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Throwing activities among Neolithic populations from the Meuse River Basin (Belgium, 4500–2500 BC) with a focus on adolescents

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The anterior band of the medial collateral ligament (MCL) is an important stabilizer for valgus stress at the elbow. When practised intensively and repetitively, activities using overhead throwing motions can injure this ligament and its insertion (enthesis). If these activities occur when the epiphyses are not yet fully fused, traction forces can result in bony detachments in the area of the MCL insertion. On dry bones, such lesions can only be observed as scars in adults. The individuals in this study derive from commingled graves located in 16 caves from the Meuse River Basin that are radiocarbon dated to the Middle and Late Neolithic. We recorded the presence or absence of MCL lesions on 196 humeri and studied the relation between MCL lesions, siding, and robusticity. A total of 5.1% of the humeri displayed MCL lesions, which affected only the right robust humeri. Four main types of activities may explain the presence of this enthesopathy: hunting/fishing, warfare/conflict, games, and wood-cutting. Our results suggest the hypothesis of social division in throwing activities in the Meuse River Basin during the Neolithic. They also suggest that the throwing practice started from a young age, which invites us to re-examine the role of teenagers in prehistoric societies.

KEYWORDS

Neolithic; throwing activity; avulsion fracture; adolescent; Belgium

Introduction

When practised intensively (at high velocity and force) and repetitively, overhead throwing activities are very stressful to the elbow, and more particularly, to the anterior band of the medial collateral ligament (MCL) (Nakanishi et al. 1996; Miller, Adler, and Friedman 2004; Gregory and Nyland 2013). The MCL links the humerus with the ulna, arising from the medial humeral epicondyle and inserting on the ulnar coronoid process. It is the primary stabilizer against valgus stress at the elbow (Labott et al. 2018).

If throwing activities occur near the end of skeletal maturation, when the medial epicondyle (ME) is not yet fully fused (12–18 years of age), traction forces can result in bony detachments in the area of the MCL insertion (Figure 1). In individuals younger than 15-years-old, these detachments can be complete and involve the entire medial epicondylar ossification centre. In older teens, they can be partial, leading to the avulsion of one or more bony fragments from the medial epicondylar apophysis (Klinge and Kocher 2002; Kijowski and Tuite 2010).

When the individual with an avulsion fracture reaches adulthood, the healed lesion takes the form of a bony outgrowth or lacunae depending on whether or not the avulsed fragment re-united with the condyle (Lewis 2017, 254–255). On dry archaeological bones, such lesions are mainly observed on adult humeri as scars from a traumatic event that occurred during adolescence (Villotte et al. 2010).

[Figure 1 near here]

Today, these ME injuries are common pathological findings in young baseball pitchers and are known as Little Leaguer's elbow (Klinge and Kocher 2002). They are also reported in javelin throwers (Miller 1960), but the incidence is lower, because Javelin competitions begin later – during high school in the United States (Gregory and Nyland 2013).

The aim of this study was to look for the presence of avulsion fractures at the attachment site of the anterior band of the MCL during the Neolithic period in Belgium and thus demonstrate the occurrence of overhead throwing activities during adolescence in these prehistoric populations. We then try to answer the following question: who was practising these throwing activities, and based on archaeological data, in what context were these activities performed?

Materials and methods

More than 200 karstic caves located in the Meuse River Basin of Belgium have yielded human remains (Toussaint et al. 2001). The majority of these funerary sites date to the Middle and Late-Final Neolithic, as evidenced by over 100 available radiocarbon dates; only about a dozen sites belong to the Early Mesolithic, and some caves contained skeletons from the Protohistoric Period (Toussaint 2007). Many of these sites were excavated as early as the 19th century (Table 1). Unfortunately, the skeletal remains are commingled and disarticulated. This is, of course, due to taphonomy, but it is also due to human manipulation of the remains, beginning in Prehistoric times (Toussaint et al. 2001). A great number of Neolithic burials include the remains of 5–15 individuals (Polet 2011) belonging to adults of both sexes and children (Toussaint et al. 2001).

[Table 1 near here]

For this study, we selected 196 left and right adult humeri (fully fused epiphyses) with preserved distal epiphyses from a collection housed at the Royal Belgian Institute of Natural Sciences. They derived from 16 cave burials and come from 9 sites in the Meuse Basin (Figure 2). Five caves are radiocarbon dated to the Middle Neolithic, nine to the Late-final Neolithic, and one (Grotte de la Cave in Maurenne) covers both periods (Table 1). One of the caves was not radiocarbon dated and is therefore indicated as ‘supposed Neolithic’. The minimum number of individuals varies from 5 to 59 individuals (Table 1).

[Figure 2 near here]

The presence or absence of changes at the humeral attachment site for the anterior band of the MCL (see fig. 5 in Villotte et al. 2010) was macroscopically recorded. We looked for two types of changes (see Villotte et al. 2016 for definitions and illustrations): a clearly distinct protrusion from the surface of the enthesis (Figure 3), or alternatively, a large surface discontinuity affecting the cortical bone and underlying trabecular bone (Figure 4; also see fig. 4 in Villotte et al. 2010).

[Figures 3 and 4 near here]

We studied the relation between the MCL lesions, siding, and robusticity, which was used instead of sex because skeleton individualization was not possible for these collective burials. Pelvic bones could not be associated with the humeri, and thus no reliable methods for a pelvis-based sex determination could be applied. Robusticity was evaluated using distal humerus measurements. From a series of six measurements (Table 2, Figure 5), two were selected because they could be taken on a maximum number of Neolithic humeri (Leunda Martiarena 2016, 40–41). These were the epicondylar breadth and the minimum trochlear depth. The epicondylar breadth (Measurement 4 in Martin 1928, 1010) is the maximum breadth between the most extreme aspects of the medial and lateral epicondyles of the humerus perpendicular to the axis of the humeral diaphysis. The minimum trochlear depth is the minimum anteroposterior dimension of the trochlea (Trinkaus 1983, 227). The humeri were classified as either gracile or robust based on a bivariate plot, where specimens with values below the median for both measurements were considered gracile, and those above were considered robust (Figure 6).

[Table 2 and Figure 5 near here]

We applied the Fisher Exact test (2×2 contingency table) to test whether there was a difference in the lesion frequency between the Middle and Late Neolithic individuals. The Fisher–Freeman–Halton test (2×4 contingency table) was used to test whether there was a difference in frequency among the four groups of humeri: left and right gracile, and left and right robust.

[Figure 6 near here]

Results

Of the two types of lesions at the attachment site of the MCL anterior band, only the lacunar form was observed (Figure 4).

Table 3 shows the prevalence of MCL lesions at the 16 Neolithic burial sites. From a total of 196 humeri, 10 (5.1%) displayed this kind of lesion, affecting 10.3% (7/68) of the Late Neolithic individuals and 7.7% (1/13) of the Middle Neolithic individuals (in the Grotte de la Cave in Maurenne dated to the Middle and Late Neolithic, 12.5% [2/16] of the individuals were affected). The probability derived from the Fisher Exact test (1.000) used to compare these two groups was greater than 5%, and thus we cannot reject the null hypothesis (the distribution of the MCL lesions is independent of the chronological groups). We conclude that the frequency of fracture avulsions does not vary among the Late and Middle Neolithic groups.

[Table 3 near here]

The selection of robust and gracile individuals unfortunately resulted in the ‘loss’ of 91 individuals (specimens where either both measurements could not be taken or those where both measurements were not above or below the median values). The discussion will thus mainly concern the 105 remaining humeri.

The MCL lesion only affected the right robust bones (33.3% [7/21]; [Table 4](#)). None of the left humeri (gracile and robust) or right gracile humeri showed lesions. The probability determined from the Fisher–Freeman–Halton test (0.0000749) used to compare these four groups was less than 5%, meaning we should reject the null hypothesis (the distribution of the MCL lesions is independent of the humeri groups). We conclude that the frequency of fracture avulsions varies among the four categories of humeri.

[Table 4 near here]

Discussion

Fracture avulsion scars at the insertion of the anterior band of the MCL on nine Neolithic individuals from the Meuse Basin indicate that severe valgus stress occurred at their elbows. No significant difference in the prevalence of lesions was observed between the Middle and the Late Neolithic individuals, indicating that throwing activities were performed during both periods.

Only the right humeri were affected by the avulsion fractures. This result was expected, as the valgus extension of the elbow is usually only reached by the dominant upper limb, given its dynamic and complex properties. Today, the right arm is dominant for about 90% of the population (Scharoun and Bryden 2014), which and it was also likely the case in prehistoric times based on studies on tool processing (Steele and Uomini 2005) and handling (Phillipson 1997), cut mark direction (Bromage and Boyde 1984; Pickering and Hensley-Marschand 2008), humeral diaphysis asymmetry (Trinkaus, Churchill, and Ruff 1994; Sparacello et al. 2017), enthesal changes (Villotte and Knüsel 2014), directional skew in dental wear (Bermúdez de Castro, Bromage, and Fernández Jalvo 1988; Frayer et al. 2012), cave art (Coren and Porac 1977), and endocast asymmetries (Holloway 2008; Poza-Rey, Lozano, and Arsuaga 2017).

In our Neolithic sample, only robust humeri were affected by the avulsion fractures. Can we go one step further and state that some specific activities that produce severe valgus stress concerned only male individuals? Several studies have shown a marked sexual dimorphism also exists at the humerus level that allows reliable sex determination when it is not possible to sex either the pelvis or skull (e.g. İşcan et al. 1998; Steyn and İşcan 1999; Kranioti and Michalodimitrakis 2009). In addition, the application of our graphic method based on the median values of two distal humerus measurements to a modern identified collection (known sex) shows good sexual discrimination (Leunda Martiarena 2016, 40–41). Finally, the fact that we used parameters (medians) calculated from our data avoids the bias of transposing methods created on a given population to another with different body proportions (Ruff 2002). All of the above indicates that humerus robusticity can be a good sex indicator in our Neolithic sample. Thus, most of the gracile humeri probably belonged to females, and most of the robust humeri to males. However, it is not impossible that some robust humeri belong to females and vice versa, and thus some avulsions actually occurred in females.

If we look at current sport medicine data, the lesions in our Neolithic sample were likely due to activities that involve a throwing motion (Kijowski and Tuite 2010). These lesions typically result from repetitive stress due to overuse, but they can also be secondary to acute localized trauma (Gore et al. 1980; Gregory and Nyland 2013). Our results are similar to those of previous studies that, on the basis of changes at the ME (including the attachment site of the MCL), have demonstrated that prehistoric males were engaged in activities inferring a throwing motion (Dutour 1986; Villotte and Knüsel 2014; Villotte et al. 2010).

As the lesions observed on the ME in our sample are scars from avulsions that occurred in adolescents whose skeletons had not fully matured, they indicate these activities began before biological adulthood. This is a major outcome, because adolescent activities in prehistoric periods are poorly documented. Information on their place in prehistoric society has been

inferred by funerary anthropology by associating the study of skeletal remains with patterns in grave goods and burial rites (Thomas, Chambon, and Murail 2011; Leroy 2015). However, this provides little information on their actual activities during life. Based on the study of artefacts, child participation in craft activities, including stone-tool production, ceramic manufacture, and weaving, has already been demonstrated in prehistoric populations (Baxter 2008). Still, only a few of these studies were able to distinguish different age categories in non-adults (including adolescents) using the types of errors related to cognitive developmental stages (Crown 1999; Bagwell 2002). Two anthropological studies have nevertheless demonstrated a strenuous lifestyle (in the broader sense) during adolescence in prehistoric populations: Lovejoy and Heiple (1981), based on fracture rates in a Late Woodland sample from Ohio in the United States; and Mays et al. (2018), looking at spondylosis (a fatigue fracture of the neural arch, usually occurring in late adolescence or early adulthood in archaeological groups) in one Middle Neolithic male individual from Stonehenge

Based on archaeological and ethnographical data, we tried to reconstruct the activities which caused the ME lesions. They could belong to four main categories: hunting/fishing, warfare/conflict, games, and wood-cutting.

Faunal remains analyses from Neolithic sites in Belgium show that breeding was the most important source of animal protein (Cauwe, Vander Linden, and Vanmonfort 2001). However, hunting and fishing were still performed, as demonstrated by the faunal remains at some Neolithic sites (e.g. De Ceunynck, Van der Plaetsen, and Vanmoerkerke 1985; Léotard, Straus, and Otte 1999) and by stable isotope analyses (Bocherens, Polet, and Toussaint 2007). The use of the bow, widely attested for the Neolithic period in Europe, does not seem to be stressful for the ME (Villotte et al. 2010). However, its frequent adoption does not exclude

the use of more simple overhead throwing weapons such as the sling, harpoon, killing stick, or even the boomerang (Ramseyer 1988, 2000; Thomas 2000).

Interpersonal violence, which has been detected in the Middle Pleistocene (Sala et al. 2015), increased during the development of the first agro-pastoral societies in the Neolithic (Keeley 1997; Guilaine and Zammit 2001; Beyneix 2001; Maxwell Heath 2017). Although the traumatic lesions observed on the skeletons from Belgian Neolithic sites generally attest to injuries by arrows (Cauwe 1999; Polet et al. 1996; Joppart, Polet, and Warmenbol 2017), it is easy to imagine that overhead throwing weapons, such as the spear in Denmark (Bennike 1985, 110–112), could also have been used.

Games and sports are seldom considered as an interpretative model in archaeology due to the belief that they were insignificant in prehistory, as well as the paucity of uncovered artefacts (Fox 1977; Sansone 1988, 5). Nevertheless, many scholars are convinced that play has been a part of human society since prehistoric times given its ubiquity among primates and the free time at the disposal of prehistoric people (Blanchard and Taylor Cheska 1985, 96–97). Throwing games could have been practiced by all the male members of the Neolithic society in the Meuse River Basin or only by adolescents as training for the accurate and coordinated throwing of weapons for killing prey (or enemies?) (Reid 2001, 3).

It should also be noted that the use of the axe and adze require very similar movements of the upper limb as those made during overhead throwing and could also lead to ME lesions (Villotte and Knüsel 2014). It can be assumed that their use, observed since the Mesolithic (Verhart 2012), was very frequent during the Neolithic period, when intense deforestation occurred to clear land for agriculture (Roberts et al. 2018).

The participation of adolescents in any of the above activities should be considered. Parallels can, for example, be drawn with present-day traditional societies such as contemporary hunter-gatherers, where teenagers learn various complex skills such as big

game hunting during apprenticeships and initiation rites (MacDonald 2007; Hewlett 2016; Lew-Levy et al. 2017).

Conclusions

Lesions at the attachment site of the anterior band of the MCL were present during the Neolithic period in the Meuse Basin of Belgium. We have demonstrated that activities involving a throwing motion began in adolescence, suggesting we re-examine the role of teenagers in these prehistoric societies. The fact that it is only the more robust individuals that were affected leads to the hypothesis that it was probably the male individuals that were involved in throwing activities. This, in turn, suggests the hypothesis of a form of social/gender division in throwing activities in the Meuse River Basin during the Neolithic.

Based on archaeological data, four main types of activities can be proposed to explain the presence of this enthesopathy related to throwing activities: hunting/fishing, warfare/conflict, games, and wood-cutting. However, it is difficult based on our present knowledge and the available data to determine which is the more probable.

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Tables

Locality	Name of the site	excavation	Date ¹⁴ C BP	Date Ref.	Date BC 2 σ	Cultural attribution	Ref.	MNI	N
Sclaigneaux	Grotte de Sclaigneaux	1872	4155 \pm 35	GrA-32975	2880-2620	LN	De Paepe and Polet 2007	58	47
Anseremme	Abri du Grogneau	1946-47	4945 \pm 55	OxA-9089	3780-3660	MN	Orban et al. 2000	?	2
	Abri des Autours	1992	5300 \pm 55	OxA-5387	4320-3980	MN	Cauwe 1993	9	1
Hastière	Caverne B	1869-1879	5180 \pm 45	OxA-9021	4160-3930	MN	Orban et al. 2000	14	5
	Caverne L	1869-1879	5070 \pm 60	OxA-9088	3980-3710	MN	Orban et al. 2000	5	6
	Caverne M	1873 ?	4345 \pm 60	OxA-6852	3320-2870	LN	Orban et al. 2000	44	17
	Petite Caverne	1869-1879	4300 \pm 50	OxA-6852	3090-2700	LN	Orban et al. 2000	20	1
	Le Cimetière	1869-1879	4280 \pm 50	OxA-6851	3030-2690	LN	Orban et al. 2000	19	4
	Caverne C	1869-1879	4220 \pm 45	OxA-6853	2910 – 2620	LN	Orban et al. 2000	?	4
Maurenne	Grotte de la Cave	1869-1879	4635 \pm 45	OxA-9025	3630-3130	MN	Orban et al. 2000	59	34
			4360 \pm 45	OxA-6854	2880-2590	LN	Orban et al. 2000		
			3830 \pm 30	Lv-1482	2600-1950	LN	Gilot 1985		
			3830 \pm 70	Lv-1483	2470-2030	LN	Gilot 1985		
Furfooz	Trou du Frontal	1864-65	4430 \pm 80	OxA-8828	3350-2920	LN	Charles 1998	21	8
			4430 \pm 30	GrN-10179	3330-2920	LN	Leguebe and Orban 1984		
	Trou Rosette	1864-65	4165 \pm 70	OxA-5041	3900-2500	MN	Polet et al. 1996	14	7
Brunot	Bois Madame	1938	4110 \pm 110	Lv-265	2950-2300	LN	Dumbruch 2007	57	17
			4090 \pm 110	Lv-264	2950-2300	LN			
Beauraing	Martouzin-Neuville	1977	4230 \pm 40	KIA-48286	2920-2670	LN	Joppart, Polet and Warmenbol 2017	34	31
			4140 \pm 40	KIA-48293	2880-2580	LN			
			4135 \pm 35	KIA-48292	2880-2580	LN			
			3760 \pm 35	KIA-48285	2290-2040	LN	Gilot 1986		
			4070 \pm 100	Fra-98	2870- 2480	LN			
			3790 \pm 90	Lv-1243	2500-1950	LN			
Bouvignes	Trou Madame	1869-1879	Supposed Neolithic					?	1
Humain	Abri sous-roche d'Humain	1962	4150 \pm 35	KIA-48288	2880-2620	LN	Polet et al. 2014	40	32
			4085 \pm 45	KIA-48289	2780-2480	LN			

Table 1. General information on the 16 burial sites from which the Mosan human material originates: locality, name of the site, excavation date, radiocarbon dating, cultural attribution, bibliographic references, minimum number of individuals (MNI; estimated on all the available adult and non-adult human remains), and the number of left and right humeri selected for this study. MN, Middle Neolithic; LN, Late Neolithic.

Name	Reference	No.	Definition
epicondylar breadth	Martin (1928, 1010)	4	maximum distance between the most extreme aspects of the medial and the lateral epicondyles, perpendicular to the axis of the diaphysis
distal articular breadth	Martin (1928, 1012)	12.a	distance between the most medial point on the trochlea to the most lateral point on the capitellum.
olecranon fossa breadth	Martin (1928, 1012)	14	distance between the most medial point and the most lateral point on margin the of the olecranon fossa
trochlear depth	Martin (1928, 1012)	13	distance between the most anterior point and the most posterior point on the trochlea
epiphysis thickness at the proximal limit of the olecranon fossa	(Leunda Martiarena 2016, 29)		distance between the most anterior point to the most posterior point of the epiphysis at the level of the proximal limit of the olecranon fossa, perpendicular to the axis of the diaphysis
minimum trochlear depth	Trinkaus (1983, 227)		minimum anteroposterior dimension of the trochlea

Table 2. List of the six measurements taken on the distal humerus.

Locality	Name of the site	Cultural attribution	N	Prevalence					
				Left	Right	Left gracile	Left robust	Right gracile	Right robust
Sclaigneaux	Grotte de Sclaigneaux	LN	47	0/26	3/21	0/7	0/10	0/7	3/5
Anseremme	Abri du Grogneau	MN	2	0/2	-	-	-	-	-
	Abri des Autours	MN	1	-	0/1	-	-	0/1	-
Hastièrre	Caverne B	MN	5	0/2	0/3	0/2	-	0/1	-
	Caverne L	MN	6	0/3	0/3	0/1	0/1		
	Caverne M	LN	17	0/11	1/6	0/4	0/2	0/3	1/2
	Petite Caverne	LN	1	-	0/1	-	-	-	-
	Le Cimetière	LN	4	0/2	0/2	-	-	-	-
	Caverne C	LN	4	0/4	-	-	-	-	-
Maurenne	Grotte de la Cave	MN + LN	34	0/18	2/16	0/8	0/2	0/5	2/6
Furfooz	Trou du Frontal	LN	8	0/4	0/4	0/1	-	0/1	-
	Trou Rosette	MN	7	0/6	1/1	0/2	0/2	-	-
Brunot	Bois Madame	LN	17	0/7	1/10	-	0/2	0/3	0/3
Beauraing	Martouzin-Neuville	LN	31	0/13	1/18	0/5	0/3	0/4	0/3
Bouvignes	Trou Madame	Neolithic	1	0/1	-	-	0/1	-	-
Humain	Abri sous-roche d'Humain	LN	12	0/5	1/6	0/2	0/1	0/1	1/2
Total			196	0/104	10/92	0/32	0/24	0/28	7/21

Table 3. Prevalence of medial collateral ligament (MCL) lesions in the Mosan human material. Locality, site name, excavation date, radiocarbon dating, cultural attribution, bibliographic references, minimum number of individuals (MNI), and the number of left and right humeri selected for this study. MN, Middle Neolithic; LN, Late Neolithic.

humerus		N _{tot}	MCL lesion	
			N _{obs}	Freq. (%)
right	gracile	28	0	0
	robust	21	7	33.33
left	gracile	30	0	0
	robust	24	0	0

Table 4. Number and frequency of medial collateral ligament (MCL) lesions on the Neolithic humeri according to side and robusticity.

Figures

Figure 1. Diagrammatic representation of the consequences of traction force exerted on the medial epicondyle (ME) of an adolescent humerus during throwing, which can lead to an avulsion fracture or epiphyseal detachment. When the individual with an avulsion fracture reaches adulthood, the healed lesion takes the form of a bony outgrowth or lacunae depending on whether or not the avulsed fragment re-united with the condyle.

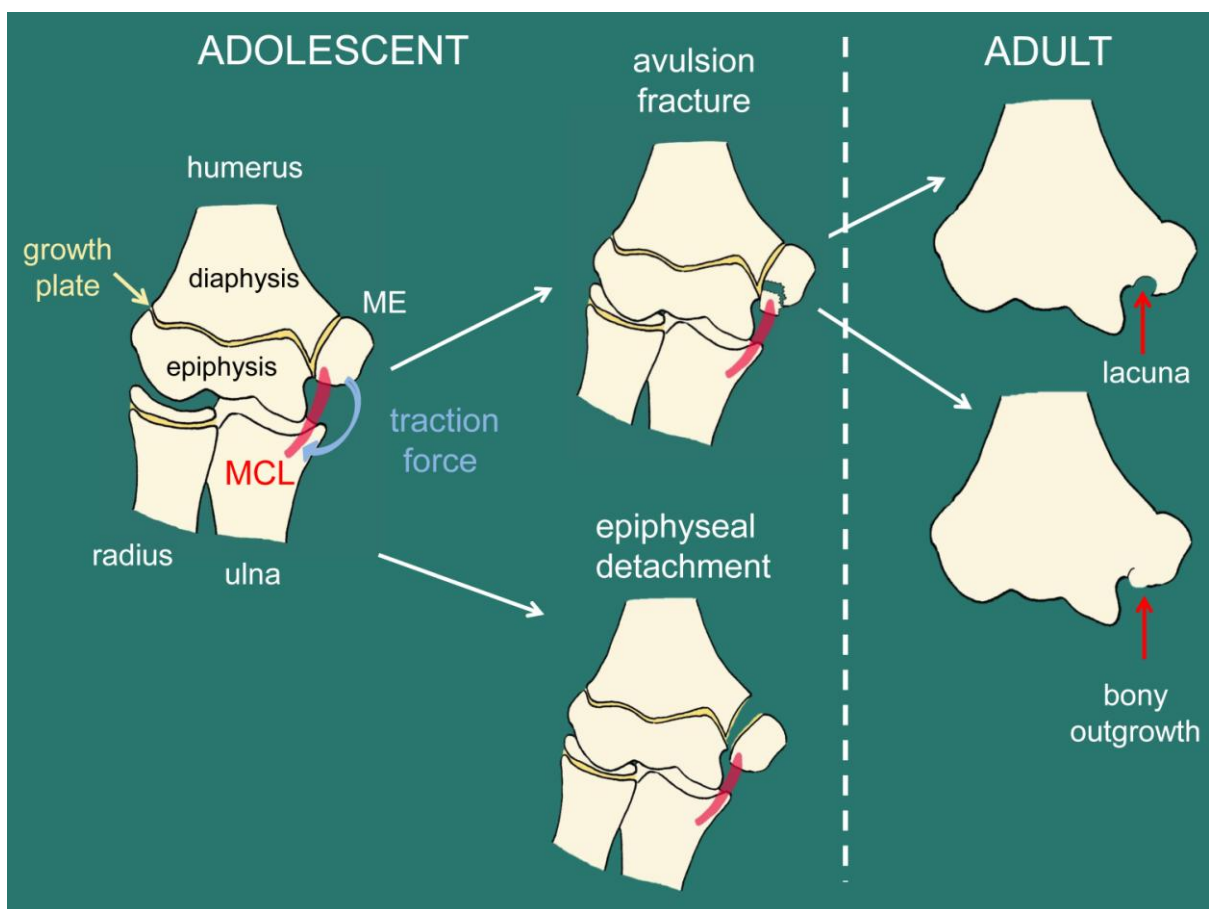


Figure 2. Map of Belgium with the locations of the studied sites. 1, Sclaigheaux; 2, Anseremme; 3, Hastière; 4, Maurenne; 5, Furfooz; 6, Burnot; 7, Beauraing; 8, Bouvignes-sur-meuse; and 9, Humain.



Figure 3. Example of a distinct bony protrusion from the enthesis surface resulting from an avulsion fracture in a right humerus that comes from an historical collection.

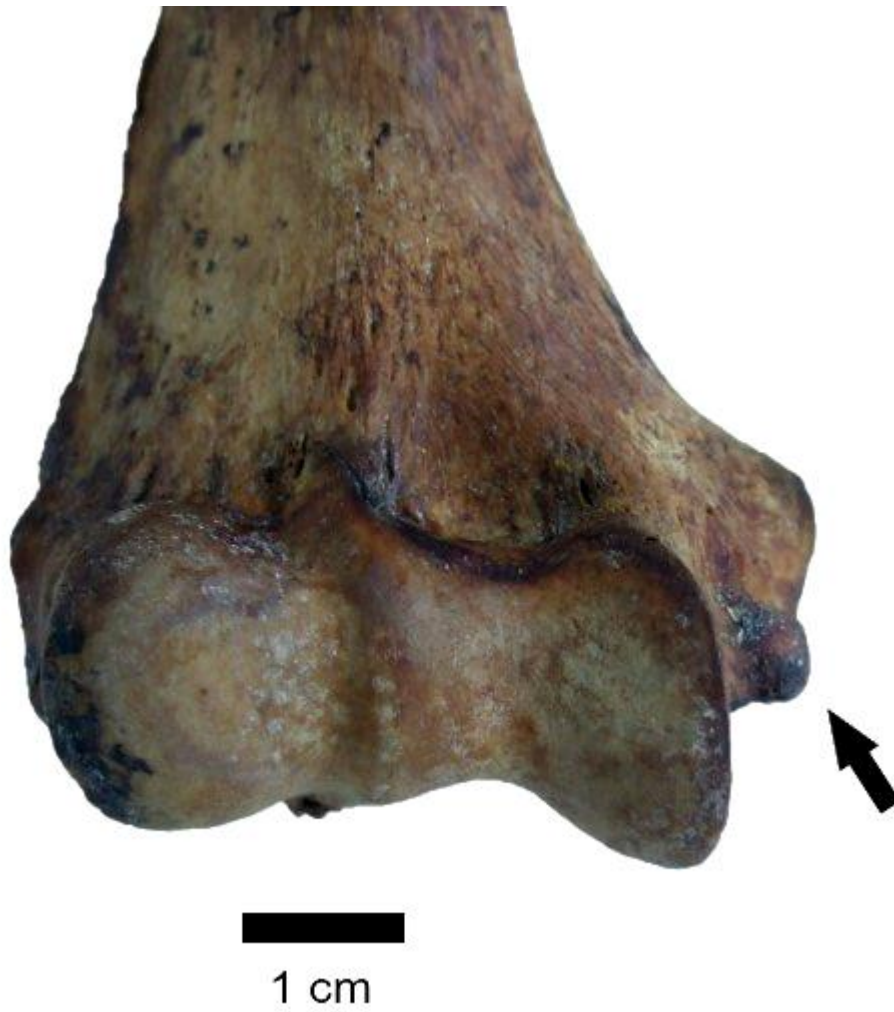


Figure 4. Example of bony defect resulting from an avulsion fracture in a right Neolithic humerus from the Meuse Basin.



Figure 5. Measurements taken on the distal humerus. 1, epicondylar breadth; 2, distal articular breadth; 3, olecranon fossa breadth; 4, trochlear depth; 5, epiphysis thickness at the proximal limit of the olecranon fossa; 6, minimum trochlear depth.

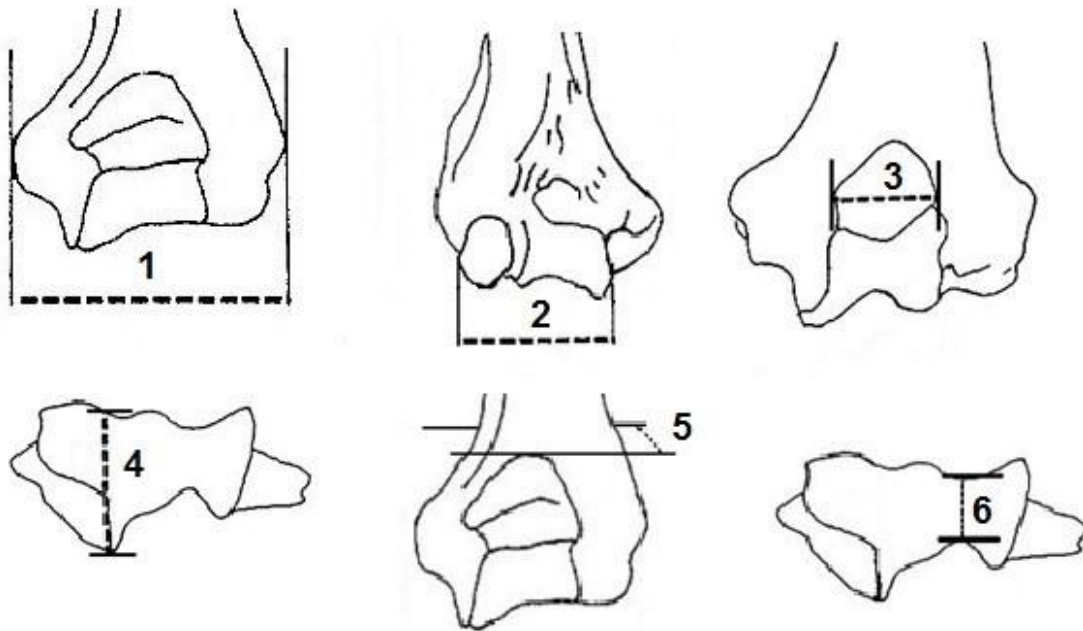


Figure 6. Bivariate plot with the epicondylar breadth and minimum trochlear depth for the Mosan humeri. The medians are represented by red dotted lines. The specimens with values below the median of both measurements were classified as gracile, and those above the median were considered robust.

