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Sex determination based on sacral and coccygeal measurements using multidetector computed tomography in a contemporary Japanese population

Suguru Torimitsu[a,b,*], Yohsuke Makino[a,b], Hisako Saitoh[b], Ayaka Sakuma[b], Namiko Ishii[b], Daisuke Yajima[b], Go Inokuchi[a,b], Ayumi Motomura[a,b], Fumiko Chiba[a,b], Rutsuko Yamaguchi[a,b], Mari Hashimoto[a,b], Yumi Hoshioka[b], Hirotaro Iwase[a,b]

[a] *Department of Forensic Medicine, Graduate School of Medicine, The University of Tokyo, 7-3-1, Bunkyo-ku, Tokyo, Hongo, 113-0033, Japan*
[b] *Department of Legal Medicine, Graduate School of Medicine, Chiba University, 1-8-1 Inohana, Chuo-ku, Chiba 260-8670, Japan*

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ABSTRACT

Sex determination is an integral and foremost step in determining the identity of an unknown individual. The present study aimed to examine skeletal sexual dimorphism of the sacrum and coccyx using computed tomography (CT) images in a contemporary Japanese population and to derive discriminant function formulae for sex determination. Data were collected from 230 cadavers (115 male and 115 female subjects) subjected to postmortem CT scanning and subsequent forensic autopsy. Seven measurements of the sacrum and coccyx were obtained from CT images of each subject. The measurements were analyzed using descriptive statistics and discriminant function analyses. All except one measurement exhibited statistically significant sexual dimorphism, and the maximum sex determination rate was 83.5% according to discriminant function analyses. The results of this study suggest that discriminant analysis of sacral and coccygeal traits may be useful for the sex determination of skeletal remains in the Japanese population when applied with additional methods, such as morphological trait evaluation of other available bones.

1. Introduction

The identification of incomplete, mutilated, or decomposed bodies is an important part of a forensic investigation [1]. Defining attributes from skeletal elements, such as sex, age, ancestry, and stature may help forensic anthropologists identify an individual [2]. In particular, sex estimation is a critical initial step in determining the identity of an unknown individual because other traits (e.g., age, ancestry, and stature) are usually estimated using sex-specific standards [3,4].

Although morphological methods based on sexual dimorphic traits of the pelvis and skull provide valuable information with respect to identification, these traits are often subjective [5,6]. In addition, human skeletal parts may be damaged, fragmented, or incomplete in situations involving decomposition or carnivore modification, thus reducing the accuracy of a morphological examination [7–9].

In contrast to subjective morphological methods, morphometric methods based on sex-related differences in skeletal dimensions can be implemented even by relatively inexperienced examiners [10]. Previous studies have described the use of statistical analyses and derived models and equations for sex determination using a variety of bones, including the long bones, sternum, scapula, mandible, and ribs [11–16]. Notably, the sacrum is an important bone for sex determination because of the functional sex-related differences in the pelvic region [17]. Several authors have assessed the sacrum and demonstrated that its dimensions exhibit a sufficient degree of sexual dimorphism for use in sex estimation [10,18,19]. Despite this, no previous study has assessed sex determination based on sacral and coccygeal measurements in a contemporary Japanese population. This omission is of concern because population differences in the skeletal framework can significantly affect morphometric assessments of biological profiles [9]; accordingly, non-population-specific diagnostic criteria for sex estimation generally yield low classification rates [20]. Therefore, population-specific standards are needed to optimize identification accuracy.

Currently, postmortem computed tomography (PMCT) prior to

* Corresponding author at: Department of Forensic Medicine, Graduate School of Medicine, The University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-0033, Japan.
E-mail addresses: torimitsu-tky@umin.ac.jp (S. Torimitsu), ymakino-tky@umin.ac.jp (Y. Makino), hms1466@faculty.chiba-u.jp (H. Saitoh), a.sakuma@chiba-u.jp (A. Sakuma), acua2807@chiba-u.jp (N. Ishii), yajima.d@faculty.chiba-u.jp (D. Yajima), goinokuchi@chiba-u.jp (G. Inokuchi), aama0171@chiba-u.jp (A. Motomura), chibafumico@chiba-u.jp (F. Chiba), rymgch@yahoo.co.jp (R. Yamaguchi), kane.a.nite.01@gmail.com (M. Hashimoto), yhoshioka@chiba-u.jp (Y. Hoshioka), iwase@faculty.chiba-u.jp (H. Iwase).

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Table 1
Definitions of the measurements of the sacrum and coccyx in this study.

Measurement	Definition	Image	Reference
Anterior sacral length (ASL)	Linear distance from the anterosuperior edge of S1[a] to the anteroinferior edge of S5[b]	Sagittal	[30]
Posterior sacral length (PSL)	Linear distance from the posterosuperior edge of S1 to the anteroinferior edge of S5	Sagittal	[30]
Anterior sacrococcygeal length (ASCL)	Linear distance from the anterosuperior edge of S1 to the anteroinferior edge of LCV[c]	Sagittal	[30]
Posterior sacrococcygeal length (PSCL)	Linear distance from the posterosuperior edge of S1 to the anteroinferior edge of the LCV	Sagittal	[30]
Maximum anterior-posterior diameter (APD)	Linear distance from the two anterior point to the most posterior point on the body of S1	Axial	[29]
Maximum transverse diameter (MTD)	Linear distance between the two most laterally projecting points on the body of S1	Axial	[18]
Maximum breadth of sacral alae (MBA)	Maximum transverse distance between the two most lateral parts of the sacral alae	Axial	[18]

[a] First sacral vertebra.
[b] Fifth sacral vertebra.
[c] Last coccygeal vertebra.

autopsy has become useful for forensic practice in some institutions [21]. PMCT accurately depicts osseous structures [22,23], allowing forensic anthropologists to collect contemporary population-specific skeletal data and subsequently formulate standards to estimate biological parameters, including sex [13,24–26]. Given the potential for more accurate and objective evaluation, postcranial skeleton-based methods are beginning to incorporate modern techniques such as CT [27]. Although traditional morphological analyses require experienced anthropologists, quantitative bone measurements based on CT images can be performed by relatively inexperienced researchers [10]. In addition, the use of CT images increases both accuracy and reproducibility, which are important for the establishment of formulae to determine a biological profile [25,28].

The purpose of this study was to assess sexual dimorphism of the sacrum and coccyx in a Japanese population using CT image-based morphometric data to develop formulae for sex determination.

2. Material and methods

The study protocol was approved by the ethics committee of our university, and the requirement for approval from the subjects' relatives was waived.

PMCT images of 230 Japanese cadavers of known age and sex (115 male and 115 female subjects) were analyzed. All subjects underwent PMCT scanning and subsequent forensic autopsy at the department of legal medicine at our university between September 2011 and April 2016. The mean ages ± standard deviation of the male and female subjects were 56.3 years ± 15.4 (range, 21–87 years) and 58.6 years ± 19.3 (range, 21–91 years), respectively. Subject exclusion criteria included fractures, burns, and acquired or congenital abnormalities.

PMCT scanning was performed using a 16-row detector CT system (Eclos; Hitachi, Ltd., Tokyo, Japan). The following scanning protocol settings were used: collimation, 0.63 mm; reconstruction interval, 0.63 mm; tube voltage, 120 kVp; tube current, 200 mA; rotation time, 1 per second. A hard filter was used. Raw CT data were processed on a workstation (Synapse Vincent; Fujifilm Medical, Tokyo, Japan) to obtain orthogonal multiplanar reconstruction images and volume-rendered images. Reconstructed cross-sectional images were viewed using a window width and level of 2000 and 400 HU, respectively.

According to Zech et al. [10], CT images were assessed in a multiplanar mode to obtain appropriate views of the sacrum and coccyx. Seven measurements were performed according to Martin [29], Benazzi et al. [18], and our previous study [30]. The definitions of the morphometric variables obtained are shown in Table 1. Four measurements (ASL, PSL, ASCL, and PSCL) were obtained from sagittal images (Fig. 1) and three (APD, MTD, and MBA) from axial images (Fig. 2). All seven measurements were obtained using an electronic cursor with an accuracy of 0.1 mm.

To evaluate intra- and inter-observer errors, a subset of 20 subjects was randomly selected for re-examination. One month following the initial measurements, the first author re-collected data from the selected subset for evaluation of intra-observer error and another co-author collected data of the same subset for evaluation of inter-observer error. The relative technical error of measurement (rTEM, %) and coefficient of reliability (R), which demonstrated the proportion of between-subject variance free of measurement errors, were calculated. Acceptable rTEM values for intra-observer and inter-observer errors were $< 1.5\%$ and $< 2.0\%$, respectively [31]; an R value > 0.75 was considered sufficiently precise [32,33].

All statistical analyses were performed using SPSS version 21.0 computer software (IBM, Armonk, NY, USA) and Excel software (Microsoft Office 2013; Microsoft, Redmond, WA, USA). Means, standard deviations, standard errors, and ranges were calculated for all measurements. The Shapiro-Wilk test and Levene's test were performed to evaluate normality and equality of variances, respectively. All p values were > 0.05, indicating normal distributions with equal variances. Accordingly, Student's-t-test was used to compare mean differences between the sexes. A p value < 0.05 was considered statistically significant.

A univariate discriminant function analysis (DFA) was performed for each morphometric variable to determine a formula for sex classification. A stepwise DFA was also performed (Wilk's lambda test, with F=3.84 to enter and F=2.71 to remove) for the sacrum and coccyx to determine a formula that would provide the most accurate sex classifications. The sectioning points were zero because male and female subject sample sizes were equal. Accurate prediction rates of the derived discriminant functions were obtained using the leave-one-out cross-validation procedure. Wilk's lambda values were also calculated to determine how well each function classified subjects into male and female groups. Lambda values emphasize different group means of values near zero and similar group means of values near one.

3. Results

The rTEMs values for intra- and inter-observer errors were $< 1.5\%$ (0.324–1.263%) and $< 2\%$ (0.520–1.477%), respectively, and the R values were > 0.750 (0.970–0.997) (Table 2), indicating high reproducibility of these measurements.

Table 3 presents descriptive statistics of the seven sacral and coccygeal variables evaluated. The mean values of six variables (ASL, PSL, ASCL, PSCL, APD, MTD) were significantly larger in male subjects ($p < 0.001$ by Student's t-test), whereas no significant difference in mean MBA was observed between the sexes (p=0.901); thus, this latter measurement was excluded from the following sex prediction analyses.

The results of univariate DFA are shown in Table 4. PSCL contributed most significantly to sex determination, followed by PSL, with accuracy rates of 77.0% and 73.0%, respectively. Stepwise analysis based on overall measurements of the sacrum and coccyx identified four measurements (PSL, PSCL, APD, and MTD) that collectively yielded a correct prediction rate of 83.5% (Table 5).