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FSI-8426; No. of Pages 6
ARTICLE IN PRESS
Forensic Science International xxx (2016) xxx–xxx
Contents lists available at ScienceDirect
Forensic Science International
journal homepage: www.elsevier.com/locate/forsciint

Forensic Anthropology Population Data

Sexual determination based on multidetector computed tomographic measurements of the second cervical vertebra in a contemporary Japanese population

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ARTICLE INFO

Article history:
Received 22 February 2016
Received in revised form 4 April 2016
Accepted 7 April 2016
Available online xxx

Keywords:
Forensic anthropology population data
Multidetector computed tomography
Axis
Japanese
Sexual dimorphism
Discriminant analysis

ABSTRACT

Accurate sex estimation is important in forensic investigation to determine the identity of unknown individuals. The aim of this study was to investigate the accuracy of sex assessment based on measurements of the second cervical vertebra (C2) using computed tomographic (CT) images in a Japanese population and to develop discriminant function formulae. The data were collected from 224 Japanese cadavers (112 male subjects, 112 female subjects) on which postmortem CT scanning and subsequent forensic autopsy were performed. Nine CT measurements of the C2 were performed for CT images of each subject. The measurements were assessed using descriptive statistics and discriminant function analyses (DFA). All of the measurements demonstrated significant sexual dimorphism. Multiple DFA with stepwise variable selection resulted in multivariable models; a five-variable model reached an accuracy rate of 92.9%. Our results suggest that metric analysis based on CT images of the C2 can accurately determine the sex from the human skeletal remains in a contemporary Japanese population and may be useful for sex estimation in forensic anthropology.

1. Introduction

When incomplete, mutilated, or decomposed bodies are found, defining attributes, such as sex, age, ancestry, and stature from skeletal elements may help forensic anthropologists to identify an individual [1]. Particularly, accurate sex estimation is crucial for determining the identity of an unknown individual because other elements (age, ancestry, and stature) of the biological profile are usually estimated using sex-specific standards [2].

Examination of morphological characteristics of the pelvis and skull is the most reliable technique for estimating the sex of an individual [1,3]. However, in some situations, the human skeletal parts are damaged or incomplete because taphonomic processes, such as decomposition and carnivore modification, may damage these bones [4,5]. In cases in which the pelvis and skull are not available, other parts of the human skeleton should be used for sex determination. Therefore, it is essential to develop techniques that enable sex estimation based on skeletal regions that are less dimorphic [6]. Previous studies have examined the sexual dimorphism of various skeletal elements such as the long bones, talus, metatarsals, sternum and ribs [7–10].

Researchers have investigated the second cervical vertebra (C2) and determined that there is a sufficient degree of sexual dimorphism in its dimensions to allow estimation of sex by metric analysis with a considerable degree of accuracy [4,11–13], probably because of the later growth spurt in vertebral height and a greater growth in the transverse diameter in males [14]. The C2 has certain morphological characteristics, such as the dens, which allow forensic investigators to immediately identify the bone as

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http://dx.doi.org/10.1016/j.forsciint.2016.04.010
0379-0738/

the C2 [15]. In addition, cervical vertebrae are known to be the best preserved of all vertebrae in cadavers [16], and the C2 has been more frequently recovered in its entirety than pelvic bones [17]. However, no study has yet examined sex determination based on measurements of the C2 in the contemporary Japanese population. It has been recognized that the magnitudes of sexually dimorphic characteristics vary among populations [18]. Non-population-specific standards for sex estimation usually provide a low classification rate [19]. Thus, different populations should have specific standards to optimize the accuracy of identification.

Recently, postmortem computed tomography (PMCT) prior to autopsy has become a useful tool in forensic practice in some forensic institutions [20]. PMCT imaging is an effective technique for depiction of osseous structures [21,22]; therefore, forensic anthropologists can collect contemporary population-specific data and formulate standards for estimation of biological profiles, including sex, using the skeleton [10,23–25]. In addition, metric bone measurements using computed tomographic (CT) scans can be performed by relatively inexperienced investigators [26], and the use of CT images increases accuracy and reproducibility over traditional morphological analyses in establishing a biological profile [24,27].

The aim of this study was to evaluate the degree of sexual dimorphism of the C2 and develop discriminant function formulae based on metric data using CT images for sex estimation in a Japanese population.

2. Materials and methods

This retrospective study protocol was approved by the ethics committee of our university, and approval from the subjects' relatives was not required.

The data were collected from 224 Japanese cadavers of known age and sex (112 male subjects, 112 female subjects) on which PMCT scanning and subsequent forensic autopsy were performed at the department of legal medicine of our university between February 2012 and October 2015. The mean age ± standard deviation of male and female subjects were 57.0 years ± 15.5 (range, 21–87 years) and 60.5 years ± 18.7 (range, 20–91 years), respectively. The exclusion criteria were cervical spine injury, burning, and acquired or congenital abnormalities.

PMCT scanning was performed using a 16-row detector CT system (Eclos; Hitachi Medical Corporation, Tokyo, Japan). The following scanning protocol settings were used: collimation of 0.63 mm, reconstruction interval of 0.63 mm, tube voltage of 120 kVp, tube current of 200 mAs, and rotation time of 1 per second. A hard filter was used. Image 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.

Nine measurements were performed to obtain morphometric characteristics of the C2. The definitions of the nine measurements of the C2 are described and illustrated in Table 1 and Fig. 1. Two measurements (DA and AS) were taken from sagittal images that were checked for tilt and corrected using axial and coronal images to acquire the appropriate view of the center of the C2; the other measurements were taken from axial images that were checked for tilt and corrected using coronal and sagittal images to get the proper orientation when viewed. The nine measurements were taken by using electronic cursors placement accurate to the nearest 0.1 mm.

A subset of 20 subjects was randomly selected to evaluate intra- and inter-observer errors. In two different sessions, the first author re-collected data on the selected subset (1 month apart) to calculate the intra-observer error. In addition, another observer obtained data in the same subset to calculate inter-observer error. The relative technical error of measurement (rTEM, %) and coefficient of reliability (*R*), which indicated the proportion of the between-subject variance free of measurement errors, were subsequently computed. The acceptance ranges of the rTEM for the intra-observer and inter-observer errors were $<1.5\%$ and $<2.0\%$, respectively [28], and an *R* value of >0.75 was considered to be sufficiently precise [29,30].

All statistical analyses were performed on a personal computer by 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 for all nine measurements were calculated, and one-way analysis of variance (ANOVA) was used to compare mean differences between males and females. A p value <0.05 was considered to indicate statistical significance.

Univariate discriminant function analysis (DFA) was performed for each measurement of the C2 to determine a formula for the classification of sex. Stepwise DFA was also performed (Wilk's lambda test, with $F = 3.84$ to enter and $F = 2.71$ to remove, was used) to select the optimal combination of measurements for the most accurate sex classification. The sectioning points were zero because the sample sizes of males and females were equal.

Table 1
Definitions of the measurements of the second cervical vertebra (C2) in the present study.

Measurement	Definition	Image	Reference
Maximum height of the dens (DA)	Length from the superior point on the dens to the antero-inferior point on the vertebral body	Sagittal	[13,15]
Maximum sagittal length (AS)	Length from the antero-inferior point on the vertebral body to the posterior point on the spinous process	Sagittal	[15]
Maximum width of the axis (LMA)	Maximum width measured from the more extreme side of the transverse process	Axial	[11]
Maximum distance between the superior facets (DMFS)	Maximum distance between the most lateral edges of the superior articular facets	Axial	[13]
Dens sagittal diameter (DSD)	Maximum sagittal diameter of the dens measured between the anterior and posterior points on the dens	Axial	[13]
Dens transverse diameter (DTD)	Maximum transverse diameter of the dens measured between the most lateral edges of the dens	Axial	[13]
Width of vertebral foramen (WVF)	The maximum internal width of the vertebral foramen	Axial	[13]
Maximum sagittal diameter of the body (DSMC)	Maximum sagittal diameter of the body measured from the antero-inferior point on the board to postero-inferior point	Axial	[33]
Maximum transverse diameter of the body (DTMC)	Maximum transverse diameter of the body measured between the most lateral edges of the body	Axial	[11]