ANTHROPOLOGICAL REVIEW • Vol. 74, 13–23 (2011)
Available online at: https://doi.org/10.2478/v10044-010-0002-3

Does human sexual dimorphism influence fracture frequency, types and distribution?

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ABSTRACT This study explores the hypothesis that the pattern of gender inequality in a community influences the frequency, patterns and distribution of fractures. As it is not possible to read gender relations from skeletons, it is – following several research results – assumed that the level of gender inequality is reflected in sexual dimorphism. Thus the study design consists in correlating a measure of sexual dimorphism with measures of frequencies, patterns and distribution of skeletal trauma between the two sexes. Nearly two hundreds individuals from two medieval Danish cemeteries have been examined (43 females/48 males from Jutland and 46 females/49 males from Funen). Sexual dimorphism was assessed by means of measurements on the pelvis and, in accordance with conventional wisdom, the level of sexual dimorphism was found to be lower in the Funen than in the Jutland sample. The fracture frequencies, patterns and distribution were estimated for the two skeletal samples. No significant difference between the fracture frequencies or types on the two sites was found, but the distribution of fractures between the sexes in Ribe was found to be significantly different. The study indicates a level of relationship between human sexual dimorphism, gender roles, and the distribution of fractures between the sexes. Studies of larger samples will help clarify this.

KEY WORDS: interpretation of injuries, gender roles, medieval Denmark

Studies of old skeletal remains often indicate a relatively high fracture frequency in ancient communities compared to more recent data, and this higher fracture frequency is assumed to have been more pronounced for women. Central to the interpretation of this difference seems to be an almost unanimous consensus to interpret fractures seen in women as an indication of them having been controlled by beating by their men and thus that these women were socially inferior to men. Consequently, the frequency of fractures contributes to the sociological interpretation of women's status in historic and prehistoric communities.

The incentive for embarking on this study was to evaluate alternative explanations of fracture by testing the hypoth-

Received 20 November 2010; accepted 8 July 2011
DOI: 10.2478/v10044-010-0002-3

esis that the human sexual dimorphism observed in a community correlates with the distribution of fractures (work/accident as well as violence related) between the two sexes, whereas fracture frequency and types could be influenced by other factors. This study correlates a measure of human sexual dimorphism with measures of frequencies, types and the distribution of skeletal traumas. Although the two osteological elements (human sexual dimorphism and fractures) have been studied separately by various scholars [Smith & Jones 1910; Nielsen 1970; McWhirr *et al*. 1982; İşcan & Miller-Shaivitz 1984; Rösing 1990; İşcan *et al*. 1994; Smith 1996; Steyn & İşcan 1997; González-Reimers *et al*. 2000; Judd 2002*a*,*b*, 2004, 2006, 2008; Rich *et al*. 2005; Šlaus & Tomičic 2005], the correlation between the two types of data has, to the best of my knowledge, never been studied before, and has a potential which needs to be more widely acknowledged and explored. It is important to note that this study is focused on patterns of daily activity and the distribution of fractures between the two sexes, and not so much on individual cases and distribution of fractures between social classes.

In order to carry out this study, it was essential to have material from two locations, one with a documented high degree of human sexual dimorphism and one with a low degree. It was necessary that the material came from a compatible time period, and the communities presented a well documented and compatible socio-economic structure. The Danish medieval skeletons stored at ADBOU at the University of Southern Denmark were found to be highly suitable for this study. After years of study of the more than 12000 skeletons held here, the staff had developed the theory that the skeletons from Jutland presented a much higher human sexual dimorphism than the skeletons from Funen. This theory was tested and supported by another study carried out alongside the present study.

Materials

Skeletal remains and their dating

The skeletal remains from Funen used for this study came from excavations of two adjoining cemeteries in central Odense. The excavations, initiated by Odense City Museum, were under the supervision of Jacob Tue Christensen. The main part of the material for this study came from the excavation OBM no. 9784, which was conducted in March-May 1998. This excavation provided skeletal material from a total of 165 graves. The subsequent excavation OBM no. 9785 provided skeletal material from 170 additional graves.

The skeletal remains from Jutland were unearthed in connection with an excavation in Ribe. The excavation ASR no. 1015, headed by Jacob Kieffer-Olsen, was conducted in 1993. In total, 592 graves were excavated.

The dating of skeletal material from Odense was based on the observed arm position “a, b, c or d” (see Fig. 1) in the grave according to the method described by Jacob Kieffer-Olsen [Christensen 1999]. This method of dating, supported by archaeological and written evidence, indicated that the vast majority of the skeletons from Odense could be ascribed to the Danish medieval period from 1086 AD to 1542 AD [Christensen 1999]. Assuming that Jacob Kieffer-Olsen used the above-mentioned method described by him in combination with the archaeological and written evidence, the skeleton remains from Ribe could be dated from mid 1200 AD to 1400 AD.

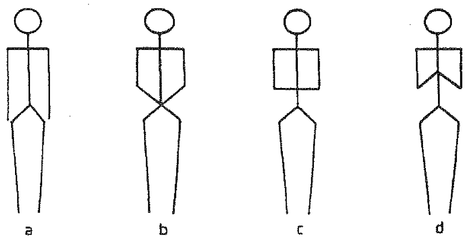

Fig. 1. Schematic drawing of arm positions used in the Danish medieval period ("a" being the oldest, and "d" the youngest) [Christensen 1999, p. 89].

Socio-economic mix of skeletons

As studies such as those carried out by Rösing [1990], Judd [2006] and others indicate that social class and occupation (subsistence related activities) will influence fracture frequencies and patterns, it was essential to ascertain that the two sites provided material from compatible societies with compatible social mix. Both written and archaeological sources give us a very clear picture of the medieval period in Ribe and Odense. Both cities functioned as important centres for trade and craft [Nielsen 1985, Christensen 1988]. Odense was right in the centre of the trade routes linking the western and the southern parts of Denmark, and Ribe controlled the connection to the European market. Hence, both cities were major urban locations in medieval Denmark, and their inhabitants engaged in identical occupations (e.g., merchants, craftsmen, dignitaries, clergymen). So, all in all, the material from the two locations seems to indicate a fairly compatible mix in the socio-economic structure of the societies from which the skeletons came, and thus in the two samples. Studies of the excavation reports, in particular the position of the graves, further support this assumption [Christensen 1999: 86]. The skeletons came from the more prestigious locations in and just outside the church as well as from other sections of the cemeteries. Comparisons of the socio-economic structure, dating of the remains and age distribution (as will be seen later) seem to indicate a fairly high compatibility in the material from the two locations.

Methods

Age and sex determination

As human sexual dimorphism was a central part of this study, it was decided to use only skeletons from adults for this investigation; thus individuals where SOS (spheno-occipital synchondrosis) had not yet fused and where the epiphysis lines indicated an age below 16 [Bass 2005] were excluded, as were very fragmented skeletons. A similar method was used by Judd [2002*a*, 2004] when examining the skeletal remains from the Nubian site Kerma.

Sex determination was made based on examination of the skull, the pelvis and the post-cranial skeleton [Mays 1998, Bass 2005]. On the skull the following 5 points were assessed: absence or presence of a brow ridge (glabella), size of the mastoid process, size of the muscular attachment in the neck, the thickness of the eye cavity rim (orbital rim) and the height and angle of the lower jaw (mandible). The pelvis was assumed to provide the most accurate indication of the individual's sex. In the pelvis, sex indication was determined on the form of the pubic bone (pubis), the angle of the bones (ischium) leading to the pubic bone, and the general "openness" of the pelvis (providing a birth canal). The overall size and robustness of other bones of the skeleton (the post-cranial bones) were also considered. After the overall assessment described above, each skeleton was given an individual score ranging from 1 to 7, 1 being evidently male, 4 denoting that sex could not be determined, and 7 being evidently female. The scores 3 and 5 were given to individuals with low sexually dimorphic characteristics.

Ages were determined from multiple osteological age indicators as suggested by leading scholars (Calibrated Expert Inference – J.L. Boldsen, pers. com., 2010). Age determination was based on the presence/visibility of epiphyseal lines, tooth eruption [Bass 2005] and, where possible, followed a 7-point methodology developed by the staff at ADBOU involving, among other things, an investigation of the general ”smoothness” of or presence of exostosis and attrition on the femoral head (femur caput) and the shin-bone head (tibia caput). After examining as many of the above-mentioned points as possible, a more comprehensive individual age assessment based on the whole skeleton was made.

Registration of fractures

All the bones from all of the skeletons were examined for signs of ante- and perimortem fractures. All of the observed traumas were entered into an excel spreadsheet to ensure optimal registration of all fractures and to facilitate further statistical evaluations. On the spreadsheet were entered the grave number, sex and age of the individual, the degree of preservation of the skeleton, as well as the specific bones fractured, side indication (right/left part of the body), and probable cause of the fracture (impact of high- or low-energy). The statistical analysis was performed with the computer program R for Mac OS.11 using χ^2 tests.

Results

Age and sex distribution

Based on the criteria for ageing and sexing the skeletons mentioned above, the Odense material yielded a total of 91 individuals, 43 females and 48 males. The material from Ribe provided 46 females and 49 males, giving a total of 95 individuals. The age distribution observed in the Odense material is shown in Table 1. 79% of the women died between ages 26-35 compared to only 58% of the men, and only 9% of the women could expect to reach their 36th birthday compared to 31,5% of the men. In the material from Ribe, an almost identical distribution is observed (see Table 1). In this sample, 72%

Table 1. Age distribution of females and males in the Odense and the Ribe samples

Age group	Odense				Ribe			
	Females		Males		Females		Males	
	N	%	N	%	N	%	N	%
17-25	5	12	5	10,5	6	13	7	14
26-35	34	79	28	58	33	72	29	59
36-45	4	9	10	21	7	15	10	21
46+	0	0	5	10,5	0	0	3	6
Total	**43**	100	**48**	100	**46**	100	**49**	100

women died between ages 26-35 compared to 59% men, and only 15% of the women could expect to reach the age of 36, the value for men being 27%. Thus, a very similar age distribution is observed in the two samples. In accordance with what is traditionally observed in historic skeletal samples, a high number of women died in the childbearing and nursing age group, but in contradistinction to the norm, women are not seen to outlive men in either of these two locations.

Sexual dimorphism

Human sexual dimorphism is defined as the difference in the mean size/stature of women compared to men, as well as differences in morphological traits (such as in the pelvis or skull). Size is a variable factor and therefore human sexual dimorphism is indicated as a degree of human sexual dimorphism and not as the presence or absence of human sexual dimorphism in a society. The human sexual dimorphism in the two samples used for this study was established (in a separate study) based on measurements of the pelvis using the DSP method developed by Murail *et al*. [2005], and was found to be high in the Ribe sample and low in the Odense sample.

Fractures in the Odense material

In the skeletal remains from Odense, a total of ten individuals with fractures were observed, five women and five men (see Table 2). Of these three women and two men displayed minor injuries such as broken fingers, toes or broken/bent ribs. The same general types of fractures were observed in both women and men.

One woman, aged between 28 and 38, had a fractured left ulna (midshaft), and the patella, distal end of her right femur and proximal end of the tibia had been crushed and found to be completely fused. The patella of her left leg had heavy ebonation, indicating that walking might have been difficult and quite painful for this woman (Fig. 2). One man aged between 29 and 34 had a fractured right radius and phalanx in his right hand. Another man between ages 26 and 36 had fractured his left humerus and femur caput

Fig. 2. Right femur/tibia fracture, left patella (same individual) with heavy ebonation (photo J. Nielsen).

Fig. 3. Fractured left humerus (photo J. Nielsen).

Fig. 4. Fractured left femur caput (photo J. Nielsen).

(Figs. 3 and 4), as well as a rib on the right side. The individual displaying most traumas was a male aged 35-43 with no less than four fractures: the right ulna (midshaft), right humerus, right pubis bone, and three ribs on the left side. Most fractures in this sample were observed on the right side of the skeletons.

Fractures in the Ribe material

In the skeletal remains from Ribe, a total of 11 individuals with fractures were observed, two women and nine men (see Table 2). The same general types of fractures were observed in both woman and man as seen in the Odense sample.

The two women had, respectively, a fracture of the left rib and a small fracture on the right tibia. In the group of men, four minor fractures such as broken fingers, toes or broken/bent ribs were observed. Two men had clavicle fracture, one left sided and

Table 2. Number of fractured skeletons in the Odense and the Ribe samples

Sex	Odense		Ribe	
	No. of skeletons	Fractures	No. of skeletons	Fractures
Females	43	5	46	2
Males	48	5	49	9
Total	**91**	**10**	**95**	**11**

one right sided, and one individual exhibited a fatigue fracture of the right ulna. One man, between 30 and 40, had more than one trauma, displaying fractures to a right rib and the left finger. Most fractures were observed on the right side of the skeletons as was the case for the Odense sample.

High- versus low-energy fractures

Low-energy fractures (fatigue fractures) are caused by continuous stress to the bone [Mays 1998], and are usually assumed to be work related. High-energy fractures are caused by a sudden impact to the bone (twisting, bending, breaking or crushing), and the fracture may be complete or partial [Mays 1998]. In the material from Odense and Ribe, a total of 30 fractures were found in 21 individuals. Only one of these, a fractured right ulna, was assumed to be a low-energy fracture (fatigue fracture). All of the fractures were completely healed well before the individual died. High-energy fractures are attributed to accidents or violence [Grauer & Stuart-Macadam 1998]. Traumas related to accidents result in a diffuse distribution of the fractures on the skeleton. Traumas to the cranium, in particular to the nasal area or to the left temple, are often seen as an indication of violence or physical abuse, as are fractures below midshaft of the ulna (“parry-fractures”) [Judd 2008]. Because most people are right-handed, violence related fractures are often seen situated on the left side of the skeleton [Mays 1998].

The material examined in this study did not reveal fractures to the skull. The Odense material yielded one fractured right ulna, one left ulna and a right radius. There were no fractured ulnae or radii related to violence in the Ribe material, aside from the observed aforementioned fatigue fracture.

Accumulation of fractures

Assuming that accumulation of fractures occurs over time, individuals with multiple fractures are often found in the older age groups [Mays 1998]. This assumption indicates implicitly that no age group is more prone to fractures than another [Mays 1998]. An elderly individual has simply had more time to incur fractures. However, studies by Judd [2002*a*] suggest that “injury recidivism” can also be observed. Judd found that certain socio-economic/age groups were more prone to fractures and displayed a higher frequency of multiple fractures than the rest of the population. Of the 21 individuals with fractures, four in the Odense material had more than one fracture and one in the Ribe material. All except one of the individuals with multiple fractures were males in their 30s.

Comparison of fractures from the two sites

The same general types of fractures were found in both locations. In the total material from Odense, consisting of 43 woman and 48 men, fractures were found in five women and five men, i.e., a total of ten individuals with fractures. The sex distribution in the Ribe material was 46 woman and 49 men, with a total of 11 individuals with fractures, being two women and nine men. On comparing the fractures from the two sites using the chi-square test, no significant difference was found. Approximately ten individuals with fractures in a sample of approx. 100 individuals seem to be the norm for a Danish medieval urban population. Consequently, the fracture frequency was found not to have been influenced by the degree of human sexual dimorphism. The two locations in this study, with respectively low and high sexual dimorphism, displayed a similar fracture frequency.

However, again using a chi-square test, comparison of the sex distribution of fractures in the Ribe sample yielded a significant difference. Men were significantly more prone to fractures than women in Ribe, whereas the fractures were more evenly distributed in Odense.

Discussion

Sexual dimorphism

It is obvious that biology, specifically the inheritance of biological traits, determines the size/stature/morphology of an individual: big, strong parents are more likely to conceive big, strong children than small, less robust parents. This fact does not, however, explain why some societies favour spouses of different size whilst others favour spouses of more equal size, and consequently why high or low human sexual dimorphism develops. In polygynous societies there will be a continuous shortage of women of childbearing age which will lead to an earlier menarche age [Kanazawa & Novak 2005]. As girls stop growing after the onset of the menarche, their physical size will decrease from generation to generation [Kanazawa & Novak 2005]. Though polygynous societies might favour large or more aggressive men in the "combat for women" leading to high sexual dimorphism [Kanazawa & Novak 2005] and encouragement of a society with gender inequality, this explanation seems to disregard any active role women might have played in matchmaking and restricts female life to one of producing children. Even in polygynous societies, other factors than height or physical strength, such as wealth and social relations, might matter [Hammond 1964, Eriksen 1998, McGee & Warms 2000]. Furthermore, high human sexual dimorphism is not solely linked to polygynous lifestyles, as indicated in the study of the Ribe skeletal sample. Eliminating the presence or absence of male physical aggression as the sole factor in the development of human sexual dimorphism opens the field for interpretations drawing on an array of other possible social factors.

Considering the above statements about high human sexual dimorphism, it might be suggested that low sexual dimorphism is seen in societies with a tendency to a more monogamous lifestyle. Directed by social norms a woman or a man may only choose one partner at a time (though women and men may have several partners in a lifetime as they lose their previous spouse as is seen in serial monogamy), thus significantly reducing the stress on women caused by early menarche age which would have resulted in a large difference in the mean size of the two sexes, and increased stress on a man to fight for women. Women in monogamous societies might be more equal in size to men, as women physically more equal to men will have a greater chance of finding a partner than they would have in a polygynous society, and this selection is repeated from generation to generation.

In the medieval societies of Odense and Ribe, indications of serial monogamy have been found [Nielsen 1985, Christensen 1988] where one individual could have more consecutive partners/spouses through life. In both locations, an almost identical percentage of women died in the childbearing age group and so it can be assumed that both had an identical shortage of /competition for women. Thus, the reason for the observed difference in sexual dimorphism in the two locations needs to be looked for elsewhere in the patterns of social interaction.

Sexual dimorphism, types of fractures and frequency

The statistical calculations have indicated no difference in the fracture frequencies in the Odense and Ribe material. An average of ten individuals with fractures in a sample of approximately 100 seems to be the norm for a Danish urban medieval population. The different human dimorphism on the two locations was not found to have caused a difference in the pattern of daily activity or violence on the two sites.

None of the examined skeletons show evidence of trauma to the head. Only three individuals had fractured ulna bones – one female from the Odense sample with a broken left ulna, and one male from the same sample with a broken right ulna (both mid-shaft). In the Ribe sample, one male had a broken ulna, but this fracture was more likely caused by work related stress (a fatigue fracture) than violence. Overall, the fractures observed in the material from Odense and Ribe were very mixed and with diffused distribution on the skeleton, indicating more labour-/accident related origins.

The fractures observed in the material gave no indication that men competed physically for the women. Furthermore, neither the Odense nor the Ribe material indicated that men tried to control women through physical violence. The different sexual dimorphism did not make the smaller women from Ribe more exposed to violence from their husbands than the larger women from Odense. This study therefore shows no correlation between the degree of human sexual dimorphism and the frequency of violence/assaults against persons of the same or the opposite sex or the frequency of the more accident or work related fractures.

Sexual dimorphism and sex distribution of fractures

The fractures in Odense where there was low sexual dimorphism show a fairly symmetrical pattern of distribution between the two sexes, whereas the men in Ribe where there was high sexual dimorphism had a significantly greater proportion of work-/accident related fractures. This could indicate that women in communities with low sexual dimorphism, being physically more equal to men, undertook more and/or harder physical labour than women in communities with a high sexual dimorphism. As women are assumed to have more fragile bones than men due to loss of bone density caused by nursing, childbirth and menopause, a totally equal distribution of physical labour would cause more fractures in women than in men. The material indicates that this had not been the case.

The more even distribution of fractures in Odense compared to Ribe found in this study is probably due to interaction between the sexes, or in other words the roles gender has ascribed to them [Grauer & Stuart-Macadam 1998]. Where sex is a biological reality, gender is a social construction [Grauer & Stuart-Macadam 1998], and in this study gender seems to influence the distribution of fractures in the sample [Judd 2004]. In addition, the results indicate a selection for gender equality in Odense where there was low human sexual dimorphism. Women physically more equal to men had a greater chance of finding a partner, and this selection was repeated from generation to generation, whereas the opposite seems to have been the case in Ribe. Thus, gender in a society seems to leave "physical marks" on the skeletons in the degree of human sexual dimorphism and the distribution of fractures.

Conclusions

This study seems to indicate that it cannot be ruled out that human sexual dimorphism has an influence, not on fracture frequency or fracture patterns, but on the distribution of fractures between the two sexes. In societies where women play a more equal role to men, there will be selection for low human sexual dimorphism, and the similarity of activity is reflected in the distribution of fractures between the two sexes. This suggests that gender in a given society leaves physical traces on the skeletal material as indicated in the degree of human sexual dimorphism and distribution of fractures. It is necessary, however, that further studies be carried out on larger samples. In order to explore the universality of the hypothesis, studies on samples from other time periods and in other parts of the world are preferred.

Notes

Acknowledgements The author wishes to thank an anonymous reviewer for her/his helpful suggestions and comments on an earlier version of the manuscript.
The article was presented at the 17th Congress of the European Anthropological Association in August 2010.

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Streszczenie

W pracy poddano testowaniu hipotezę, że niejednakowy status obu płci w danej grupie ludzkiej odzwierciedla się w częstościach, rodzaju uszkodzeń i ich rozmieszczeniu na kościach mężczyzn i kobiet. Chociaż nie można orzekać o relacjach płci w społeczeństwie na podstawie materiałów szkieletowych, wyniki niektórych badań sugerują, że poziom nierówności płciowych znajduje odzwierciedlenie w dymorfizmie płciowym. W pracy postanowiono zbadać korelację między stopniem wyrażenia dymorfizmu płciowego a częstością i rodzajem przyżyciowych uszkodzeń na szkieletach.

Zbadano szkielety około 200 osobników z dwóch średniowiecznych cmentarzysk duńskich (rys. 1 wyjaśnia sposób datowania materiałów z tych cmentarzysk) – 50 męskich i 50 żeńskich z Jutlandii i tyleż z Fionii. Oznaczenia płci wykonano na podstawie czaszek, miednic i kości szkieletu pozaczaszkowego. Za najpewniejsze uznano oznaczenia płci na miednicach. Wiek osobników określano na postawie wielu cech osteologicznych. Ponieważ dymorfizm płciowy stanowił główny problem pracy, osobniki z nieskostniałym chrząstkozrostem klinowo-potylicznym oraz takie u których linie nasadowe wskazywały na wiek poniżej 16 lat, zostały z opracowania wyłączone. Ostatecznie więc na materiał z Odense (Fionia) składało się 91 osobników (43 K i 48 M), a z Ribe (Jutlandia) 95 (46 K i 49 M); rozkłady wieku w tab. 1. Dymorfizm płciowy oceniano na podstawie pomiarów miednicy i – zgodnie z przewidywaniem – okazał się on większy w serii z Jutlandii niż z Fionii.

Wszystkie szkielety z obu stanowisk zbadano pod względem śladów urazów powstałych przed lub w związku ze śmiercią, a dane wprowadzono do arkusza Excela, by poddać je dalszej analizie statystycznej (szczególne przypadki pokazano na rys. 2-4). Częstości urazów ich rodzaj i rozmieszczenie porównano między płciami w obu seriach szkieletowych (tab. 2). Wyniki ocen statystycznych nie wykazują istotnych różnic między stanowiskami, natomiast rozmieszczenie urazów u obu płci w serii z Ribe okazało się istotnie różne.

Wyniki przedstawionego opracowania sugerują, że choć dymorfizm płciowy nie wpływa na częstość urazów oraz ich rodzaj, to różnicuje rozmieszczenie ich u mężczyzn i u kobiet. Problem ten wymaga dalszych badań.