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Skeletal bilateral asymmetry in a medieval population from Deir an-Naqlun (Nekloni), Egypt

Elżbieta Jaskulska
Department of Bioarchaeology,
Institute of Archaeology, University of Warsaw,
ul. Krakowskie Przedmieście 26/28, 00-927 Warszawa, Poland
email: ejaskulska@uw.edu.pl

Abstract: *Directional asymmetry in upper limb bones was studied in a sample of human remains excavated at a medieval cemetery located near the monastery Deir an-Naqlun, Egypt. Humeri, ulnae, radii and clavicles of 97 adult individuals (mostly males) were measured and Directional Asymmetry and Absolute Asymmetry values were counted for maximum lengths, diaphyseal circumferences, epiphyseal measurements and robusticity indices. Most measurements exhibited some degree of asymmetry with right-side domination and only maximum length of the clavicle was skewed towards the left side. No significant differences between the sexes were observed and only the length of the humerus and combined humerus+radius length did not differ from the human-specific handedness rate with ~80% of right-handed and ~15% of left-handed individuals. The results are in concordance with the general pattern observed in other skeletal samples, suggesting that the pattern of directional asymmetry may be related to factors other than handedness.*

Key words: upper limb, handedness, directional asymmetry, medieval Copts, bone metric measurements

Introduction

The phenomenon of human handedness (including left hand preference) is a topic that provokes interest from different fields of science from neurobiology to archaeology (Laurens et al. 2009). As many other authors have shown, human hand preference (handedness) is visible in both modern and historical populations at a constant proportion of about 80:5:15 (percent of people with preference of right:none:left hand) (Steele & Mays 1995:42; Steele 2000:212; Peters et al. 2006:179; McManus et al. 2010:205).

Research on past populations often is focused on examining paired elements of the human skeleton for bilateral asymmetry, which is thought to be a direct consequence of differential mechanical loading as a result of hand preference. The occurrence of bilateral asymmetry is thought to be sexually dimorphic trait. Peters et al. (2006:179-180) found significant sexual dimorphism in handedness in particular segments of a a worldwide sample (Pearson χ^2=350.43, $p<0.0001$), with left handedness more common in males. Similar observations were reported by other investigators (see Gilbert & Wysocki 1992; Vuoksimaa et al. 2009:1296). In addition, previous research has shown that females have longer right forelimb bones in comparison to males (Steele 2000:206), although the reason for this sexual dimorphism was not fully explained. It can be argued that the observed dimorphism is the result of division

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of labor between the sexes, where differences in mechanical stress load because of activity result in differences in observed bone proportions. At the same time, researchers have found differences in bone proportions in heavy manual works in comparison to office workers where there are slight to no differences in bone measurements (Josty et al. 1997:268).

The purpose of this paper is to search for bilateral asymmetry patterns in individuals from the medieval cemetery located near the Coptic monastery of Deir an-Naqlun.

Material

Deir an-Naqlun (Nekloni) is an archaeological site, known also as Deir el-Malak Ghubriel, Archangel Gabriel Monastery. It is situated in the West Desert about 16km south of town of Fayum and 120km from Cairo. It is one of the oldest still functioning monasteries in the Fayum oasis, dating back to at least the 6th–7th c. AD. Excavations at the site have been conducted since 1986 by the University of Warsaw, Poland and directed by Prof. Włodzimierz Godlewski. Between 1986 and 2000, 130 burials were explored (Bourguet 1991:278; Godlewski et al. 1990; Godlewski 1999:117) that yielded the remains of 189 individuals. The presence of human remains of both sexes as well as of children suggests that the cemetery was a burial place for individuals from nearby villages and not only for the monastery (Godlewski, personal communication).

The skeletons were analyzed by the present author (juvenile skeletons and adult postcranial bones) and by Prof. Karol Piasecki (adult skulls) in the excavation house during the autumn excavation season of 2001. Due to time constraints the skeletal remains were described and measured only superficially, and the data were not specifically collected for the present analysis. Because the remains were not stored adequately and are now commingled, most of the sample cannot be re-analyzed and re-measured.

Only measurements of adult individuals were analyzed in the present paper and individual measurements exceeding three standard deviations were excluded, assuming that they may have belonged to individuals with pathological change. The sample includes 97 adult individuals (28 females, 66 males and 3 individuals of undetermined sex). The overwhelming presence of male skeletons may have result from the burial of monks from the monastery. It should be mentioned, however, that the character of the rule of St. Pachomius, which governs Coptic monasticism since before 346 AD, states that monks should work for their living (Atteya n.d.:15; Keller 2005:16). It can be assumed then that they should not much differ from the rest of the sample and may be considered as a part of local population in respect of mechanical stress load.

Methods

Complete long bones of all individuals were measured using an osteological board, a sliding caliper, and a metal measuring tape; the set of measurements included maximum lengths, several epiphyseal breadths and shaft circumferences (after Buikstra & Ubelaker 1994). Pelvic morphology (pubic symphysis and greater sciatic notch) was used for sex assessment (Acsadi & Nemeskeri 1970). Upper limb length was approximated, as the sum of the humerus and radius (Steele & Mays 1995). Raw data were used to calculate Directional Asymmetry (DA) according to the equation [1] proposed by Mays as SDA (2002), which is the same as the %DA in Auerbach & Ruff (2006). Total (absolute) asymmetry value (Mays STA, Auerbach & Ruff's %AA), which is simply the absolute value of DA, was also calculated. Absolute Asymmetry (AA) deviates from the normal distribution, which is typical for all unsigned asymmetry measures. It requires data transformations or the use of non-parametric statistics. As Mays (2002:440) points out, AA scores could potentially obscure functional asymmetry by inter-individual variations in fluctuating asymmetry.

$$DA = \frac{(R - L)}{(R + L)/2} \times 100 \qquad [1]$$

The bone robusticity index was calculated for each bone according to the equation [2]. This index combines diaphyseal circumference and the maximum length of the bone, providing an overall idea of the robusticity of each whole bone, and possible changes in the diaphysis due to physical load caused by strenuous activity (Malinowski & Bożiłow 1997:195-197). It is thus possible that differences in usage of the upper limbs could be recognized in using this robusticity index.

$$bone\_robusticity = \frac{bone\_diaphyseal\_circumference}{bone\_maximal\_length} \times 100 \qquad [2]$$

As most DA and AA values deviated from the normal distribution, non-parametric tests were used. The χ^2 test was used to determine whether the observed distributions of arm bone measurements differed from the expected distribution of human handedness ratio. The author used the Wilcoxon signed rank test to test for left/right side differences and the two-sample Kolmogorov-Smirnoff test to determine whether there were female/male differences in DA and AA values.

Results

The basic statistics for each of the measurements are presented in **Table 1**. **Table 2** shows basic statistics for DA and AA values, and **Figures 1** and **2** present box-and-whiskers plot for distribution of DA and AA for each of the sexes. The DA distribution in males shows clearer asymmetry in humeral dimensions than in the forearm. Both sexes show expected left side bias of clavicular maximum length. Asymmetry in females is less clear, which can be related to small sample size. Some variables show left side smaller than right side, which could correspond to observed behavioural and osteometric data, but there are some that are more right side biased than in males (e.g., humeral maximum length; humeral head circumference, or radial maximum length). The differences of directional asymmetry between sexes were not statistically significant and because of this the measurements of both sexes were pooled together in further analyses.

Asymmetry in the measured variables was checked for statistical significance. As **Table 3** shows, most of the variables show significant difference between left and right side, though it is interesting to observe that the diaphyseal circumferences of both forearm bones are not significantly asymmetrical. This observation is also true for the robusticity indices (see **Table 4**) calculated from these variables. In the researched population, only measurements of humeral maximum length (χ^2=1.16, df=2, p<0.56) and arm length (χ^2=1.55, p<0.22) do not differ significantly in proportions from expected handedness 80:5:15 ratios.

Table 1. Basic statistics for the left and right side skeletal measurements along with Shapiro-Wilk Normality Test results. Measurements with poor fit are bolded.

Measurement	Side	n	Min	Max	Mean	SD	Shapiro -Wilk	p
Arm length (HML+RML)	left	76	419.0	647.0	548.18	47.807	0.987	0.64
	right	82	422.0	645.0	551.68	44.771	0.981	0.26
Humeral maximal length (HML)	left	86	236.0	369.0	308.26	25.967	0.994	0.97
	right	89	240.0	374.0	311.62	25.146	0.991	0.81
Humeral diaphyseal circumference (HDC)	left	84	217.0	309.0	261.02	21.240	0.983	0.29
	right	83	205.0	306.0	260.41	22.752	0.979	0.16
Humeral epicondylar breadth (HEB)	left	83	183.0	288.0	240.59	22.658	0.972	0.06
	right	90	182.0	287.0	240.66	21.699	0.986	0.49
Humeral head circumference (HHC)	left	82	25.0	40.0	31.94	3.152	0.977	0.14
	right	88	24.0	39.0	32.18	2.958	0.978	0.16
Ulnar maximal length (UML)	left	87	46.0	77.0	61.06	6.238	0.984	0.39
	right	89	48.0	79.0	62.87	6.639	0.977	0.15
Ulnar diaphyseal circumference (UDC)	left	87	25.0	47.0	34.39	4.476	0.982	0.29
	right	86	24.0	43.0	34.45	3.934	0.984	0.37
Ulnar proximal epiphyseal breadth (UPEB)	left	82	108.0	170.0	143.32	13.416	0.980	0.20
	right	87	104.0	169.0	141.66	13.559	0.984	0.38
Radial maximal length (RML)	left	86	49.0	72.0	59.26	5.439	0.984	0.37
	right	89	48.0	72.0	60.30	5.599	0.985	0.41
Radial diaphyseal circumference (RDC)	left	85	17.0	31.0	23.65	2.898	**0.959**	**0.01**
	right	84	17.0	32.0	24.12	2.996	0.974	0.07
Radial distal epiphyseal breadth (RDEB)	left	83	33.0	49.0	41.96	4.304	0.980	0.23
	right	92	32.0	56.0	42.11	4.715	0.982	0.25
Clavicular maximal length (CML)	left	85	109.0	161.0	133.99	10.670	**0.966**	**0.03**
	right	85	110.0	163.0	136.28	11.276	0.985	0.41

Table 2. Basic statistics of Directional Asymmetry (DA) and Absolute Asymmetry (AA) variables.

Variable	Directional Asymmetry					Absolute Asymmetry				
	n	Min	Max	Mean	SD	n	Min	Max	Mean	SD
Arm length	48	-1.3	2.8	0.77	0.980	66	0.0	7.6	1.22	1.154
HML	81	-3.5	14.8	1.25	2.111	94	0.0	14.8	1.47	1.735
HDC	83	-13.8	24.2	2.32	4.376	95	0.0	24.2	3.17	3.369
HEB	82	-11.8	14.0	1.14	3.849	95	0.0	14.0	2.44	2.807
HHC	79	-8.1	6.3	1.11	2.397	94	0.0	8.1	1.72	1.695
UML	75	-10.4	5.0	0.51	2.101	93	0.0	10.4	1.34	1.400
UDC	81	-16.7	10.9	0.39	5.432	93	0.0	16.7	3.61	3.553
UPEB	79	-22.2	18.2	1.88	8.660	94	0.0	22.2	5.75	5.698
RML	78	-4.3	5.8	0.49	1.786	94	0.0	5.8	1.20	1.176
RDC	82	-7.4	16.7	0.17	3.730	93	0.0	16.7	2.33	2.606
RDEB	78	-11.8	12.5	1.41	5.228	93	0.0	12.5	3.42	3.568
CML	79	-10.9	17.7	-0.95	3.621	94	0.0	17.7	2.19	2.632

Table 3. Number of individuals with greater dimension on left or right side in a given measurement. The two last columns show Wilcoxon Signed-Rank Test for differences between left and right side arm bone variables. Statistically significant differences are bolded.

Measurement	L>R	L=R	L<R	L>R	L=R	L<R	Z	p
HML	15	6	63	17.86%	7.14%	75.00%	**5.558**	**0.00**
HDC	15	13	59	17.24%	14.94%	67.82%	**5.169**	**0.00**
HEB	20	24	42	23.26%	27.91%	48.84%	**2.804**	**0.01**
HHC	15	17	53	17.65%	20.00%	62.35%	**4.068**	**0.00**
UML	21	8	51	26.25%	10.00%	63.75%	**2.761**	**0.01**
UDC	28	22	36	32.56%	25.58%	41.86%	1.031	0.30
UPEB	21	24	41	24.42%	27.91%	47.67%	**2.164**	**0.03**
RML	29	7	44	36.25%	8.75%	55.00%	**2.356**	**0.02**
RDC	29	29	28	33.72%	33.72%	32.56%	0.135	0.89
RDEB	21	25	37	25.30%	30.12%	44.58%	**2.242**	**0.02**
CML	48	13	25	55.81%	15.12%	29.07%	**-3.177**	**0.00**
Arm length	15	0	51	22.73%	0%	77.27%	**5.273**	**0.00**
Humerus robusticity	26	0	55	32.10%	0%	67.90%	**3.250**	**0.00**
Ulna robusticity	39	0	36	52.00%	0%	48.00%	-0.374	0.71
Radius robusticity	44	0	34	56.41%	0%	43.59%	-1.191	0.23

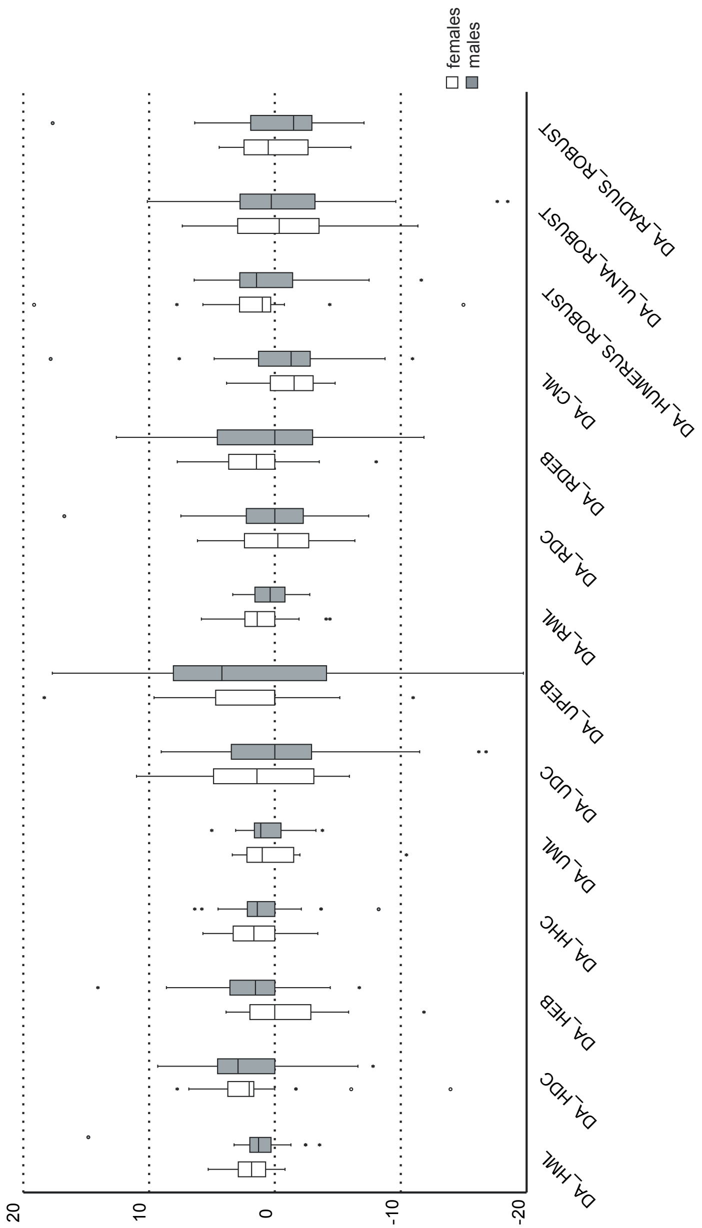

Figure 1. Differences between Directional Asymmetry values of bone measurements and bone robusticity indices for the two sexes. Box and whiskers plot for median, quartiles and non-outlier range. Outliers marked with asterisks (above 1.5 interquartile range) or circles (above 3 interquartile range). See **Table 1** for abbreviations.

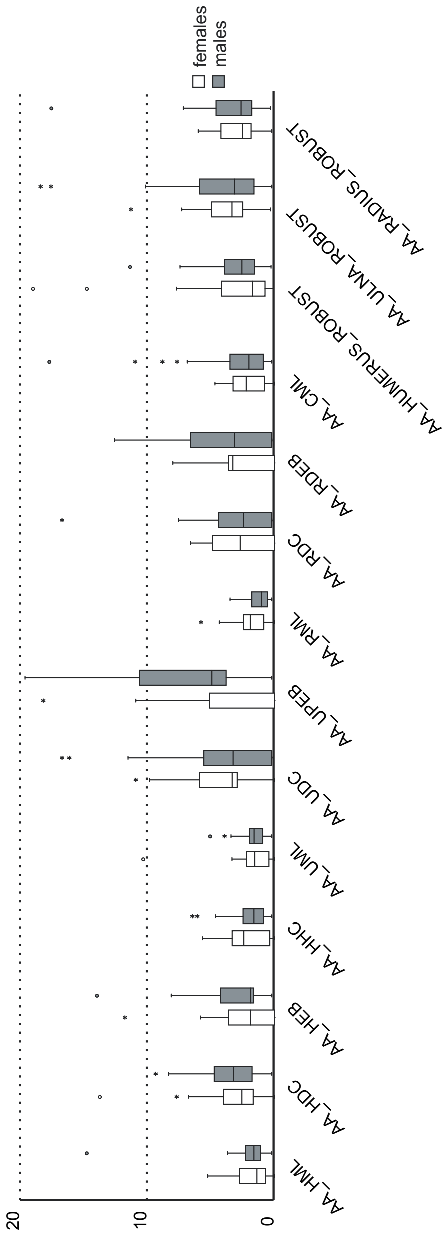

Figure 2. Differences between Absolute Asymmetry values of bone measurements and bone robusticity indices for the two sexes. Box and whiskers plot for median, quartiles and non-outlier range. Outliers marked with asterisks (above 1.5 interquartile range) or circles (above 3 interquartile range). See **Table 1** for abbreviations.

Table 4. Basic statistics of bone robusticity indices, Directional Asymmetry (DA) and Absolute Asymmetry (AA) of bone robusticity with Shapiro-Wilk test results.

Bone Robusticity	n	Min	Max	Mean	SD	Shapiro-Wilk	p
Left Humerus Robusticity	86	0.0	23.4	19.09	3.969	0.551	0.00
Right Humerus Robusticity	89	0.0	23.7	19.39	3.959	0.544	0.00
Left Ulna Robusticity	84	10.7	17.3	13.19	1.408	0.958	0.01
Right Ulna Robusticity	83	0.0	17.7	12.90	2.401	0.640	0.00
Left Radius Robusticity	83	0.0	21.0	16.75	3.518	0.535	0.00
Right Radius Robusticity	90	0.0	22.7	17.23	2.372	0.668	0.00
DA of Humerus Robusticity	78	-14.8	19.0	1.14	4.270	0.891	0.00
DA of Ulna Robusticity	74	-18.4	21.2	-0.15	5.867	0.951	0.01
DA of Radius Robusticity	76	-7.0	17.6	-0.39	3.958	0.923	0.00
DA of Arm Length Robusticity	66	-1.3	7.6	0.98	1.369	0.883	0.00
AA of Ulna Robusticity	78	0.1	19.0	3.07	3.161	0.736	0.00
AA of Radius Robusticity	74	0.0	21.2	4.27	3.993	0.787	0.00
AA of Arm Length Robusticity	75	0.1	17.6	3.11	2.474	0.787	0.00

Discussion and conclusion

Bilateral asymmetry in paired elements of the human skeleton is a controversial topic in physical anthropology. Some authors attribute it to human hand preference and functional difference between limbs, especially upper limb (Schulter-Ellis 1980; Blackburn & Knüsel 2006). These studies are based on Wolff's Law—that bone adapts to differential mechanical loading. Wolff's Law continues to be controversial and various researchers point to problems with previous studies making use of the rule (for discussion and suggestions see Ruff et al. 2006). Also, studies looking at limb asymmetry often express doubts concerning its causes (Glassman & Bass 1986; Roy et al. 1994), about whether the mind function can be traced in skeletal remains (for further discussion see Steele 2000:194-211) and about the mechanism of inheritance of handedness in humans (McManus 1991; Llaurens et al. 2009).

The problem itself is further complicated by overlapping effects of different types of asymmetry, which, although very hard, or even impossible to separate, all influence asymmetry as measured on the limb bones (Steele 2000:213). Developmental asymmetry is less clear, as different researchers provide contradictory theories and observations (Steele 2000: 213-214). Also, pathological conditions can make the picture of bilateral asymmetry less clear, though in many cases pathological asymmetry is comparatively easy to exclude (Steele 2000:214). Nonetheless, some studies suggest that limb morphological asymmetry that parallels asymmetry in behavioural handedness as seen in modern populations develops from infancy and could be attributed to bone functional adaptation to differentiated mechanical loading (Steele & Mays 1995:47). Although all these aspects make the whole problem difficult, bilateral asymmetry is an interesting way of looking at the activity patterns in past populations (Auerbach & Raxter 2008:668-670).

The present analysis demonstrates expected 80:5:15 proportions in the humeral maximum length and arm length. This agrees with the observation presented by Steele and Mays (1995) who also found that the length of the humerus and humerus+radius lengths closely parallels the pattern of behavioural handedness found in modern populations. However, a different pattern for other variables studied in the present paper suggests that the directional asymmetry in the upper limb bones is a more complicated phenomenon that should be explained not only by handedness.

The presented upper limb asymmetry results from the Naqlun population have confirmed previous reports concerning both living and past populations. Right hand domination in measurements (Schulter–Ellis 1980, Steele & Mays 1995, Steele 2000, Blackburn & Knüsel 2006), as well as left side bias of the clavicle (Auerbach & Raxter 2006; Scheuer & Black 2000:248) were observed in Naqlun. For many of the variables left side domination was recorded more often than expected and can be attributed to the aforementioned lesser difference between two hands in heavy manual workers (cf. Josty et al. 1997:268).

The results do not reveal a significant difference in asymmetry patterns between sexes, but the size of the female sample may be a factor and it is not possible to verify if the observed lack of dimorphic differences is due to similarity of labour. In addition, it was not possible to determine whether the female presented longer long bones in the right forelimb (as in Steele 2000:206). It may be only cautiously suggested that the activities carried out by the inhabitants of medieval Naqlun were mainly heavy manual work, and also that there is no evidence in upper limb asymmetry of any sex doing work which preferred use of a dominant hand.

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Bibliography

Acsádi G.Y., Nemeskéri J. (1970), *History of human life span and mortality*, Akadémiai Kiadó: Budapest.

Atteya A.S. (n.d.) *The Coptic contribution to Christian civilization*, Orthodox Ebooks; retrieved from http://books.google.com/books?id=9a2R6TE--qYC on 15 May 2011.

Auerbach B.M., Raxter M.H. (2008), *Patterns of clavicular bilateral asymmetry in relation to the humerus: variation among humans*, Journal of Human Evolution 54:663-674.

Auerbach B.M., Ruff C.B. (2006), *Limb bone bilateral asymmetry: variability and commonality among modern humans*, Journal of Human Evolution 50:203-218.

Blackburn A., Knüsel C.J. (2006), *Hand dominance and bilateral asymmetry of the epicondylar breadth of the humerus. A test in a living sample*, Current Anthropology 47:377–382.

Bourguet P. du (1991), *Sztuka Koptów*, Wydawnictwa Artystyczne i Filmowe: Warszawa.

Buikstra J.E., Ubelaker D.H., ed. (1994), *Standards of data collection from human skeletal remains*, "Arkansas Archaeological Survey Research Series" 44, Fayetteville.

Gilbert A.N., Wysocki C.J. (1992), *Hand preference and age in the United States*, Neuropsychologia 30(7):601-608.

Glassman D.M., Bass W.M. (1986), *Bilateral asymmetry of long arm bones and jugular foramen: implications for handedness*, Journal of Forensic Sciences 31:589-595.

Godlewski W. (1999), *Naqlun. Excavations 1998*, Polish Archaeology in the Mediterranean 10:113-117.

Godlewski W., Herbich T., Wipszycka-Bravo E. (1989), *Deir el-Naqlun (Nekloni), 1986-1987, First preliminary report*, Nubica 1/2:171-207.

Josty I.C., Tyler M.P., Shewell P.C., Roberts A.H. (1997), *Grip and pinch strength variations in different types of workers*, Journal of Hand Surgery [British edition] 22(2):266-269.

Keller D.G.R. (2005) *Oasis of wisdom. The worlds of the Desert Fathers and Mothers*, Liturgical Press: Collegeville.

Llaurens V., Raymond M., Faurie C. (2009), *Why are some people left-handed? An evolutionary perspective*, Philosophical Transactions of the Royal Society B 364:881-894.

Malinowski A., Bożiłow W. (1997), *Podstawy antropometrii. Metody, techniki, normy*, Wydawnictwo Naukowe PWN: Warszawa-Łódź.

Mays S.A. (2002), *Asymmetry in metacarpal cortical bone in a collection of British post-mediaeval human skeletons*, Journal of Archaeological Science 29:435-441.

McManus I.C. (1991), *The inheritance of left-handedness*, Ciba Foundation Symposium 162:251-267.

McManus I.C., Moore J., Freegard M., Rawles R. (2010), *Science in the making: Right hand, left hand III: Estimating historical rates of left-handedness*, Laterality 15(1/2):186-208.

Peters M., Reimers S., Manning J.T. (2006), *Hand preference for writing and associations with selected demographic and behavioral variables in 255,100 subjects: the BBC Internet study*, Brain and Cognition 62:177-189.

Roy T.A., Ruff C.B., Plato C.C. (1994), *Hand dominance and bilateral asymmetry in the structure of the second metacarpal*, American Journal of Physical Anthropology 94:203-211.

Ruff C., Holt B., Trinkaus E. (2006), *Who's afraid of the big bad Wolff?: "Wolff's Law" and bone functional adaptation*, American Journal of Physical Anthropology 129:484-498.

Scheuer L., Black S. (2000), *Developmental juvenile osteology*, Elsevier Academic Press: Amsterdam.

Schulter-Ellis F.P. (1980), *Evidence of handedness on documented skeletons*, Journal of Forensic Sciences 25:624-630.

Steele J., Mays S.A. (1995), *Handedness and directional asymmetry in the long bones of the human upper limb*, International Journal of Osteoarchaeology 5:39-49.

Steele J. (2000), *Handedness in past human populations: skeletal markers*, Laterality 5(3):193-220.

Vuoksimaaa E., Koskenvuoa M., Rosea R.J., Kaprio J. (2009), *Origins of handedness: A nationwide study of 30 161 adults*, Neuropsychologia 1294-1301.