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Sexual Dimorphism in Diaphyseal Cross-sectional Shape in the Medieval Muslim Population of Écija, Spain, and Anglo-Saxon Great Chesterford, UK

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ABSTRACT Differences in adult male and female activity patterns may influence levels of sexual dimorphism in physical dimensions, including the cross-sectional shape of long bone diaphyses. Previous studies of archaeological populations have demonstrated significant differences in diaphyseal shape between males and females. In this study, dimorphism in external diaphyseal shape of upper and lower limb bones (reflected in indices of external diaphyseal diameters), and bilateral asymmetry in these indices, were examined in two medieval populations: Muslim Écija (Spain) and Anglo-Saxon Great Chesterford (UK). Attempts were made to relate observed patterns to documentary and other osteological evidence for differences in male and female activity patterns. While few significant differences in upper limb bone cross-sectional shape were observed in either population, significant differences in shape were found in the lower limb diaphyses at Écija at the femoral midshaft and tibial foramen and midshaft levels, and at the tibial midshaft for Great Chesterford. Comparison with published data suggests that these differences are marked for Écija, and perhaps fairly high for Great Chesterford compared with other populations with an agriculture-based economy. This is consistent with documentary and osteological evidence suggesting marked gender differences in behaviour in medieval Muslim Spain. No significant differences in bilateral asymmetry were found, but the effects of small sample size cannot be ruled out. Copyright © 2008 John Wiley & Sons, Ltd.

Key words: sexual dimorphism; diaphyseal shape; medieval Muslim Spain; Anglo-Saxon England

Introduction

Sexual dimorphism refers to any physical characteristics which differ between the sexes (Martin *et al*., 1994), such as body size in terms of mass or length, body shape and proportions, body composition (such as adiposity), dental characteristics, or colouration. Where the gendered allocation of labour[1] or cultural norms result in different male and female activity patterns, this may influence sexual dimorphism (or perhaps more correctly 'gendered polymorphism': Lazenby, 2002) in terms of musculature, body fatness, development of muscle attachments and cross-sectional properties of long bones (e.g. Hamilton,

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[1]A term preferable to the more traditional 'sexual division of labour' (Du, 2000).

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1982; Buffa *et al.*, 2001; cross-sectional shaft properties reviewed in Ruff, 1992, 2000a; individual studies cited below). Biomechanical studies have demonstrated that the cross-sectional size and shape of long bone shafts, and thickness of the cortex, respond to mechanical loading during activities according to the law of bone functional adaptation (Ruff *et al.*, 2006a), where long bone shafts respond to increased mechanical strain through increased bone deposition.

Although some early investigators suggested that diaphyseal shape reflects nutritional adequacy, with flatter diaphyses indicating poor nutrition (see reviews in Lovejoy *et al.*, 1976; Bridges, 1989; Larsen, 1997: 222), poor nutrition appears to cause endosteal bone resorption with little effect on external size and shape (reviewed in Bridges, 1989). Therefore diaphyseal shape differences can be attributed to responses to mechanical loading (with the exception of obvious pathological alterations such as rickets). Evidence for the remodelling of bone diaphyses in response to mechanical loading comes from non-human experimental work (e.g. Lieberman *et al.*, 2001), and studies in humans of remodelling as a result of exercise (e.g. Ruff *et al.*, 1994), pathology and bilateral asymmetry (Trinkaus *et al.*, 1994).

Various studies of archaeological populations have suggested that sex differences in the cross-sectional geometric properties of long bone diaphyses (total and cortical areas, second moments of area, ratios of cross-sectional shape) and/or external measurements might relate to sex differences in activity patterns (e.g. Ruff & Hayes, 1983a,b; Ruff, 1987, 1992, 2000a; Bridges, 1989, 1991, 1993; Larsen, 1997; Bridges *et al.*, 2000; Ledger *et al.*, 2000; Ruff & Larsen, 2001; Stock & Pfeiffer, 2001, 2004; Lazenby, 2002; Holt, 2003; Weiss, 2003; Marchi *et al.*, 2006; Sládek *et al.*, 2006; Wescott, 2006; Carlson *et al.*, 2007; Wanner *et al.*, 2007). It is difficult to relate interpopulation or sex differences to specific activities, particularly for the upper limb due to its multifunctional usage in humans (Bridges, 1989; Stirland, 1993; Ruff & Larsen, 2001; Weiss, 2003), so studies are concerned with general activity levels. Lower limb diaphyseal cross-sectional properties are assumed to relate primarily to mobility patterns (Stock & Pfeiffer, 2001; Wescott, 2006), but mechanical loading of the lower limb might also relate to other activities such as lifting heavy loads whilst standing still (Ruff & Larsen, 2001), treading mud and straw in adobe brick production, or using pedal-operated machinery. However, locomotion remains likely to be the dominant mechanical load on the lower limbs in most cases. Greater mobility increases antero-posterior bending forces on the lower limb bones, resulting in greater diameter antero-posteriorly than medio-laterally and thus less circularity of the bone shaft (Ruff & Hayes, 1983b).

The degree of bilateral asymmetry (the mean difference between right and left sides for individuals within a population) can shed further light onto possible differences in activity, since those producing significant mechanical loading preferentially on one arm or leg may result in significant asymmetry in cross-sectional properties, and in sexual dimorphism in asymmetry where activities are gender-related (e.g. Stirland, 1993; Trinkaus *et al.*, 1994; Bridges *et al.*, 2000; Weiss, 2003; Wanner *et al.*, 2007).

In this study, two European medieval populations of different cultural backgrounds were examined to determine whether levels of sexual dimorphism in diaphyseal cross-sectional shape could be related to differences in activity along gender lines in these populations. It was predicted that the two populations would show gendered differences in the measured parameters, and that these gender effects would be expressed differently in the two populations. Traditional external diaphyseal measurements and ratios were used due to their demonstrated utility (Ruff, 1987; Bridges *et al.*, 2000; Pearson, 2000; Wescott, 2006) and the simple equipment needed to measure them.

Materials

The first population derived from Écija in Andalusia, southwestern Spain. The modern town of Écija is located 80 km east of Seville. Excavations in the Plaza de España between 1997 and 2002 uncovered the medieval Muslim *makbara* (cemetery), which yielded in excess of 4500 inhumed individuals (Jiménez, n.d.; Ortega, n.d.; Román, n.d.). The medieval walled town of Écija was important not only as the site of a major

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battle in AD 711, but also because of its location in the Guadalquivir valley, between Seville and Córdoba, with some control over olive oil trade. The makbara was an exclusively Islamic cemetery (which can be identified from various characteristics including grave orientation, body position and a lack of grave goods, as outlined in Insoll, 1999: 169, 172), with usage stretching from immediately post-conquest through to the 11th century (Jiménez, n.d.; Ortega, n.d.; Román, n.d.). The human remains are curated at the Écija Municipal Museum.

The second population was from Anglo-Saxon Great Chesterford, located south of Cambridge, UK. The Anglo-Saxon cemetery was exposed by commercial gravel extraction and excavated in the early 1950s (Evison, 1994: 1), and 167 human individuals were recovered (Waldron, 1994: 52). As other areas of the cemetery are known to have been destroyed or were not excavated, this represents a 'limited part of an important Anglo-Saxon cemetery' (Evison, 1994: 1). The cemetery dates to approximately AD 450–600 (Evison, 1994: 46), the 'Migration Period' of continental Europe when major population movements are commonly thought to have occurred (Hines, 2003). The cemetery is variable in nature, with some individuals buried with elaborate grave goods such as swords and brooches, while other individuals are buried without such items. Analysis of these associated grave goods has suggested that the cemetery is of 'normal economic status' (Evison, 1994: 51). Although the associated Anglo-Saxon settlement has not been located, Great Chesterford may have had reasonable importance due to its location and easy access to Cambridge and London (Evison, 1994). However, Great Chesterford probably represents an agricultural population: it was only later in the 7th and 8th centuries that the large urban trading centres like Hamwic (Southampton), London and Ipswich grew up as part of a developing continental exchange network (Hines, 2003).

Methods

Age and sex were determined by standard morphological methods (Brothwell, 1981; Lovejoy *et al.*, 1985; Buikstra & Ubelaker, 1994; Schwartz, 1995; O'Connell, 2004), and only adult individuals were studied.

A series of indices reflecting diaphyseal shape were calculated for all major long bones from external diaphyseal diameters measured to the nearest 0.1 mm with sliding callipers (Table 1).

A femoral midshaft robusticity index was also calculated. Robusticity may be defined as 'strength or rigidity of a structure relative to the mechanically relevant measure of body size' (Ruff *et al.*, 1993: 25). Although Pearson (2000) argued that this deviates from the traditional meaning which related shaft dimensions to bone length, this is not the definition adhered to in many recent biomechanical studies (Trinkaus & Ruff, 2000), since it fails to take into account the effects of body mass (Ruff, 2000a) and proportions (Wescott, 2006). Dividing by femoral head diameter (Ruff, 2000a; Wescott, 2006), which correlates with body mass sufficiently that it can be used to estimate this parameter (e.g. Ruff *et al.*, 1991, 1997; Ruff, 1994; Auerbach & Ruff, 2004), was used here to increase the likelihood of showing sex differences due to factors other than body mass. Body mass can be more accurately estimated from stature and bi-iliac breadth (Ruff *et al.*, 1997, 2005; Ruff, 2000b; Auerbach & Ruff, 2004), but skeletal preservation limited the measurement of bi-iliac breadths. However, it should be noted that femoral head area and volume show a highly positively allometric relationship to body mass in humans (Ruff, 1988), which has implications when comparing human groups of different body size, such as males and females. While femoral head breadth is still considered a better proxy for body mass than long bone length, results should be interpreted with caution.

Long bone lengths were also measured following Bräuer (1988) and Martin & Saller (1957) (maximum length in all cases) in order to give an indication of the general level of sexual dimorphism in these populations and so put the results into greater context.

Bilateral asymmetry was examined using percentages of directional asymmetry (%DA) and absolute asymmetry (%AA) calculated for each individual according to the following

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Table 1. Indices of diaphyseal shape

Index	Description	References
Clavicle midshaft	$\frac{\text{Antero} - \text{posterior midshaft diameter} \times 100}{\text{Supero} - \text{inferior midshaft diameter}}$	Measurements: Buikstra & Ubelaker (1994)
Humerus midshaft	$\frac{\text{Minimum midshaft diameter} \times 100}{\text{Maximum midshaft diameter}}$	Measurements: Bräuer (1988), Martin & Saller (1957). Index: Bridges *et al.* (2000)
Radius midshaft	$\frac{\text{Antero} - \text{posterior midshaft diameter} \times 100}{\text{Medio} - \text{lateral midshaft diameter}}$	Measurements: Bräuer (1988), Martin & Saller (1957)
Ulna midshaft	$\frac{\text{Antero} - \text{posterior midshaft diameter} \times 100}{\text{Medio} - \text{lateral midshaft diameter}}$	Measurements: Bräuer (1988), Martin & Saller (1957)
Femur platymeric	$\frac{\text{Subtrochanteric antero} - \text{posterior diameter} \times 100}{\text{Subtrochanteric medio} - \text{lateral diameter}}$	Measurements: Bräuer (1988), Martin & Saller (1957). Index: Bass (1995: 225)
Femur pilasteric	$\frac{\text{Antero} - \text{posterior midshaft diameter} \times 100}{\text{Medio} - \text{lateral midshaft diameter}}$	Measurements: Bräuer (1988), Martin & Saller (1957). Index: Bridges *et al.* (2000)
Femur midshaft robusticity	$\frac{(\text{Antero} - \text{posterior} + \text{medio} - \text{lateral midshaft}) \times 100}{\text{Transverse diameter of femoral head}}$	Measurements: Bräuer (1988), Martin & Saller (1957). Index: Wescott (2006)
Tibia cnemic	$\frac{\text{Medio} - \text{lateral nutrient foramen diameter} \times 100}{\text{Antero} - \text{posterior nutrient foramen diameter}}$	Measurements: Brothwell (1981). Index: Bass (1995: 245)
Tibia midshaft	$\frac{\text{Medio} - \text{lateral midshaft diameter} \times 100}{\text{Antero} - \text{posterior midshaft diameter}}$	Measurements: Bräuer (1988), Martin & Saller (1957). Index: Bridges *et al.* (2000)

formulae (Auerbach & Ruff, 2006):

$$\%\text{DA} = ((\text{right} - \text{left})/(\text{mean of right and left})) \times 100 \quad (1)$$

$$\%\text{AA} = ((\text{maximum} - \text{minimum})/(\text{mean of maximum and minimum})) \times 100 \quad (2)$$

%DA reflects both the magnitude and direction of asymmetry, with positive values indicating larger right-side values and negative indicating larger left-side values, while %AA reflects the total amount of asymmetry between right and left sides regardless of its direction.

Data were analysed using SPSS 14.0 for Windows, with statistical significance defined at 5% ($p \leq 0.05$). For the long bone diaphyseal indices, log-transformed data were used where the distribution differed significantly from normal. Sex differences in mean indices within each population were examined using ANOVA removing the effects of age before testing for the effects of sex, in order to control for differences in age distribution between males and females. This was necessary as continued significant deposition of bone on the outer (subperiosteal) surface occurs throughout adulthood (Garn *et al.*, 1967; Ruff and Hayes, 1982; Lazenby, 1990a,b), and was greater medio-laterally than antero-posteriorly in the femora of a modern population (Feik *et al.*, 2000), thus affecting shape. Whether this occurs in other long bones is unconfirmed.

The asymmetry data frequently showed distributions significantly different from normal which were not corrected by log transformation: a known problem with data of this kind (Auerbach & Ruff, 2006). As the data did not meet the assumptions of normality required to apply parametric tests, Mann-Whitney U-tests were used to compare the degree of asymmetry between males and females within each population.

A numerical representation of the degree of sexual dimorphism was calculated to allow comparisons between measurements within and between populations. In an extensive review of methods to express levels of sexual dimorphism, Smith (1999) demonstrated that simple ratios of male/female mean were sufficiently representative.

The ratio of male mean/female mean was used here, and can be interpreted in terms of the male mean as a percentage of the female mean.

Results

A total of 40 males and 32 females from Écija, and 19 males and 23 females from Great Chesterford were studied. Due to variable preservation, sample sizes for individual measurements vary especially for bilateral asymmetry.

Table 2 summarises sexual dimorphism in long bone lengths and femoral head diameter for Écija and Great Chesterford. Dimorphism indices range from 1.073–1.139 for Écija and 1.087–1.147 for Great Chesterford. Variation in dimorphism between elements and left and right sides of the same element is less for Great Chesterford than Écija. There appears to be no consistent pattern within the upper or lower limb as to which side of the body is more dimorphic, which in light of relatively small sample sizes may suggest random sampling effects.

In the upper limb, the only significant difference in diaphyseal shape is in the right radius for Écija (Tables 3 and 4). This difference appears to result from a particularly low radial midshaft index in females compared with the left side, while male right and left indices are similar in magnitude. This indicates that the shaft is less circular in the female right radius as a result of greater medio-lateral diameter relative to antero-posterior diameter.

In the lower limb, significant differences between the sexes in diaphyseal shape are more commonly observed. In the Écija population (Table 5) there are significant sex differences in mean indices of diaphyseal shape at the left femoral midshaft (pilasteric index), the foramen level of the tibia (cnemic index) and the tibial midshaft. The significantly higher mean index in males than females at the femoral midshaft (pilasteric) and significantly lower mean index at the tibial foramen level (cnemic) and midshaft indices show that the male antero-posterior measurement is greater relative to the medio-lateral measurement, indicating greater antero-posterior bending strength than in females.

For Great Chesterford (Table 6), sex differences in diaphyseal shape are only significant at the tibial foramen level (cnemic index), and occur in the same direction as in the Écija sample.

The femoral robusticity index shows no significant difference in means between the sexes for either population.

Table 2. Sexual dimorphism in long bone lengths and femoral head transverse diameter (TD) for the Écija and Great Chesterford populations

Variable	Side	Écija			Great Chesterford		
		Mean (±SD)		Dimorphism index	Mean (±SD)		Dimorphism index
		Male	Female		Male	Female	
Clavicle	L	150.00 (±9.20)	135.86 (±9.82)	1.104	160.27 (±9.63)	139.70 (±7.63)	1.147
	R	148.60 (±8.71)	134.40 (±7.94)	1.106	152.88 (±12.40)	138.30 (±7.87)	1.105
Humerus	L	315.04 (±15.64)	291.65 (±18.64)	1.080	336.50 (±17.25)	309.43 (±17.07)	1.087
	R	325.45 (±19.68)	293.85 (±15.16)	1.108	346.27 (±16.50)	311.92 (±18.56)	1.110
Radius	L	248.67 (±18.41)	218.32 (±14.04)	1.139	260.79 (±11.98)	235.40 (±14.38)	1.108
	R	247.52 (±15.12)	223.91 (±14.58)	1.105	258.93 (±11.72)	234.86 (±13.39)	1.102
Ulna	L	271.15 (±17.95)	241.61 (±12.12)	1.122	279.25 (±13.14)	250.92 (±16.21)	1.113
	R	271.35 (±14.33)	244.35 (±12.26)	1.110	282.07 (±14.31)	253.17 (±16.69)	1.114
Femur	L	450.79 (±29.61)	409.83 (±25.45)	1.100	479.00 (±21.97)	435.76 (±18.19)	1.099
	R	452.05 (±29.80)	409.92 (±23.51)	1.103	473.21 (±24.15)	434.59 (±19.93)	1.089
Tibia	L	371.81 (±22.69)	346.40 (±20.44)	1.073	388.85 (±20.82)	349.69 (±16.27)	1.112
	R	378.32 (±27.58)	341.29 (±18.86)	1.109	389.25 (±21.10)	352.53 (±16.18)	1.104
Femoral	L	46.33 (±2.59)	41.39 (±2.39)	1.119	48.87 (±2.69)	42.61 (±1.99)	1.147
head TD*	R	46.55 (±2.46)	41.37 (±2.40)	1.125	47.98 (±5.25)	42.36 (±2.43)	1.132

*Femoral head transverse diameter.
All measurements in millimetres. All long bone lengths are maximum lengths as defined by Martin & Saller (1957) and reproduced in Bräuer (1988).

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Table 3. Male and female upper limb diaphyseal shape for the Écija population

Index	Side	Male		Female		Significance (*p*) of:		Dimorphism index
		n	Mean	*n*	Mean	Age effect	Sex effect	
Clavicle midshaft	L	*23*	*109.41*	*20*	*110.68*	*0.613*	*0.938*[L]	*0.989*
	R	*20*	*106.55*	*20*	*113.25*	*0.541*	*0.786*	*0.941*
Humerus midshaft	L	*26*	*78.77*	*17*	*74.96*	*0.159*	*0.931*	*1.051*
	R	*27*	*78.79*	*26*	*76.59*	*0.894*	*0.538*[L*]	*1.029*
Radius midshaft	L	*27*	*80.34*	*22*	*79.51*	*0.663*	*0.297*[L]	*1.010*
	R	31	80.59	22	74.96	0.657	0.027[L*]	1.075
Ulna midshaft	L	*27*	*86.80*	*18*	*82.50*	*0.042*	*0.597*[L*]	*1.052*
	R	*23*	*83.51*	*17*	*82.65*	*0.571*	*0.645*[L]	*1.010*

[L] Denotes ANOVA applied to log transformed data.
[L*] Denotes data which still show a non-normal distribution even after log transformation: ANOVA was applied to the log transformed data but consequently the result must be used with caution.
Italics denote non-significant sex effects.

Table 4. Male and female upper limb diaphyseal shape for the Great Chesterford population

Index	Side	Male		Female		Significance (*p*) of:		Dimorphism index
		n	Mean	*n*	Mean	Age effect	Sex effect	
Clavicle midshaft	L	*10*	*112.78*	*10*	*117.35*	0.954	*0.509*	*0.961*
	R	*8*	*110.07*	*10*	*118.38*	0.957	*0.434*	*0.930*
Humerus midshaft	L	*10*	*78.56*	*14*	*76.36*	*0.494*	*0.596*	*1.029*
	R	*15*	*77.25*	*14*	*76.67*	0.809	*0.585*	*1.008*
Radius midshaft	L	*14*	*77.88*	*10*	*76.99*	0.903	*0.890*	*1.012*
	R	*13*	*75.19*	*14*	*76.72*	0.581	*0.304*	*0.980*
Ulna midshaft	L	*12*	*78.48*	*13*	*75.92*	*0.933*	*0.524*	*1.034*
	R	*14*	*81.77*	*12*	*79.11*	*0.566*	*0.566*	*1.034*

Italics denote non-significant sex effects.

Table 5. Male and female lower limb diaphyseal shape for the Écija population

Index	Side	Male		Female		Significance (*p*) of:		Dimorphism index
		n	Mean	*n*	Mean	Age effect	Sex effect	
Femur platymeric	L	*25*	*86.32*	*24*	*82.69*	*0.520*	*0.269*	*1.044*
	R	*36*	*86.03*	*30*	*83.59*	*0.821*	*0.294*[L]	*1.029*
Femur pilasteric	L	19	109.96	23	102.12	0.593	0.024	1.077
	R	*22*	*113.33*	*24*	*104.51*	*0.177*	*0.112*	*1.084*
Femur midshaft robusticity	L	*18*	*124.30*	*23*	*124.12*	*0.860*	*0.802*[L*]	*1.001*
	R	*20*	*123.40*	*21*	*122.57*	*0.900*	*0.286*	*1.007*
Tibia cnemic	L	26	67.85	27	71.95	0.586	0.011	0.943
	R	31	68.60	25	73.59	0.945	0.008[L]	0.932
Tibia midshaft	L	18	70.80	19	74.49	0.042	0.013	0.951
	R	19	69.39	21	76.80	0.110	<0.001	0.904

[L] Denotes ANOVA applied to log transformed data.
[L*] Denotes data which still show a non-normal distribution even after log transformation: ANOVA was applied to the log transformed data but consequently the result must be used with caution.
Italics denote non-significant sex effects.

Table 6. Male and female lower limb diaphyseal shape for the Great Chesterford population

Index	Side	Male		Female		Significance (*p*) of:		Dimorphism index
		n	Mean	*n*	Mean	Age effect	Sex effect	
Femur platymeric	L	*19*	*86.34*	*20*	*82.19*	*0.823*	*0.508*[L*]	*1.050*
	R	*16*	*88.40*	*20*	*81.40*	0.538	*0.148*[L*]	*1.086*
Femur pilasteric	L	*17*	*102.96*	*17*	*98.36*	*0.468*	*0.235*	*1.047*
	R	*12*	*106.16*	*16*	*99.10*	*0.599*	*0.055*[L]	*1.071*
Femur midshaft robusticity	L	*13*	*122.59*	*15*	*123.35*	*0.086*	*0.832*	*0.994*
	R	*11*	*127.55*	*13*	*123.46*	0.602	*0.846*[L*]	*1.033*
Tibia cnemic	L	17	67.08	18	73.02	0.390	0.002[L*]	0.919
	R	18	67.46	20	72.35	0.684	0.016[L*]	0.932
Tibia midshaft	L	*13*	*73.60*	*16*	*76.06*	*0.691*	*0.256*	*0.968*
	R	*16*	*74.91*	*15*	*78.46*	*0.904*	*0.144*	*0.955*

[L] Denotes ANOVA applied to log transformed data.
[L*] Denotes data which still show a non-normal distribution even after log transformation: ANOVA was applied to the log transformed data but consequently the result must be used with caution.
Italics denote non-significant sex effects.

There are no significant sex differences in bilateral asymmetry in diaphyseal shape for either population (results not shown). This suggests that the relative loading of the right and left sides for both upper and lower limbs was similar in males and females in these populations. However, samples sizes are small due to the preservation of the material (10–24 individuals of each sex for Écija, and 6–18 individuals of each sex for Great Chesterford); ideally, minimum samples of 30 each are needed for analyses of differences in asymmetry (Stirland, 1993). Although some patterns in asymmetry may be suggested in the data presented above, interpretation should be reserved in the absence of more individuals with both sides of the body sufficiently well-preserved for measurement.

Comparative external diaphyseal shape data from three other studies (Ruff, 1987; Bridges *et al.*, 2000; Wescott, 2006) may help to put these results into context. Percentage dimorphism (100× (male mean-female mean)/female mean) has been calculated from data presented in each of these and the current study for comparison. Many studies of diaphyseal properties use cross-sectional geometry rather than the external diaphyseal measurements employed here, and the results from these different methods are only broadly comparable (Ruff, 1987; Bridges *et al.*, 2000; Pearson, 2000; Wescott, 2006). Throughout these comparisons, it should be borne in mind that they are not statistically tested and that the majority of data available are from North American populations. The pattern of statistically significant differences between male and female means for the Écija and Great Chesterford populations should also be taken into account (although it is not stated whether such differences were significant for the comparative data).

Ruff (1987) presented data from a variety of world (but predominantly North American) populations. He showed that dimorphism in diaphyseal shape or cross-sectional properties tended to decrease from hunter-gatherer to agricultural to modern populations, a pattern supported by subsequent analyses (Ruff, 2000a; Wescott, 2006), and that the femoral midshaft shape was most strongly associated with a subsistence strategy. Tibial foramen level and midshaft shape also showed reasonable associations with subsistence, but the subtrochanteric region of the femur did not, probably because it is strongly influenced by the effects of sex differences in pelvic breadth in relation to childbirth (Ruff, 1987). At the femoral midshaft, tibial foramen and tibial midshaft levels, the Écija population shows a level of dimorphism within the hunter-gatherer range and outside the agricultural range (Figure 1). This might suggest more marked gendered activity differences than is commonly observed in agricultural populations. The Great Chesterford population shows dimorphism at the mid-high end of the agricultural range for femoral and tibial midshaft, and is within the hunter-gatherer range for the tibial foramen level.

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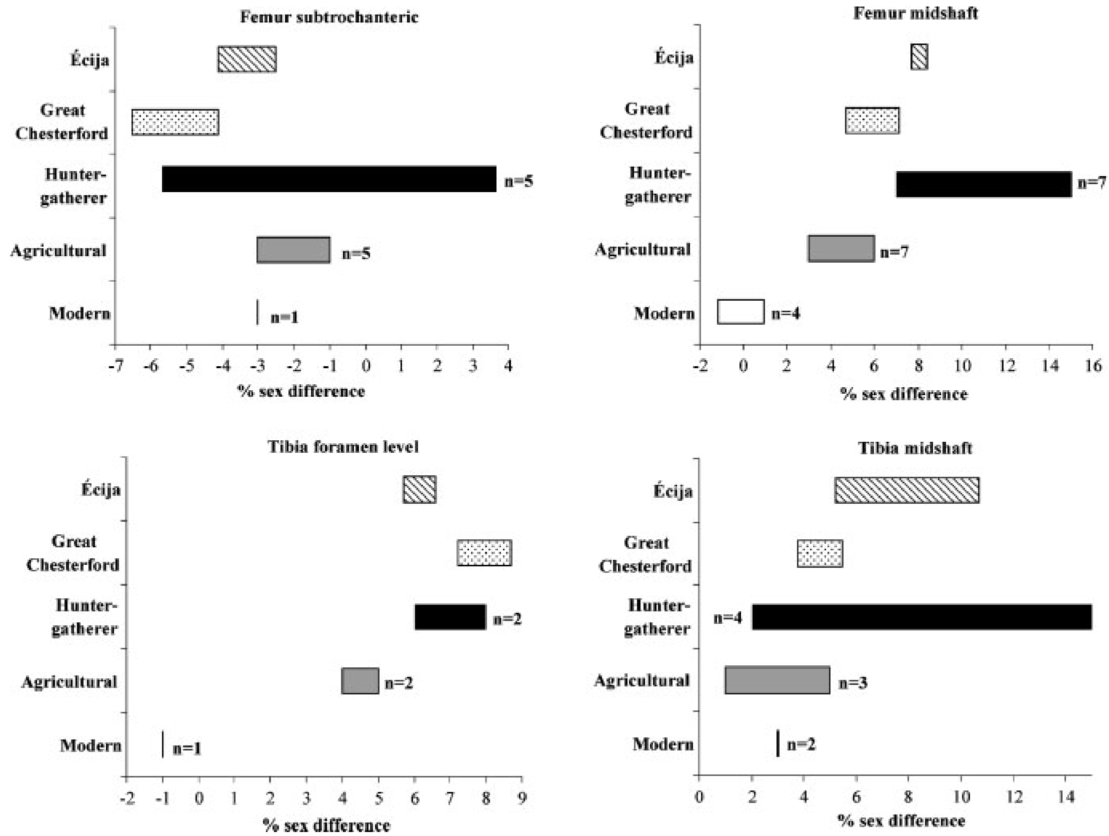

Figure 1. Comparison of dimorphism in the Écija and Great Chesterford populations with data grouped by subsistence strategy from Ruff (1987). Ranges represent intra-sample range (between left and right sides) for Écija/Great Chesterford samples, and inter-sample ranges for populations from Ruff (1987). Indices of external tibial and femoral subtrochanteric shape have been recalculated to correspond to those presented in Ruff (1987), who employed inverted versions of the equations used here. $n =$ number of populations upon which range is based.

Bridges *et al.* (2000) presented data from west-central Illinois covering the period of intensification of crop cultivation and increasing reliance on maize agriculture (Figure 2). Low-level horticulture was practised during the Middle Woodland period (50 BC–AD 200), whilst in the Late Woodland period (AD 600–850) this was intensified and later included some maize cultivation. By the Mississippian period (AD 1050–1250), intensive maize agriculture was being practised.

Firstly, there is no consistent decrease in dimorphism over time in the Illinois populations, as we might expect in light of Ruff (1987) and subsequent studies. Sexual dimorphism in the platymeric index is greater at both Écija and Great Chesterford than for any Illinois population. For the femoral midshaft (pilasteric index), dimorphism for Écija is greater than for the Illinois populations except the early Late Woodland, while Great Chesterford is lower than all groups except the Mississippian. For both the Écija and Great Chesterford samples, dimorphism in the tibial cnemic index is greater than any Illinois population, while at the tibial midshaft Écija is again more dimorphic than all groups except the early Late Woodland, and Great Chesterford is less dimorphic than the early and late Late Woodland. These results overall suggest that the degree of dimorphism is higher than we might expect for the Écija sample, but highlights the fact that the association between dimorphism and subsistence patterns is not clear cut, even within restricted geographical areas.

Wescott (2006) presented mean femoral pilasteric and midshaft robusticity indices for

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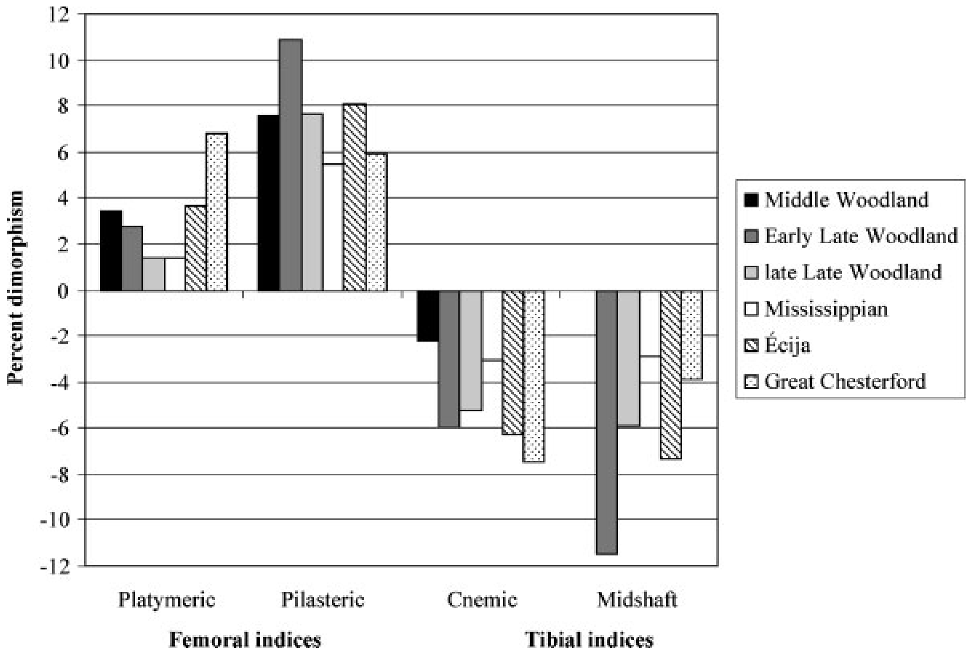

Figure 2. Comparison of sexual dimorphism in diaphyseal shape indices with data from Bridges *et al.* (2000). Mean of left and right indices shown to simplify comparisons. Percentage dimorphism = 100× (male mean - female mean)/ female mean.

North American populations grouped into six levels of mobility, ranging from broad-spectrum hunter-gatherers to late modern industrialists (Figure 3).

The Écija sample has pilasteric indices comparable with the most mobile group in Wescott's (2006) study (broad spectrum hunter-gatherers, group 5), while Great Chesterford falls between broad spectrum hunter-gatherers and all other groups. The low dimorphism in femoral midshaft robusticity for both Écija and Great Chesterford is similar to those for hunter-gatherer, horticultural and late modern industrial populations, and lower than the maize horticulture/equestrian hunter-gatherer (group 2) and early modern industrial populations (group 1), which interestingly show greater dimorphism than more mobile populations but in the opposite direction.

Discussion

The general lack of significant differences in diaphyseal shape of the upper limb bones is perhaps unsurprising. Compared with the lower limb, in which mechanical loading relates primarily to locomotion, the upper limbs perform a much wider variety of activities and consequently experience greater variation in mechanical loadings (Stirland, 1993; Weiss, 2003). So while overall robusticity of upper limb bones has been shown to relate to activity patterns (e.g. Bridges, 1989; Bridges *et al.*, 2000; Stock & Pfeiffer, 2001; Weiss, 2003, although see Weiss, 2005), upper limb bone cross-sectional shape does not do so consistently (Ruff & Larsen, 2001). In the humerus, the increased development of muscle attachments in response to greater mechanical loading may counteract the effects of mechanical loading on the bone shape itself (see Ruff & Larsen, 2001). Sex differences in relative forearm and upper-arm length (Trinkaus, 1981), musculature and hormone profiles all complicate the picture for studies concerned with sexual dimorphism in diaphyseal shape and upper limb activity

The significant sex difference in the cross-sectional shape of the right radial midshaft for Écija is difficult to explain. In addition to the factors detailed above, the radius is particularly variable in its position and orientation within the

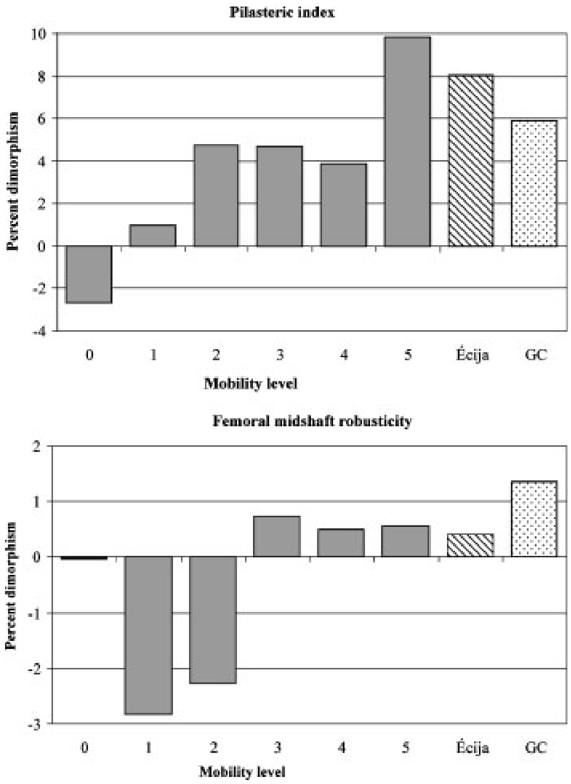

Figure 3. Comparison of sexual dimorphism in femoral indices with Wescott's (2006) categorisation according to mobility and subsistence. Mobility levels: 0 (lowest) = late modern industrial; 1 = early modern industrial; 2 = maize horticulture/equestrian hunter-gatherer; 3 = incipient horticulture/village horticulture/hunter; 4 = woodland/marine hunter-gatherer; 5 (highest) = broad-spectrum hunter-gatherer. Mean of left and right indices shown. Percentage dimorphism = 100× (male mean - female mean)/female mean.

forearm, relative to other upper limb bones and external forces, since it rotates around the ulna during pronation and supination of the hand. As cross-sectional shape reflects generalised loading of the limb, we would expect to see some differences in the humerus and particularly the ulna as well. Furthermore, there was no difference in radial bilateral asymmetry (although sample sizes were small). To confirm any differences in upper limb activity in the Écija population, larger samples are needed, particularly to assess bilateral asymmetry.

There are more significant sex differences in lower limb diaphyseal shape at Écija than Great Chesterford. Comparative data suggest that dimorphism in diaphyseal shape at the femoral midshaft and tibia foramen level and midshaft for Écija is high for an urban population, or even one with an agriculture-based economy, and implies a fairly high level of gendered differences in activity. Dimorphism for Great Chesterford is within the range expected for an agricultural population, tending towards the higher end, although differences between mean male and female shape indices were only statistically significant at the tibial foramen level (cnemic index). This suggests a greater difference between the sexes in mobility at Écija than at Great Chesterford.

Historical evidence gives some grounds to expect greater gender differences in mobility at Muslim Écija than at Anglo-Saxon Great Chesterford. Muslim religious texts, the Koran and Hadith, outline the roles of women in Muslim society and suggest their activity be restricted to maintain their chastity and thus their lineage's honour (Guichard, 1976: 110; López de la Plaza, 1992: 174–5). A woman's domain is said to be the household, while that of men is public duties (Fierro, 1989; López de la Plaza, 1992: 56), and the Koran states that women should not participate in public life, but should stay at home, and even within the home must be kept away from visitors who are not close relations (Fierro, 1989). Furthermore, the Hadith states that women should not be allowed to leave the house alone without being chaperoned by their husband or a close relative (Fierro, 1989). Within the house, a woman's duties relate to childcare, housework including bread-making, sweeping, cooking, washing clothes, and spinning and weaving (Fierro, 1989). While the Koran and Hadith may represent ideals which were not necessarily strictly followed (Fierro, 1989), and most documentary evidence concerns principally upper-class women (Viguera, 1989), it is recorded that women performed the kinds of tasks outlined above (Rubiera, 1989).

We might envisage that these restrictions on female activity could limit their mobility enough to produce marked differences from men in diaphyseal shape. However, López de la Plaza (1992: 56) suggested that in urban al-Andalus, women participated in activities such as social visits and going to the baths as much as men. The separation of women and men could be achieved

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in public places through their being accompanied by a family member, or by having different times of the day during which men and women were permitted to enter certain places, such as the baths (de Epalza, 1989). It is also known that women did sometimes take on paid work, as some upper-class women worked as teachers, and others sold their spinning and weaving to provide an income when they were widowed (Rubiera, 1989). Documents relating to the task of market inspectors describe female brocade-makers, spinners and slaves (Constable, 1997: 175–9; Shatzmiller, 1989). Nonetheless, it is generally thought that the activity of women would have been much more restricted than that of males in this society, and thus men would probably have been much more mobile on a daily basis than women.

Other osteological evidence, although limited, supports this strong distinction between male and female activities in Muslim Spain. Al-Oumaoui *et al*. (2004) found strong sexual dimorphism in muscle marker development of the arms and legs in a rural agricultural Muslim population, while a rural agricultural Christian population showed much lower dimorphism. Overall, osteological and documentary evidence suggest strong gender differences in activity, particularly mobility, in medieval Muslim Spain, and the results of the present study support this.

In early Anglo-Saxon society, men and women were probably both involved in agricultural tasks, such as harvesting and threshing corn, milking and dairy work (Hines, 2003). However, linguistic, archaeological and documentary evidence suggest that spinning and weaving were associated with women, and the word 'woman' derives from terms relating to these tasks (Fell, 1984: 39; Hines, 2003). It also seems likely that much of the dairy work and bread-making was the responsibility of women, while men were responsible for herding animals, at least on larger estates (Hagen, 1992: 26). Household bread production may have been a female task and the word 'lady' derives from the Anglo-Saxon word *hlœfdiga*, which itself derived from words meaning 'bread-kneader' (Hagen, 1992: 18), although words for 'baker' occur in male and female forms (Fell, 1984: 49; Hagen, 1992: 18).

Other osteological evidence is somewhat contentious for Anglo-Saxon England. Hines (2003) stated that pathology thought to relate to activity, such as osteoarthritis, is equally frequent in males and females, but a substantial review by Roberts & Cox (2003) indicated that males suffered more frequently from spinal and peripheral osteoarthritis than females. Our study suggests that sex differences in mobility may have existed. Female tasks seem to have been more house-based and so may have involved a lower level of mobility than tasks undertaken by men.

The results for Écija show some similarities to Ruff and Hayes (1983a,b) and Ruff's (1987) diaphyseal cross-sectional studies of the archaeological population from Pecos Pueblo, New Mexico. They found that sex differences are only significant around the knee (distal and proximal halves of the femur and tibia respectively), which they interpreted as resulting from gender differences in mobility. They argued that this was because the greatest stress during walking and, in particular, running occurs around the knee. However, the finding of more significant results in the proximal half of the tibia than the femoral midshaft for both Écija and Great Chesterford is not entirely consistent with this model.

While few other studies consider both the femur and tibia in the same population(s), variations from the predicted pattern are found (e.g. Bridges *et al*., 2000; Stock & Pfeiffer, 2004). Cross-sectional geometric studies have also shown different patterns of temporal change in the femoral and tibial midshafts (Holt, 2003; Ruff *et al*., 2006b). The femoral midshaft probably experiences both antero-posterior loading as a result of locomotion, but also a medio-lateral loading related to body (pelvic) breadth to which the tibia is less exposed (Ruff *et al*., 2006b), resulting in different patterns of response to mobility-related mechanical loading at these two locations. Where mobility is particularly high, this could increase medio-lateral loading on the femoral midshaft (as well as increasing antero-posterior loading) due to the repeated transfer of weight laterally from one leg to the other, counteracting to some extent the effects of increased antero-posterior loading. This suggests that differences in tibial diaphyseal shape may reflect differences in mobility more closely than differences in femoral midshaft shape (Ruff *et al*., 2006b).

Similarly, the significant sex differences for the left femoral midshaft but not the right at Écija also require explanation. Other studies have also found disparity in results for left and right sides (e.g. Bridges *et al.*, 2000), although most do not present data from right and left sides separately, making it difficult to assess how commonly this occurs. It is highly possible that this is a stochastic effect of small sample size and variable sample composition due to incomplete individuals. While the majority of humans are right-handed, it is thought that the left leg is most commonly used for stability and 'pushing off' during locomotion (see Auerbach & Ruff, 2006, and references therein). Therefore where one group is more mobile than another, differences might be more marked on the left side and more likely to reach significance in small samples. However, the right tibia is more dimorphic and the differences more highly significant than the left for Écija. More widespread documentation of the differences in diaphyseal shape between right and left sides in other populations will help to elucidate the probable cause of this result, and increase our understanding of the causes of variation in diaphyseal shape.

If mean shape indices themselves were directly comparable between populations, this might suggest whether particularly high or low mobility in one sex is the main contributor to high or low dimorphism in that population. However, Wescott (2006) found that even within a relatively restricted geographical region, the level of dimorphism was associated with mobility levels, but the correlation between diaphyseal shape indices and mobility levels within sexes was poor. Comparing diaphyseal indices between this and other studies confirms that there is indeed a wide variation in these indices between populations sharing similar subsistence or mobility patterns, thus precluding any meaningful insight into the origin of differences in dimorphism between these populations. This variation may well, as Wescott (2006) suggests, arise from other factors influencing diaphyseal shape. As such factors are probably local rather than universal (Wescott, 2006), both a greater body of regional comparative material and deeper understanding of other factors influencing lower limb diaphyseal shape is needed, before insights into the origin of dimorphism from the shape indices themselves can be gained.

Social differentiation within these societies may have influenced the results of this study. The slave trade was a major element of the medieval Spanish economy (Guichard, 1976: 113; Collins, 1995: 192). However, the Koran states that non-Muslims captured in war are the only legitimate source of slaves (Collins, 1995: 148–9), so slaves would rarely have been buried in the Muslim cemetery. Social status may also have affected the activity levels of free individuals if, for example, they were able to afford slaves to undertake heavy and menial tasks. In Anglo-Saxon England, documentary evidence suggests that the freedom of certain groups including slaves and bondsmen or clients was limited, and they were bound by various obligations (Hines, 2003). The quantity and quality of grave goods are often considered to reflect differentiation by wealth and social status within Anglo-Saxon groups (e.g. Härke, 1997; Lucy, 2000; Privat *et al.*, 2002, but see Arnold, 1997: 177–80). From the wide range of graves, from unfurnished to richly furnished (Evison, 1994), the individuals buried at Great Chesterford were probably drawn from across the social spectrum. Activity may well have varied by social status, but in this non-urbanised, agricultural community we might expect that the majority of individuals were actively involved in daily subsistence activities.

Economic specialisation within societies may have created variation in the activity patterns within sexes, although this is probably less important at Great Chesterford since economic specialisation mainly occurred in the later Anglo-Saxon period (Hines, 2003). The identification of individual occupations is rarely possible, and sexual dimorphism must be examined at the population level. However, we should remain aware of the potential influence on the results of this and other studies.

The comparisons made here with data from other studies are limited in terms of the number of populations and their similarity genetically and temporally. North American populations strongly dominate the comparative data for dimorphism in external diaphyseal shape, and differences in body size and shape may limit the comparability of these data with the European populations in

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this study. The ways in which populations are grouped by subsistence strategy or mobility also have limitations. Although external diaphyseal shape and cross-sectional properties of lower limb bones show a decrease in dimorphism with the transition to agriculture (Ruff, 1987, 2000a), differences between major subsistence categories are not clear cut. Bridges *et al*. (2000) have shown that changes in activity may precede major transitions between subsistence categories which are gradual processes, and that these changes do not occur smoothly. While Wescott's (2006) mobility categories recognise that variation may occur within major subsistence strategies, differences in mobility are difficult to measure and infer for archaeological populations, and such categorisations are necessarily subjective. These comparative data have still proved useful for placing the current results into context, but a greater body of data from European populations may increase the insight gained from these results.

Conclusions

This study of external diaphyseal shape suggests that the medieval Muslim population of Écija shows a high level of sexual dimorphism. This is consistent with and supports documentary and other osteological evidence for strong gender differences in activity patterns, which may relate to the restriction of female activity and mobility in order to preserve family honour in this society. Sexual dimorphism was also fairly high in the lower limb for the Anglo-Saxon population of Great Chesterford (although differences between male and female means are generally not significant), consistent with documentary evidence for a possibly weaker gendered difference in mobility. Sex differences in mean upper limb bone diaphyseal shape indices were not significant for either population, although differences in upper limb activities are more difficult to demonstrate due to greater variation in the nature of mechanical loading than in the lower limb. Results for sexual dimorphism in the degree of bilateral asymmetry are inconclusive due to small sample sizes.

The results obtained here have also highlighted gaps in our knowledge of: (i) right and left side differences in diaphyseal shape indices within populations; (ii) interpopulation variation in absolute diaphyseal shape indices with major subsistence categories, and the causes of this variation; and (iii) changes in dimorphism with subsistence strategy in European populations. More extensive documentation and understanding of these areas will allow even greater insight into sex differences in activity to be gained from this and other studies of cross-sectional diaphyseal shape.

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