Legal Medicine 51 (2021) 101873

Contents lists available at ScienceDirect

Legal Medicine

journal homepage: www.elsevier.com/locate/legalmed

Announcement of Population Data

Sex estimation from knee breadth dimensions in a Finnish population

Heli Maijanen[a,*], Juho-Antti Junno[a,b,c], Asla Keisu[b,c], Jaakko Niinimäki[d], Petri Lehenkari[b,c], Petteri Oura[e,f,g]

[a] Faculty of Humanities, Department of Archaeology, University of Oulu, Oulu, Finland
[b] Medical Research Center Oulu, Oulu University Hospital and University of Oulu, Oulu, Finland
[c] Faculty of Medicine, Cancer and Translational Medicine Research Unit, University of Oulu, Oulu, Finland
[d] Faculty of Medicine, Research Unit of Medical Imaging, Physics and Technology, University of Oulu, Oulu, Finland
[e] Center for Life Course Health Research, Faculty of Medicine, University of Oulu, Oulu, Finland
[f] Department of Forensic Medicine, University of Helsinki, Helsinki, Finland
[g] Forensic Medicine Unit, Finnish Institute for Health and Welfare, Helsinki, Finland

ARTICLE INFO

Keywords:
Sex estimation
Distal femur
Proximal tibia
Finland
Radiographs

ABSTRACT

Sex estimation is an important part of osteological analysis of skeletons and forensic identification process. Traditionally cranial and pelvic traits are utilized for accurate sex estimation. However, post-cranial measurements have also been proven to accurately estimate sex especially from robust bones such as the femur. In this study, we investigated the potential of knee breadth dimensions in sex estimation in a Finnish population. To conduct this study we utilized a study sample (n = 1654) belonging to the Northern Finland Birth Cohort 1966. All individuals were 46 years of age at the time of the examination. Three knee breadth dimensions were measured from subjects' knee posteroanterior radiographs: femoral biepicondylar breadth (FBEB), mediolateral breadth of the femoral condyles (FCML), and mediolateral breadth of the tibial plateau (TPML). Sex estimation was performed using logistic regression. The study clearly demonstrated that all three measurements were different between males and females. Sectioning points for individual knee breadth measurements were 82.9 mm for FBEB, 76.6 mm for FCML and 75.4 mm for TPML. The classification rates ranged from 90.9% to 93.6%. The less commonly used measurements of FCML and TPML showed higher accuracy than FBEB in sex estimation. Our study confirmed that knee breadths can be successfully utilized to improve sex estimation in cases where the skeleton is only partially preserved and other major components of sex estimation are absent. We can also provide new standards for sex estimation from the knee joint in a Finnish population.

1. Introduction

Sex estimation is one of the major components of the biological profile when analysing unknown skeletal remains in both forensic and osteoarchaeological contexts. Although molecular techniques can be used for sex estimation, basic skeletal analysis still benefits from anthropological investigation and it is cost-effective. The most accurate osteological sex estimates have been generally obtained from the pelvis using both morphological and metric methods [1–3]. Cranial morphology and measurements have also been used for sex estimation, but their accuracy, especially in the case of morphology, often varies depending on the population and the researcher [4,5].

Several post-cranial measurements have been found to give more accurate sex estimates than cranial measurements. Spradley and Jantz [6] tested 44 post-cranial measurements and 24 cranial measurements in a sample of modern White Americans, and they found that the top four measurements were tibial proximal epiphyseal breadth, scapula height, femoral epicondylar breadth, and femoral maximum head diameter (with classification rates varying from 88 to 90%). Two of these measurements are from the knee area demonstrating its suitability for sex estimation.

In addition to Spradley & Jantz's study [6] multiple measurements from the knee have been used for sex estimation [7–14]. Probably the most common distal femur measurement used is the epicondylar breadth of the femur which has yielded classification rates between 86.0 and 95.4% [7,8,15,16]. The maximum epiphyseal breadth of the tibia has been reported to give accuracies between 80.9 and 93.8% [7,9–11,17,18]. Holland [19] used a slightly different measurement,

* Corresponding author.
E-mail address: heli.maijanen@oulu.fi (H. Maijanen).

https://doi.org/10.1016/j.legalmed.2021.101873
Received 5 March 2021; Received in revised form 17 March 2021; Accepted 23 March 2021
Available online 29 March 2021

biarticular breadth of the proximal tibia, and showed an accuracy of 95% in estimating sex of Americans.

Applying regression equations or sectioning points from one population to another population without testing their suitability has clear limitations. Measurements tend to be population-specific, and thus they should be used in a population that is similar to the reference sample [20,21]. Sex estimation methods specific to Finnish individuals are rare and even testing of known standards is lacking. Methods based on cranial measurements [22] and measurements of fourth lumbar vertebrae [23] have been created using data from Finns. Clearly, these methods need to be complemented with other measurements, since crania may not be complete enough for many measurements and fourth lumbar vertebrae may not preserve well and may be difficult to identify from incomplete remains. Thus, standards for Finnish population from various skeletal elements are needed. However, Finland does not have an extensive modern documented skeletal collection, and thus radiographs of living individuals are used in this study. Digital imaging is commonly used in situations when no appropriate skeletal collections exist [17,21,23].

In this study, three knee breadth measurements from plain radiographs of living Finns were measured to test their applicability for sex estimation. Population-specific standards for Finns were created using binary logistic regression and sectioning points.

2. Materials and methods

The study sample consists of plain radiographs of the knee from 1654 individuals (males n = 759, females n = 895) belonging to The Northern Finland Birth Cohort 1966 (NFBC1966). The cohort data is collected from two northern provinces, Oulu and Lapland, from individuals with an expected date of birth in 1966. This birth cohort is comprised of 12,055 mothers and 12,231 children. Follow-up of the cohort members includes medical examinations such as radiological imaging. All the radiographs in this study were from the right knee joint and they were taken at the age of 46 [24].

In total, 1946 individuals of NFBC1966 were radiographed and 1876 radiographs were technically adequate for this study. However, we had to exclude 192 individuals due to visible pathological changes in their bone. Osteoarthritic changes, including osteophytes, were the most common changes causing exclusion from the study. In addition, a further 30 individuals that had experienced knee surgery were excluded. The final number of individuals in our study was thus 1654.

2.1. Knee measurements

Three knee breadth dimensions were systematically measured from digital radiographs (Fig. 1) following the definitions provided by Squyres and Ruff [25]. Two of the measurements were from the distal femur: (1) Femoral biepicondylar breadth (FBEB) and (2) mediolateral breadth of the articular surface of the femoral condyles (FCML). The measurement from the proximal tibia was (3) mediolateral breadth of the tibial plateau articular surface (TPML).

FBEB is a common measurement in osteological analysis on dry bone and is the maximum breadth between the lateral and medial epicondyles of femur (See [26] for the epicondylar breadth of the femur). The other two dimensions (TPML and FCML) are measurements of the articular surfaces and less commonly measured in basic skeletal analysis. They are used more often in body mass estimation and locomotion studies [25,27].

Knee dimensions were measured from posterioanterior digital radiographs using neaView Radiology software version 2.31 (Neagen OY, Oulu, Finland). During the X-ray, patients were positioned for fixed flexion view (FFV) in which their thigh was in contact with the detector plate and their toes in the same line with the detector and feet were in a 10° external rotation. The beam was directed from behind the subject in a 10° caudal angle [24,28,29].

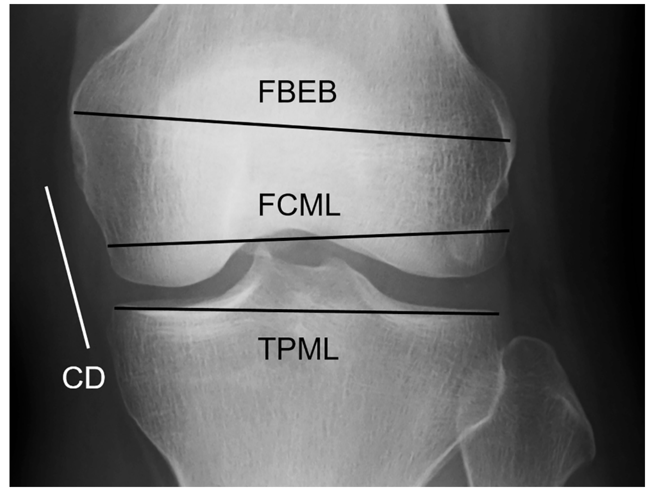

Fig. 1. Knee breadth measurements used in the study: FBEB: femoral biepicondylar breadth, FCML: mediolateral breadth of femoral condyles, TPML: mediolateral breadth of tibial plateau, CD: True size of the calibration disc (30 mm).

We used a metal 30 mm disc as a calibration gauge in each radiograph as the disc was attached on the patient's right leg. The magnification caused by the X-ray beam's course was calculated by measuring the calibration disc from the images, and the measurements were converted then to their true sizes. Measurements were taken to the nearest 0.1 mm by AK. Approximately every 100th image (n = 20 knees) was remeasured for intraobserver error to assess the repeatability of the measurements [24].

2.2. Statistical analysis

Data analysis was performed using SPSS software version 27 (IBM, Armonk, NY, USA). Descriptive statistics of the knee dimensions were calculated as means and standard deviations (SD), and sex differences were analysed using independent-samples *t*-test. The sex estimation procedure was performed using binary logistic regression as it allows more variation in the structure of the data than discriminant function analysis without compromising the accuracy of the models [30]. The outcome (i.e., sex) was coded so that 0 = female and 1 = male, and the predictors (i.e., knee breadth dimensions) were expressed in millimetres. Once a model had been fit, each individual was assigned to a predicted sex (male/female) according to the highest posterior group membership probability. Regression parameters (i.e., α = constant term of the model; β = coefficient of the predictor variable) and prediction accuracies (i.e., percentage of correct predictions) were documented from the data output.

3. Results

The technical error of measurement (TEM) and relative technical error of measurement (rTEM) were reported in Keisu et al. [24] and the repeatability was good for all the measurements (TEM 0.1–0.5 mm, rTEM 0.1–0.6%).

The descriptive statistics of the measurements are presented in Table 1. Fig. 2 demonstrates the clear sex difference in the measurements. All three knee breadth measurement means were larger in males, and sex differences were statistically significant ($p < 0.001$). The regression parameters with their accuracies in the sample are shown in Table 2. The accuracy of all dimensions separately was good, ranging from 90.9 to 93.6%. The percentages of correctly classified females were slightly higher than the correctly classified males. No multivariate models were calculated due to the strong intercorrelations between

Table 1
Knee dimensions among the study population.

Knee dimension	Reference value (mean ± standard deviation; minimum–maximum)		
	Male (n = 759)	Female (n = 895)	P for sex difference
FBEB (mm)	88.0 ± 3.9; 72.8–99.7	77.7 ± 3.6; 67.7–88.3	<0.001
FCML (mm)	82.3 ± 3.6; 71.3–97.0	71.6 ± 3.3; 62.5–83.9	<0.001
TPML (mm)	79.9 ± 3.4; 69.8–94.4	70.3 ± 3.1; 60.6–81.7	<0.001

measurements. In addition, following sectioning points were calculated for each measurement: FBEB 82.9 mm, FCML 76.6 mm and TPML 75.4 mm.

4. Discussion

This study assessed sex estimation potential of knee breadth dimensions measured from radiographs in a specific age group of modern Northern Finns. The results show a high classification accuracy for all three breadth measurements from the knee joint. The classification rates were between 90.9 and 93.6%. These accuracies are similar to accuracies from the distal femur and proximal tibia reported elsewhere [8,16,19]. These classification rates are higher than the accuracies achieved using Finnish crania and vertebrae [22,23].

In comparison to a radiograph sample from the US with same measurements [25], the Finnish knee breadth measurement means are similar to those of the American individuals. Finnish males seem to have slightly smaller means, except for the FCML, which is 0.3 mm greater in Finnish sample. Finnish females have greater average values when compared to the American females, except the TPML average is the same for both samples. However, Squyres & Ruff [25] used their measurements to estimate body mass instead of sex.

Direct comparisons between the measurements used in this study and other studies estimating sex from knee measurements is not advisable. This is due to two main factors. Firstly, breadths of the articular surfaces (FCML and TPML) are rarely measured in forensic anthropology. It is more common to measure the epiphyseal breadths (i.e. the proximal epiphyseal breadth of the tibia and epicondylar breadth in the femur (FBEB) [26]. Secondly, the datasets generally utilized in research vary from dry bones to CT-scans of living individuals. Radiographs from living individuals are not considered as applicable nowadays because of the 2D image and distortion issues [31].

Our study has several strengths. It introduces population-specific data for Finns from two knee measurements (FCML and TPML) which are not commonly used in sex estimation. The study demonstrates that their classification rates are even higher than those of traditional FBEB measurements. In forensic settings, the standards should be derived from a contemporary population rather than a past population. Using a contemporary reference data set of recent Finns will reduce the potential effects of secular change in the size of the bones [6]. Finland does not have skeletal collections with recent individuals, and thus using radiographs of living individuals is the best way to study contemporary osteological measurements. This type of cohort data will allow a large sample and sample that is representative of the Northern Finnish population. In this case, all the studied radiographs were taken at the age of 46, which minimized the effects of age related pathological changes to the knee dimensions.

Our study also has its limitations. First, as the study focused on living individuals, the measurements are from radiographs rather than dry bone. Thus, the applicability of the standards to skeletal remains from forensic or archaeological settings need to be tested. Using radiographs in these kinds of studies has some known issues including distortion and magnification. Comparisons between dry bone and Lodox Statscan-generated image measurements of the same dry bone have shown to have<2 mm difference [32]. In forensic anthropology, measurement errors of 1–2 mm, depending on the magnitude of the measurement in question, is considered acceptable in dry bone measurements [32]. In our study, the effects of distortion and magnification was taken into account with a calibration gauge.

When soft tissue is involved (either post-mortem or living individuals) the differences may be bigger. This type of error has been studied to some extent. For example, Carew et al. [33] used pig legs to study the difference between measurements from the digital imaging and from the dry bone after maceration. They noted that measurements from CT-scans were more close to the dry bone measurements than measurements from the digital radiographs. When the magnification effect with x-rays was taken into account, the results were slightly better. In this study, we cannot evaluate the effect of the shrinkage due to drying of bone [see [34–37]]. However, Ingalls [36] documented that the epicondylar breadth of the femur shrank up to 1.4 mm after maceration and drying. Thus, the difference between dry and fresh bone may be within the acceptable measurement error.

Another issue encompasses the limited age group (46-year-olds) utilized in the study. Even though the effects of age and loading in articular surfaces of long bones are commonly considered to be minimal [25,38], some studies have documented age group differences in some of the knee measurements or knee shape [39,40]. In the current study, possible age group differences cannot be evaluated. However, our mean values are quite similar to those of an American sample consisting of

Table 2
Sex estimation accuracies of knee dimensions among the study population.

Knee dimension	Sex estimation accuracy (%)			Regression parameters	
	Male	Female	All	α	β
FBEB	89.7	91.8	90.9	−58.86	0.71
FCML	92.4	94.6	93.6	−62.79	0.82
TPML	92.2	93.6	93.0	−64.06	0.85

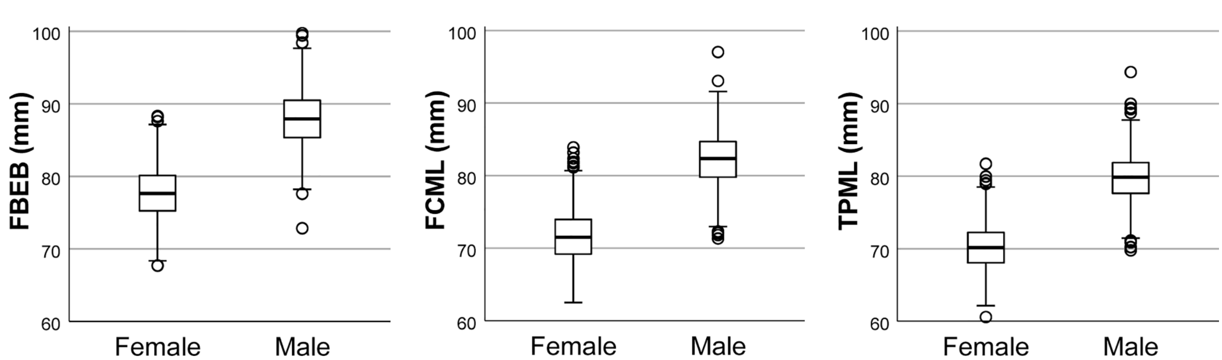

Fig. 2. Box plots demonstrating sex difference in knee dimensions.

individuals between 25 and 70 years of age [25]. Thus, we consider our standards can be applied to age groups beyond 46 years of age.

Nevertheless, this study has created new sex estimation standards for Finnish individuals from knee breadth measurements. Due to the nature of the study data, radiographs of living individuals, the standards are most suitable for partly decomposed or quite recent deaths when the bones have not dried. Future research will test these equations and sectioning points with skeletal materials. In addition, new measurements from long bones will be added to complement the measurement atlas of the recent Finnish population in the future.

Acknowledgments

We thank all cohort members and researchers who participated in the 46 yrs study. We also wish to acknowledge the work of the NFBC project center.

Funding

NFBC1966 received financial support from University of Oulu Grant no. 24000692, Oulu University Hospital Grant no. 24301140, ERDF European Regional Development Fund Grant no. 539/2010 A31592.

Data availability statement

NFBC data is available from the University of Oulu, Infrastructure for Population Studies. Permission to use the data can be applied for research purposes via electronic material request portal. In the use of data, we follow the EU general data protection regulation (679/2016) and Finnish Data Protection Act. The use of personal data is based on cohort participant's written informed consent at his/her latest follow-up study, which may cause limitations to its use. Please, contact NFBC project center (NFBCprojectcenter@oulu.fi) and visit the cohort website (www.oulu.fi/nfbc) for more information.

Ethical approval

Ethical approval was obtained from the Ethical Committee of Northern Ostrobothnia Hospital District. All procedures were in accordance with the national ethical standards and the Declariation of Helsinki including later amendments. Informed consent was obtained from all individual participants included in the study.

References

[1] T. Phenice, A newly developed visual method of sexing in the os pubis, Am. J. Phys. Anthropol. 30 (1969) 297–301, https://doi.org/10.1002/ajpa.1330300214.
[2] J. Brůžek, A method for visual determination of sex, using the human hip bone, Am. J. Phys. Anthropol. 117 (2) (2002) 157–168, https://doi.org/10.1002/ajpa.10012.
[3] J. Brůžek, F. Santos, B. Dutailly, P. Murail, E. Cunha, Validation and reliability of the sex estimation of the human os coxae using freely available DSP2 software for bioarchaeology and forensic anthropology, Am. J. Phys. Anthropol. 164 (2) (2017) 440–449, https://doi.org/10.1002/ajpa.23282.
[4] P.L. Walker, Sexing skulls using discriminant function analysis of visually assessed traits, Am. J. Phys. Anthropol. 136 (1) (2008) 39–50, https://doi.org/10.1002/ajpa.20776.
[5] D.E. Walrath, P. Turner, J. Brůžek, Reliability test of the visual assessment of cranial traits for sex determination, Am. J. Phys. Anthropol. 125 (2) (2004) 132–137, https://doi.org/10.1002/ajpa.10373.
[6] M.K. Spradley, R.L. Jantz, Sex Estimation in Forensic Anthropology: Skull Versus Postcranial Elements, J. Forensic Sci. 56 (2011) 289–296, https://doi.org/10.1111/j.1556-4029.2010.01635.x.
[7] M. Steyn, M.Y. İşcan, Sex determination from the femur and tibia in South African whites, Forens. Sci. Int. 90 (1-2) (1997) 111–119, https://doi.org/10.1016/S0379-0738(97)00156-4.
[8] V. Alunni-Perret, P. Staccini, G. Quatrehomme, Sex determination from the distal part of the femur in a French contemporary population, Forens. Sci. Int. 175 (2-3) (2008) 113–117, https://doi.org/10.1016/j.forsciint.2007.05.018.
[9] M. Yaşar İşcan, P. Miller-Shaivitz, Discriminant Function Sexing of the Tibia, J. Forensic Sci. 29 (4) (1984) 11775J, https://doi.org/10.1520/JFS11775J.
[10] M. Šlaus, Ž. Bedić, D. Strinović, V. Petrovečki, Sex determination by discriminant function analysis of the tibia for contemporary Croats, Forens. Sci. Int. 226 (1-3) (2013) 302.e1–302.e4, https://doi.org/10.1016/j.forsciint.2013.01.025.
[11] E.F. Kranioti, M.A. Apostol, Sexual dimorphism of the tibia in contemporary Greeks, Italians, and Spanish: forensic implications, Int. J. Legal Med. 129 (2) (2015) 357–363, https://doi.org/10.1007/s00414-014-1045-6.
[12] D.-I. Kim, D.-S. Kwak, S.-H. Han, Sex determination using discriminant analysis of the medial and lateral condyles of the femur in Koreans, Forens. Sci. Int. 233 (1-3) (2013) 121–125, https://doi.org/10.1016/j.forsciint.2013.08.028.
[13] E. Cavaignac, F. Savall, M. Faruch, N. Reina, P. Chiron, N. Telmon, Geometric morphometric analysis reveals sexual dimorphism in the distal femur, Forens. Sci. Int. 259 (2016) 246.e1–246.e5, https://doi.org/10.1016/j.forsciint.2015.12.010.
[14] M.H.A. Hussein, B.-S. Abulnoor, Sex estimation of femur using simulated metapopulation database: a preliminary investigation, Forens. Sci. Int.: Rep. 1 (2019) 100009, https://doi.org/10.1016/j.fsir.2019.100009.
[15] O. Gulhan, K. Harrison, A. Kiris, A new computer-tomography-based method of sex estimation: development of Turkish population-specific standards, Forens. Sci. Int. 255 (2015) 2–8, https://doi.org/10.1016/j.forsciint.2015.07.015.
[16] F. Chiba, Y. Makino, S. Torimitsu, A. Motomura, G.o. Inokuchi, N. Ishii, Y. Hoshioka, H. Abe, R. Yamaguchi, A. Sakuma, S. Nagasawa, H. Saito, D. Yajima, Y. Fukui, H. Iwase, Sex estimation based on femoral measurements using multidetector computed tomography in cadavers in modern Japan, Forens. Sci. Int. 292 (2018) 262.e1–262.e6, https://doi.org/10.1016/j.forsciint.2018.09.027.
[17] O. Ekizoglu, A. Er, M. Bozdag, M. Akcaoglu, I.O. Can, J.G. García-Donas, E. F. Kranioti, Sex estimation of the tibia in modern Turkish: a computed tomography study, Legal Med. 23 (2016) 89–94, https://doi.org/10.1016/j.legalmed.2016.10.004.
[18] E.K. Kranioti, J.G. García-Donas, P.S. Almeida Prado, X.P. Kyriakou, H.C. Langstaff, Sexual dimorphism of the tibia in contemporary Greek-Cypriots and Cretans: forensic applications, Forens. Sci. Int. 271 (2017) 129.e1–129.e7, https://doi.org/10.1016/j.forsciint.2016.11.018.
[19] T.D. Holland, Sex assessment using the proximal tibia, Am. J. Phys. Anthropol. 85 (2) (1991) 221–227, https://doi.org/10.1002/ajpa.1330850210.
[20] M.K. Spradley, Metric methods for the biological profile in forensic anthropology: sex, ancestry, and stature, Academic Forens. Pathol. 6 (3) (2016) 391–399, https://doi.org/10.23907/2016.040.
[21] A. Kotěrová, J. Velemínská, J. Dupej, H. Brzobohatá, A. Pilný, J. Brůžek, Disregarding population specificity: its influence on the sex assessment methods from the tibia, Int. J. Legal Med. 131 (1) (2017) 251–261, https://doi.org/10.1007/s00414-016-1413-5.
[22] P. Kajanoja, Sex determination of finnish crania by discriminant function analysis, Am. J. Phys. Anthropol. 24 (1) (1966) 29–33, https://doi.org/10.1002/ajpa.1330240104.
[23] P. Oura, J. Karppinen, J. Niinimäki, J.-A. Junno, Sex estimation from dimensions of the fourth lumbar vertebra in Northern Finns of 20, 30, and 46 years of age, Forens. Sci. Int. 290 (2018) 350.e1–350.e6, https://doi.org/10.1016/j.forsciint.2018.07.011.
[24] A. Keisu, P. Oura, M. Niskanen, C.B. Ruff, J. Niinimäki, T. Arvola, J. Auvinen, J. Tuukkanen, P. Lehenkari, J.-A. Junno, The association between knee breadth and body mass: the Northern Finland Birth Cohort 1966 case study, Am. J. Phys. Anthropol. 170 (2) (2019) 196–206, https://doi.org/10.1002/ajpa.23905.
[25] N. Squyres, C.B. Ruff, Body mass estimation from knee breadth, with application to early hominins, Am. J. Phys. Anthropol. 158 (2015) 198–208, https://doi.org/10.1002/ajpa.22789.
[26] N. Langley, L. Jantz, S. Ousley, R. Jantz, G. Milner, Data collection procedures for forensic skeletal material 2.0, University of Tennessee, Knoxville, 2016.
[27] C.B. Ruff, Long bone articular and diaphyseal structure in old world monkeys and apes. I: Locomotor effects, Am. J. Phys. Anthropol. 119 (4) (2002) 305–342, https://doi.org/10.1002/ajpa.10117.
[28] H. Kan, Y. Arai, M. Kobayashi, S. Nakagawa, H. Inoue, M. Hino, S. Komaki, K. Ikoma, K. Ueshima, H. Fujiwara, T. Kubo, Radiographic Measurement of Joint Space Width Using the Fixed Flexion View in 1,102 Knees of Japanese Patients with Osteoarthritis in Comparison with the Standing Extended View, Knee Surg Relat Res 29 (1) (2017) 63–68, https://doi.org/10.5792/ksrr.16.046.
[29] T. Niinimäki, R. Ojala, J. Niinimäki, J. Leppilahti, The standing fixed flexion view detects narrowing of the joint space better than the standing extended view in patients with moderate osteoarthritis of the knee, Acta Orthopaedica 81 (3) (2010) 344–346, https://doi.org/10.3109/17453674.2010.483989.
[30] G. van Belle, L. Fisher, P. Heagerty, T. Lumley, Biostatistics - A Methodology for the Health Sciences, Second Edition, Hoboken, John Wiley & Sons, New Jersey, 2004.
[31] H.M. Garvin, M.K. Stock, The utility of advanced imaging in forensic anthropology, Acad. Forens. Pathol. 6 (3) (2016) 499–516, https://doi.org/10.23907/2016.050.
[32] K.E. Stull, E.N. L'abbé, S. Steiner, Measuring distortion of skeletal elements in Lodox Statscan-generated images: Distortion in Lodox Statscan Images, Clin. Anat. 26 (6) (2013) 780–786, https://doi.org/10.1002/ca.22225.
[33] R.M. Carew, M.D. Viner, G. Conlogue, N. Márquez-Grant, S. Beckett, Accuracy of computed radiography in osteometry: a comparison of digital imaging techniques and the effect of magnification, J. Forensic Radiol. Imaging 19 (2019) 100348, https://doi.org/10.1016/j.jofri.2019.100348.
[34] T.W. Todd, The Effect of Maceration and Drying upon the Linear Dimensions of the Green Skull, J. Anat. 57 (1923) 336–356.
[35] R.R. Lanier, Effects of maceration and drying on presacral vertebrae, Am. J. Phys. Anthropol. 27 (3) (1940) 469–477, https://doi.org/10.1002/ajpa.1330270332.
[36] N.W. Ingalls, Studies on the femur. III. The effects of maceration and drying in the white and negro, Am. J. Phys. Anthropol. 10 (2) (1927) 297–321, https://doi.org/10.1002/ajpa.1330100211.

[37] J. Bertrand, M.F. Oxenham, Low-temperature-induced bone shrinkage: a controlled study using kangaroo femora, Aust. J. Forens. Sci. 47 (2) (2015) 173–181, https://doi.org/10.1080/00450618.2014.925973.

[38] D.E. Lieberman, M.J. Devlin, O.M. Pearson, Articular area responses to mechanical loading: effects of exercise, age, and skeletal location, Am. J. Phys. Anthropol. 116 (4) (2001) 266–277, https://doi.org/10.1002/ajpa.1123.

[39] H. Han, S. Oh, C.B. Chang, S.-B. Kang, Anthropometric difference of the knee on MRI according to gender and age groups, Surg. Radiol. Anat. 38 (2) (2016) 203–211, https://doi.org/10.1007/s00276-015-1536-2.

[40] E. Cavaignac, F. Savall, E. Chantalat, M. Faruch, N. Reina, P. Chiron, N. Telmon, Geometric morphometric analysis reveals age-related differences in the distal femur of Europeans, J. Exp. Orthop. 4 (1) (2017) 21, https://doi.org/10.1186/s40634-017-0095-3.