.227	0.159	18	−0.070	0.433

n – number of cases in the analysis.

Table 8. The Spearman correlation coefficient table of entheseal changes (all) and osteoarthritic changes in the Łekno material

Trait	Males			Females		
	n	R	*p*	n	R	*p*
Shoulder	61	0.345	0.006*	23	0.250	0.249
Elbow	55	0.265	0.051	20	0.536	0.015
Wrist	50	0.355	0.011*	16	0.541	0.031
Hip	53	0.403	0.003*	24	0.413	0.045
Knee	41	0.379	0.015*	16	−0.262	0.327
Ankle	40	−0.143	0.380	18	0.155	0.539
OP	65	0.650	0.000*	33	0.478	0.005
POR	66	0.210	0.090	33	0.327	0.063
EB	66	0.140	0.262	33	0.093	0.607
OA all	66	0.526	0.000*	34	0.498	0.003

n – number of cases in the analysis; OA all – all OA changes from all the joints; entheseal changes (all) – means of all observable ECs; OP – means of all observable osteophytes; POR – means of all observable porosity; EB – means of all observable eburnations.

wrist (R=0.36), hip (R=0.40) and knee (R=0.40) exhibit more developed entheseal changes. Females with more pronounced entheses have more developed osteoarthritic changes in the elbow (R=0.54), wrist (R=0.54) and hip (R=0.41) (Tab. 8). Table 8 presents also the relationship between all the entheseal changes (mean value of all the observable entheses) and OP (mean of all observable osteophytes), POR (mean of all observable porosity), EB (mean of all observable eburnation), OA all (mean of all observable types of osteoarthritic changes). Males with higher ECs development tend to yield more developed osteophytes (OP; R=0.65) and OA all (R=0.53). In the female group, the individuals with more developed entheses have much more developed osteophytes (OP; R=0.50). When all the three types are taken together (OA all), more "muscular" females exhibit more developed OA (OA all; R=0.50) (Tab. 8).

Discussion

The relationship between osteoarthritis and physical activity is a problematic issue for both medical and anthropological research. Examining these correlations is intended to assess the role of OA changes in interpretation of the biology of skeletal populations, paying special attention to the usage of OA in lifestyle reconstruction. This issue is also important in clinical science for preventing and treating osteoarthritic changes.

In the present study individuals with more developed osteoarthritis (OA for all types of changes and all joints taken together) are more "muscular" (with more developed entheses). These results are seen in both sexes (Tab. 8). Individuals with more developed entheses tend to have more developed osteophytes (all joints taken together) and general OA changes (all joints and all types of osteoarthritic changes taken together). More developed entheses predict males to have higher osteoarthritic changes in the shoulder, wrist, hip and knee, and predict females to have higher OA in the elbow, wrist and hip (Tab. 8). In the Łekno material, males with more developed osteophytes in the shoulder, wrist, hip, knee, and ankle have more developed muscle markers. Females with more developed ECs tend to have more pronounced osteophytes in a shoulder and porosity in a hip (Tab. 7).

If we assume that entheseal changes are activity markers, the results obtained could be treated as a confirmation of the influence of physical activity on osteoarthritic changes appearance – more active individuals tend to have more expressed osteoarthritis. But such a simple interpretation of the relationship between OA and ECs needs caution.

Firstly, an effect of physical activity on entheseal changes formation is questioned in anthropological literature (*for a detailed discussion see* Daly et al. 2004, Lieverse et al. 2009, Alves Cardoso and Henderson 2010, Niinimaki 2012, Weiss et al. 2012, Havelkov´a et al. 2013, Henderson et al. 2013, Lopreno et al. 2013, Villotte and Knüsel 2013). Secondly, although in our study more muscular individuals are predicted to have more severe osteoarthritis (OA from all types of changes and all joints taken together), when each joint is analyzed separately, not all correlations are significant. Moreover, results from other studies do not support a simple explanation of the activity-related relationship between OA and ECs. Palmer et al. (2016) obtained low correlation between entheseal and osteoarthritic changes. Woo and Pak (2013) found a relationship between EC and OA only in some joints. Authors underlined that these results illustrate the variability of these skeletal features, their complex etiologies and that they react in different ways to variable etiological factors, they have different levels of vulnerability to various cases (Woo and Pak 2013). Similar conclusions were drawn by Rojas-Sepúlveda and Dutour (2014). Schrader (2012), who also found a relationship between OA and ECs only in some joints, explained it as a consequence of a very low number of instances. Definite confirmation or refuting of the theory about an effect of physical activity on OA formation is not possible yet, and the impact of other factors on OA formation must be considered. But an omission of occupation as a possible cause of osteoarthritic changes formation in further discussions seems to be unjustified.

The significant correlations between ECs and OA obtained in this work and in other studies (Rogers et al. 2004, Molnar et al. 2011, Schrader 2012, Palmer et al. 2016) are meaningful. Although these results cannot undeniably indicate similar etiology of these two skeletal group of features, but they cannot be ignored when discussing this problem. These results may indicate that increased physical activity or the lack of it can be significant for the formation of osteoarthritic changes. But it should be borne in mind that OA and ECs have multifactorial etiology (Arden and Nevitt 2006, Roach and Tilley 2007, Weiss and Jurmain 2007, Gabay et al. 2008) and physical activity is not the only etiological factor for it. Furthermore, the existence of a relationship between OA and entheses might not indicate a link between these two skeletal traits and physical activity. Using etheses as markers of occupational stress is still questioned. Although muscle markers have been treated in anthropology as markers of physical activity (Hawkey and Merbs 1995, Kennedy 1998, Eshed et al. 2004, Molnar 2006), most researchers are skeptical underlining the multifactorial aetiology of EC and emphasizing the role of factors other than physical activity in their formation, like genes, age, sex, hormones, body mass (Niinimäki 2011, Milella et al. 2012, Schlecht 2012, Henderson and Alves Cardoso 2013, Villott and Knüsel 2013).

An effect of sex as a specific risk factor in osteoarthritic changes formation should not be omitted. A relationship between OA and sex is well documented in clinical studies (Cushnaghan and Dieppe 1991, Manninen et al. 1996, Srikanth et al. 2005, McKean et al. 2007, Hanna et al. 2009, Prieto-Alhambra et al. 2013). According to epidemiological data, osteoarthritis has a higher prevalence in women than men, especially after the age of 50 (Felson 2003). These sex-related differences after the age of 50 years are linked to hormone deficiency in women (especially estrogen deficiency in post-menopausal period) (Nevitt et al. 1995, Oliveria et al. 1996, Zhang et al. 1998, Felson et al. 2000, Gokhale et al. 2004, Mandl 2007).

In our sample males are usually more affected than females, but sex differences are not significant (Tab. 3). An effect of sex on OA formation is the most supported finding in anthropological literature (Weiss and Jurmain 2007). There is no homogeneity in sex differences in osteoarthritis frequencies and prevalence. There are populations where males (or some joints in males) have higher OA scores than females (Bridges 1991, Šlaus 2002, Weiss 2006, Klaus et al. 2009, Eng 2016). In some skeletal materials, females (or some joints in females) have higher frequencies of OA than males (Molnar et al. 2011, Eng 2016). Some researchers did not find any significant sex differences in OA (Bridges 1991, Šlaus 2000, Lieverse et al. 2007, Eshed et al. 2004, Schrader 2012, Woo and Pak 2013, Woo and Sciulli 2013, Palmer et al. 2016). Although, pointing the genetic and environmental background of sex differences, the assessment of sex differences in OA analyzes as a necessary condition for reliable interpretation of the disorder in past population is needed (Weiss and Jurmain 2007), paleopathologists are limited in explaining of this lack of homogeneity of the results. Skeletal material specificity (usually small sample size; material not well preserved, not complete; difficulties in explicit sex assessment; unknown occupation of individuals/population) could be one but not an adequate explanation.

According to clinical views, osteoarthritis is thought to be a classic age-related disorder (Anderson and Loeser 2010, Arden and Nevitt 2006). Taking into account contemporary data, osteoarthritis is a progressive disease that affects 60% males, 70% females over the age of 65 (Sarzi-Puttinni et al. 2005) and more than 30% of adults between 45–64 years of age (WHO 2003). A strong correlation between age and osteoarthritis is connected with biochemical changes in the cartilage that make it weaker and less resistant to biomechanical stress (Alexander 1990). Some studies document an effect of age on OA appearance and progression (Petersson and Jacobsson 2002, Arden and Nevitt 2006).

In past skeletal populations the influence of age on OA formation is not so obvious. It is both positive and negative, in many cases it is not significant, and depends mostly on an individual joint (for the discussion see Weiss and Jurmain 2007). In the population from Łekno an impact of age on osteoarthritic changes is not homogenous and in the majority of the cases non-significant (Tab. 5). An increase of osteoarthritic changes with age was observed by Waldron (1991), Weiss (2006), Molnar et al. (2011), Eng (2016), Calce et al. (2018). However, non-significant age differences in OA formation have been also observed in a study by Palmer et al. (2016). In Schrader (2012), and Woo, Pak (2013) older individuals have higher OA changes but only for a few joints the correlation is significant. As can be seen above, there is no such homogeneity in anthropological literature results regarding age differences in osteoarthritis. Specificity of the skeletal material does not always allow for detailed analyses and/or reliable interpretation of the differences in the separate age groups. In the majority of studies, such analyses are omitted. Moreover, some researchers question the concept of a simple correlation between these two features, underline the multifactorial etiology of OA and suggest that aging contributes to but does not directly cause the osteoarthritic changes (Anderson and Loeser 2010, Loeser 2011). They argue that the occurrence of these correlations is not only an effect of aging of joint tissues but results also from the influence of other factors, such as joint loading from obesity over time (Sharma 1999, Newman et al. 2003), increased joint instability due to ligamentous laxity and others (Sharma 1999).

Age and sex are considered to be a confounding factors also in entheseal changes development (Havelková et al. 2011, Niinimäki 2011). Older individuals usually have more pronounced entheses than younger ones, what many anthropologists relate to cumulative effect of stress over the lifespan (Turner 2000, Weiss 2007). But the results are not homogeneous and some authors require caution with regard to simple interpretation of the effect of age on entheses (Mays 2000, Weiss 2007, Milella et al. 2012). A significant influence of age on entheses formation was found by Weiss (2007), Alves Cardoso and Henderson (2010), Niinimäki (2011), Villotte et al. (2010), Milella et al. (2012), Nolte and Wilczak (2012), Molnar et al. (2011), Calce et al. (2018). But the results of the studies by Al-Oumaoui et al. (2004), Havelková et al. (2011), Weiss (2010), Henderson et al. (2013), Myszka, Piontek (2013), Niinimäki and Sotos (2013), Takigawa (2014), Yonemoto (2016) and the present study results (Tab. 6) show that although a general trend for ECs increasing with age can be observed, statistical significance is not always found and depends on sex or entheses. An explanation of this lack of homogeneity is not obvious, and usually related to specificity of skeletal material, problems with age assessment. Robb (1998), and Milella et al. (2012) found that EC increase from the maturity to 40–50 years, and after this age the process level off, argued that the reason of that fact may be self-limiting process, changes of activity regime, age-dependent decreasing of physical activity, or decrease in muscle mass. It could be one possible explanation of the obtained here negative impact of age on ECs formation in male group from Łekno (Tab. 6). Another reason could be found in skeletal material specificity (small number of individuals, difficulties in age assessment), that can influence the results. But in spite of the lack of homogeneity and not well-known mechanisms that determine the direction and power of age influence on ECs formation, this etiological factor should not be omitted when interpretting the results.

Taking the fact that increased age plays an important role both in the expression of entheseal changes (Niinimäki 2011, Villotte et al. 2010, Milella et al. 2012), and osteoarthritis (Eng 2016, Calce et al. 2018), we cannot exclude the possibility that the high correlation between EC and OA in our sample is a result of the impact of age on OA and EC expression.

Sex differences are commonly analyzed with respect to entheseal changes (Peterson and Hawkey 1998, Al-Oumaoui et al. 2004). Similarly to age, the results are not unanimous. In the majority of skeletal samples, males have more developed muscle markers than females (Steen and Lane 1998, Weiss 2010, 2015, Al-Oumaoui et al. 2004, Molnar 2006, Havelcová et al. 2011), but this tendency is not always significant, and it does not apply to all analyzed entheses (Tab. 4). There are studies where females muscle markers are more prominent compared with males (Chapman 1997, Al-Oumaoui et al. 2004). Sex differences in entheses are usually attributed to differences in habitual activity patterns. Weiss et al. (2012) warns against such a simple interpretation of these differences. Weiss (2010) underlines the effect of factors other than physical activity (e.g. genes, body size or hormonal) on entheseal changes formation.

To sum up, the present study results show that entheseal changes are important factors in osteoarthritic changes formation. Although some authors indicate the need to take them into account when interpreting OA in past human groups, the exact directions and strength of their influence are not unequivocal, and can differ for individual joints and populations. This supports the view that the formation of osteoarthritic changes is a complex process with multifactorial etiology, and suggests the need for further studies to reach precise final conclusions about the contribution of these etiological factors to OA onset and development in past humans.

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Authors' contributions

JP, JT, MZ are the contractors of the project, co-authors of the draft and the final version of the manuscript; AM, MZ are a performers of the statistical analysis, interpretation of the results; AM is the head of the research team, the contractor of the project, co-author of the draft and the final version of the manuscript.

Conflict of interest

The authors declare that there is no conflict of interest.

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