Forensic Science International 257 (2015) 521.e1–521.e10

Contents lists available at ScienceDirect

Forensic Science International

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

Forensic Anthropology Population Data

Determination of sex from various hand dimensions of Koreans

Soo-Chan Jee [a], Sangwoo Bahn [b,*], Myung Hwan Yun [a]

[a] Department of Industrial Engineering, Seoul National University, Seoul 151-742, Korea
[b] Department of Industrial and Management Engineering, Myongji University, Yongin 449-728, Korea

ARTICLE INFO

Article history:
Received 23 February 2015
Received in revised form 6 September 2015
Accepted 18 October 2015
Available online 25 October 2015

Keywords:
Forensic anthropometry population data
Identification
Hand dimension
Korean
Sex determination
Sexual dimorphism

ABSTRACT

In the case of disasters or crime scenes, forensic anthropometric methods have been utilized as a reliable way to quickly confirm the identification of victims using only a few parts of the body. A total of 321 measurement data (from 167 males and 154 females) were analyzed to investigate the suitability of detailed hand dimensions as discriminators of sex. A total of 29 variables including length, breadth, thickness, and circumference of fingers, palm, and wrist were measured. The obtained data were analyzed using descriptive statistics and *t*-test. The accuracy of sex indication from the hand dimensions data was found using discriminant analysis. The age effect and interaction effect according to age and sex on hand dimensions were analyzed by ANOVA. The prediction accuracy on a wide age range was also compared. According to the results, the maximum hand circumference showed the highest accuracy of 88.6% for predicting sex for males and 89.6% for females. Although the breadth, circumference, and thickness of hand parts generally showed higher accuracy than the lengths of hand parts in predicting the sex of the participant, the breadth and circumference of some finger joints showed a significant difference according to age and gender. Thus, the dimensions of hand parts which are not affected by age or gender, such as hand length, palm length, hand breadth, and maximum hand thickness, are recommended to be used first in sex determination for a wide age range group. The results suggest that the detailed hand dimensions can also be used to identify sex for better accuracy; however, the aging effects need to be considered in estimating aged suspects.

1. Introduction

In the cases of large-scale natural disasters, terror, or crime scenes, the forensic anthropometry method has been utilized as a reliable means of confirmation of identity by using only a few body parts [1,2]. In recent years, the importance of this method has been highlighted and its accuracy has also been improving when combined with various statistical techniques [3,4]. Due to its time and cost-effectiveness and relatively accurate identification ability, forensic anthropometry with DNA analysis is widely used in many countries including Korea [5]. One of the most fundamental identifications in forensic anthropometry is sex determination, which could eliminate 50% of the cases.

Among many traces of body parts, hand prints are frequently found on a crime scene, and usually provide important clues in the investigation. The hand is composed of 27 bones and 15 joints, which provide important information such as length, breadth, circumference, and thickness of various hand dimensions. Some hand dimensions were found to have significant correlation with a human's stature and weight. In the case of disasters or air crashes, a dismembered or fragmentary hand is commonly used to confirm a victim's identity [6–8].

In previous studies, the importance of the hand in sex determination was emphasized. Many studies using hand anthropometry have been conducted for sex determination (Table 1). For the Indian population, many attempts have been made to estimate sex using hand dimensions [9,10]. Kanchan measured the hand length and palm length of 500 males and females (from 17 to 20 years old) in North and South India. He tried to identify the subject's sex using sectioning point analysis of hand and palm lengths [11]. This study showed that the hand breadth, palm lengths, and hand lengths showed 87%, 85.7%, and 83% accuracies for males, and 91%, 89.6%, and 88.5% for females respectively. Ishak conducted a study to determine sex using the dimensions of various hand parts and hand prints collected from 200 Australian subjects [12]. In the study, the hand breadth and length were reported to offer the highest identification accuracy. Jowaheer and Agnihotri measured the hand and foot lengths of 250 Mauritians (from 18 to 30 years old). They derived a logistic regression model

* Corresponding author. Tel.: +82 31 330 6445; fax: +82 31 330 6957.
E-mail addresses: mdmds2@snu.ac.kr (S.-C. Jee), sbahn@mju.ac.kr, panlot@gmail.com (S. Bahn), mhy@snu.ac.kr (M.H. Yun).

http://dx.doi.org/10.1016/j.forsciint.2015.10.014
0379-0738/

Table 1
Previous studies on sex estimation using hand dimensions.

Author	Population	Age	Used dimension for estimation	Year
Manning [17]	Chinese, Jamaican, African	2–25	2D, 4D length	2004
Case [14]	European	18–60	Phalange, metatarsal, metacarpal length	2007
Kanchan [11]	Indian	17–20	Hand length, hand breadth	2009
Kanchan [27]	Indian	2–12	2D, 4D length	2010
Aboul-Hagag [15]	Egyptian	Over 18	Hand length, hand breadth, 2D, 4D length	2011
Krishan [10]	Indian	17–20	Hand length, hand breadth	2011
Jowaheer [13]	Mauritian	18–30	Hand length, hand breadth	2011
Ishak [12]	West Australian	18–63	Hand length, palm length finger length	2012
Mahakkanukrauh [21]	Thai	19–94	Proximal hand phalange length	2013
El morsi [20]	Egyptian	17–65	Phalange, metacarpal length	2013
Krishan [18]	Indian	14–18	2D, 4D length	2013

2D: Index finger, 4D: Ring finger.

for prediction, which showed 91.2% accuracy by using hand length and hand breadth; the model also yielded an R^2 value of 0.77 [13].

Previous studies using various hand parts have also been conducted. Case and Ross predicted the sex of 259 individuals by using the length of the phalange, metatarsal, and metacarpal bones. In their research, the phalange length showed higher prediction accuracy than the length of the metatarsal or metacarpal [14]. Aboul-Hagag et al. attempted sex determination by using variables such as hand length, hand breadth, and index finger versus ring finger length ratio. In the study, the hand index (hand breadth/hand length) showed 80.0% of accuracy for males, and 78.0% for females [15]. Manning et al. attempted to distinguish sex using the ratios of the length between the index (2D) and ring finger (4D). The study showed that there is a higher possibility of a greater 2D to 4D ratio for females than for males due to growth hormones [16,17]. From an empirical study of Indian subjects, Kanchan, Kumar, and Menezes reported that 2D to 4D ratio can be used as a significant sex indicator [18], but Voracek's study did not concur because the ratio varies considerably for different regions and nationalities [19]. Osteological and radiologic analysis of hand bones has been conducted. El Morsi and Howary used X-ray radiographs from 3800 Egyptian metacarpals and phalanges to derive a logistic regression model. In their research, the thumb proximal phalange length showed the highest accuracy value of 85% in prediction [20]. Pasuk scrutinized 249 skeletons from the Thai population and derived regression equations using the length of proximal hand phalanges. The model yielded 96.1% of accuracy by using diverse hand dimensions [21].

A number of previous studies analyzed the aging effect of anthropometric dimensions. Arslan analyzed the effects of age and region using ANOVA in estimating the anthropometric characteristics of Turkish adults [22]. In his research, a statistically significant difference was observed depending on the age and region for both sexes. As a subject's age increases, the weight of subjects tended to increase and their height decreases. Perissinotto observed the height and weight changes of 3356 Italian subjects who were more than 65 years old. The results showed that the height and weight for both sexes were significantly reduced as the subject's age increases [23].

The previous studies discriminated the sex of subjects mainly based on the hand length and breadth. However, in an accident or incident area, it is not possible to measure hand length or hand breadth in many cases because the human body is usually damaged or fragmented. Thus, gender prediction using the detailed hand anthropometric method will be effective in such conditions. Moreover, the hand is a highly complex structure with 27 bones and 15 joints, and detailed measurements of the hand will therefore provide more information for sex identification. In this study, besides the length and breadth of fingers and palms, the detailed dimensional measurements such as breadth, length, thickness, and circumferences of finger joints, wrist, and unique features of the hand are considered. By applying statistical techniques, a sex determination method is proposed. In addition, according to the previous studies, it is also difficult to clarify whether the accuracy of sex determination utilizing the hand dimensions is valid for the wide age range group because the hand dimensions of the subjects of a certain age range were measured mainly in the previous research. For example, if the prediction accuracy is 77% when predicting sex by using hand length, it is not certain whether 77% accuracy will still be valid for aging people. Thus, this study also aims to verify the effect of age on hand dimensions and its prediction accuracy based on the comparisons between the results of various ages. Depending on the different ethnic groups, the sectioning point for sex determination was reported to differ [2,12,19]. Therefore, the sectioning point that has been derived from other nationalities would not be applicable to the Korean population. Through this study, which is the first empirical attempt at sex determination of Koreans by using hand dimensions, we propose reliable criteria that would be applicable in a forensic investigation.

2. Method

2.1. Material

Data used in this study were gained from body measurements of the Size Korea Project organized by the National Agency for Technology and Standards Measurement, an institution for anthropometric survey in the Republic of Korea. The subjects were a total of 321 people (167 males and 154 females) who had no history of disease associated with the hand or spine. The subjects comprised even proportions in age (from the 20s to 70s) to reflect demographic diversity (Table 2). The mean age of the male subjects was 42.5 (minimum 20 and maximum 75), and that of the female was 46.5 (minimum 20 and maximum 76). All subjects were born and grew up in Republic of Korea and are of Korean ethnicity. We selected a wide range of ages within the population because we considered increasing the perpetrator's age to reflect the aging population of South Korea, and to address the need to identity

Table 2
Subject characteristics.

Gender	Age range			
	20's–30's	40's–50's	60's–70's	Total
Male	58 (35%)	57 (34%)	52 (31%)	167
Female	53 (34%)	52 (34%)	49 (32%)	154

threatening situations or airline accidents, which happen regardless of age.

2.2. Measurement

A total of 29 variables including length, breadth, thickness, and circumference of fingers, palm, and wrist were measured as presented in Table 3 and Fig. 1 [2,12,15]. To reduce the measurement errors, each investigator examined the dimension of one measurement variable. Digital calipers were used to measure the length, breadth, and thickness (stated accuracy ±0.1 mm), while tape measures were used to measure the circumferences. All investigators were instructed of the measurement methods for at least 18 h. When measuring, the subjects were asked to undress their top layer of clothing, sit down, and place their palms parallel to the measurement unit facing up and fully opened. Data values greater than $\pm 3\sigma$ from the mean were regarded as outliers, and the data were then compared to other body sizes. When the data had no relevance, it was removed. In the aggregation, 0.02% of the total data (10,759) was removed. To avoid any possible measurement error, reference points were marked on the subjects' bodies using a water-based pen and a digital caliper was used to measure the distance between the points. Before starting measurement, the hand parts were measured on 12 subjects twice at different times and the technical error of measurement was evaluated. Intra-observer error was measured by calculating the relative technical error of measurement (rTEM) and the coefficient of reliability (R); rTEM was less than 5% and R was greater than 0.91. Therefore, the intra observer error was considered to be within acceptable standards for all measurements [24].

Table 3
Definition of hand measurement employed in this research from references [2,12,15].

Hand dimension	Abbreviation	Definition
Hand length	HL	The distance from the middle of inter stylion to the tip of middle finger
Palm length	PL	The distance from the middle of inter stylion to the proximal flexion crease of the middle finger
Thumb; index; middle; ring; little finger length	1DL, 2DL, 3DL, 4DL, 5DL	The distance from proximal flexion crease of the finger to the tip of the respected finger
Hand breadth	HB	The distance from the most lateral point on the head of the 2D metacarpal to the most medial point on the head of 5D metacarpal
Maximum hand breadth	MHB	The distance from the most lateral point on the head of the 1D metacarpal to the most medial point on the head of 5D metacarpal with closing fingers
Wrist breadth	WB	The distance from the most lateral point on the wrist to the most medial point of wrist
Thumb; index; middle; ring; little finger proximal breadth	1D2B, 2D2B, 3D2B, 4D2B, 5D2B	The distance from the most lateral point on each finger proximal joint to the most medial point of each finger proximal joint
Index; middle; ring; little finger distal breadth	2D1B, 3D1B, 4D1B, 5D1B	The distance from the most lateral point on each finger distal joint to the most medial point of each finger distal joint
Hand thickness	HT	The distance from the back of the middle finger to the most medial point of palm
Maximum hand thickness	MHT	The maximum distance from the back of the hand to the most projected point of abductor pollicis brevis
Hand circumference	HC	The superficial distance around the edge of metacarpal
Maximum hand circumference	MHC	The maximum superficial distance around the edge of the hand with closing fingers
Wrist circumference	WC	The superficial distance around the edge of the wrist
Thumb; index; middle; ring; little finger proximal circumference	1D2C, 2D2C, 3D2C, 4D2C, 5D2C	The superficial distance around the edge of proximal joint in each finger

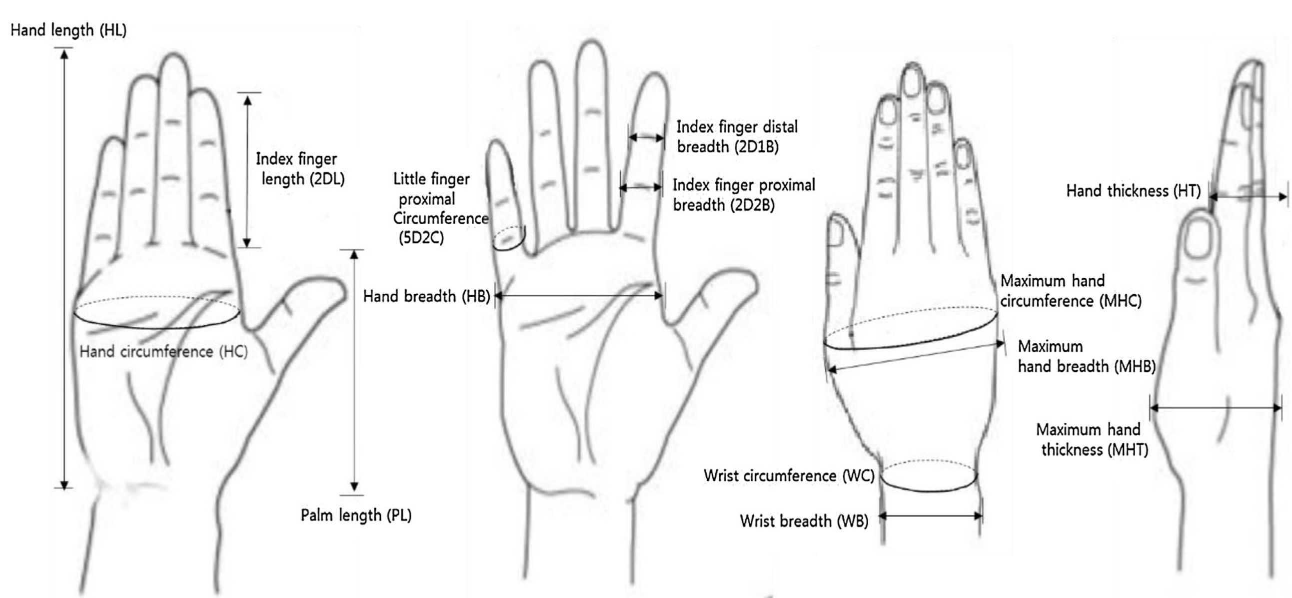

Fig. 1. Various hand landmarks in human hand.

2.3. Statistical analysis

The obtained hand dimension data were calculated and analyzed using SPSS 21. A descriptive statistic (mean, SD) was presented for each dimension. The body dimension differences between sexes were compared using a *t*-test. The accuracy of sex determination was derived using discriminant analysis [25], and the accuracy of the method was confirmed using a cross validation method. Based on the demarking points, the genders were classified into males with higher values and females with lower values.

3. Result

3.1. Descriptive statistics

Mean, SD, and range of hand dimensions are presented in Table 4. All dimensions, including length, breadth, thickness, and circumferences, appeared larger in males than in females, with statistical significance. The *t*-test results indicate that the maximum breadth and circumference of the hand show the greatest differences between sexes. On the other hand, the length of the index and little fingers shows a relatively small difference between male and female.

3.2. Discriminant analysis

3.2.1. Direct single variable

In order to evaluate the measured variables that determine sex most accurately, the accuracy according to a single variable was calculated (Table 5). The measured variables exhibited an average of more than 70% accuracy, and the maximum hand circumference (MHC) showed the highest accuracy of 88.6% for males and 89.6% for females. The highest accuracy of discrimination was followed by those predicted using the maximum hand breadth and the breadth of the second joint of the ring finger for males and using the wrist circumference, maximum hand breadth, and the maximum hand thickness for females. The demarking point was calculated from the average measurements from male and female subjects and indicated that males had the higher values and females had the lower values.

3.2.2. Stepwise discriminant analysis

In order to derive a more accurate prediction model, group variables (length, breadth, thickness, and circumference) were combined and the stepwise method was followed. The discriminant analysis using variables related to the lengths showed the sex determination accuracy of 82.6%. When the four variables (PL, 1DL, 2DL, and 3DL) were used for the discriminant analysis, the accuracy was 83.2% with −4.9% bias (Table 6). In case of breadth related variables, the discriminant analysis yielded 88.4% accuracy by using the two variables (MHB and 5D2B). The determination accuracy of 87.2% was obtained when the thickness related variables (HT and MHT) were used. When MHC and WC, the two parameters of the circumference associated variables, were used for stepwise discriminant analysis, 89.4% accuracy was obtained. By using PL, MHT, and HB variables, which showed no significant difference according to age range, the discriminant model yielded 90.0% accuracy, which was the highest accuracy in this study.

3.3. Effect of age range on hand dimension

In this study, the effect of age range on hand parts was identified by using ANOVA (Table 7). Among the variables related to the length, statistically significant difference was observed in the thumb, middle finger and ring finger by various age ranges. However, no consistent tendency was observed. Among the variables related to the breadth, significant differences in wrist breadth, proximal, and distal joint breadth of all fingers were

Table 4
Descriptive statistics of mean (in mm) and SD in hand landmarks.

	Male (n = 167)			Female (n = 154)			*T*-statistic	*P*-value
	Mean	SD	Range	Mean	SD	Range		
HL	183.28	9.04	153.05–203.37	170.73	7.67	146.22–190.83	13.34	***
PL	105.06	4.98	90.06–115.77	97.38	4.57	83.1–113.54	14.35	***
1DL	61.23	3.94	49.53–72.48	56.08	3.49	45.84–64.43	12.35	***
2DL	70.48	4.33	55.49–81.08	66.26	4.28	55.89–75.24	8.76	***
3DL	78.59	4.68	63.82–91.41	73.51	4.27	61.19–82.46	10.14	***
4DL	74.28	4.70	56.80–85.03	69.22	4.31	54.19–80.39	10.03	***
5DL	59.00	4.46	43.56–70.55	54.53	4.56	38.62–66.93	8.88	***
HB	85.96	4.19	74.61–95.75	78.03	3.98	70.94–88.32	17.34	***
MHB	107.30	5.01	94.08–119.26	95.79	4.81	84.41–110.89	20.89	***
WB	61.42	3.01	54.03–69.01	55.43	3.52	48.76–66.09	16.43	***
1D2B	22.46	1.60	19.01–26.27	19.72	1.50	15.54–23.65	15.81	***
2D2B	20.57	1.15	16.79–24.51	18.32	1.22	14.79–21.30	16.91	***
3D2B	20.76	1.21	17.01–24.35	18.49	1.25	15.25–22.44	16.47	***
4D2B	19.58	1.13	16.18–23.55	17.28	1.23	14.76–20.10	17.48	***
5D2B	17.48	1.11	13.82–20.55	15.33	1.22	12.60–18.17	16.54	***
2D1B,	18.09	1.19	15.08–22.68	16.15	1.22	13.13–19.22	14.49	***
3D1B	18.24	1.21	15.16–22.30	16.22	1.18	13.00–19.36	15.14	***
4D1B	16.86	1.14	13.82–20.27	14.95	1.14	12.45–18.33	14.98	***
5D1B	15.51	1.08	12.25–18.80	13.61	1.24	10.80–16.42	14.70	***
HT	27.66	2.06	21.43–38.86	24.69	1.79	21.00–30.92	13.72	***
MHT	49.12	4.05	38.12–62.35	42.16	3.74	34.52–58.85	15.96	***
HC	208.04	9.61	183.0–233.0	186.06	10.74	162.0–225.0	19.34	***
MHC	252.59	12.00	223.0–284.0	223.29	11.69	198.0–257.0	22.12	***
WC	175.80	10.91	156.0–254.0	156.24	8.95	137.0–185.0	17.47	***
1D2C	68.60	4.27	60.0–81.0	61.03	4.58	50.0–74.0	15.32	***
2D2C	64.86	3.71	55.0–77.0	58.24	4.05	48.0–72.0	15.26	***
3D2C	66.40	3.95	55.0–78.0	59.57	4.23	49.0–72.0	14.94	***
4D2C	62.06	3.85	52.0–77.0	55.62	4.00	47.0–66.0	14.66	***
5D2C	54.51	3.45	45.0–65.0	48.76	3.80	41.0–58.0	14.19	***

*** $P < 0.001$ is significant.

Table 5
Demarking points (in mm) of hand dimensions in estimating sex and expected accuracy.

	Variable	Demarking point	Accuracy (%)		Sex bias (%)
			Male	Female	
Length					
Function1	HL	♀ < 177.01 < ♂	75.4	76.6	−1.2
Function2	PL	♀ < 101.22 < ♂	77.8	81.8	−4.0
Function3	1DL	♀ < 58.66 < ♂	78.4	78.6	−0.2
Function4	2DL	♀ < 68.37 < ♂	65.9	70.1	−4.2
Function5	3DL	♀ < 76.05 < ♂	68.3	72.1	−3.8
Function6	4DL	♀ < 71.75 < ♂	70.7	72.1	−1.4
Function7	5DL	♀ < 56.77 < ♂	73.1	67.5	5.6
Breadth					
Function8	HB	♀ < 82.00 < ♂	83.2	85.7	−2.5
Function9	MHB	♀ < 101.55 < ♂	86.2	87.0	−0.8
Function10	WB	♀ < 58.43 < ♂	84.4	81.2	3.2
Function11	1D2B	♀ < 21.09 < ♂	79.6	81.8	−2.2
Function12	2D2B	♀ < 19.45 < ♂	81.4	81.2	0.2
Function13	3D2B	♀ < 19.63 < ♂	82.6	81.8	0.8
Function14	4D2B	♀ < 18.43 < ♂	86.2	83.1	3.1
Function15	5D2B	♀ < 16.41 < ♂	83.8	80.5	3.3
Function16	2D1B	♀ < 17.12 < ♂	79	78.6	0.4
Function17	3D1B	♀ < 17.23 < ♂	80.8	83.1	−2.3
Function18	4D1B	♀ < 15.91 < ♂	78.4	79.9	−1.5
Function19	5D1B	♀ < 14.56 < ♂	79.0	76.6	2.4
Thickness					
Function20	HT	♀ < 26.18 < ♂	76.0	82.5	−6.5
Function21	MHT	♀ < 45.64 < ♂	82.6	84.4	−1.8
Circumference					
Function22	HC	♀ < 197.05 < ♂	85.0	87.0	−2.0
Function23	MHC	♀ < 237.94 < ♂	88.6	89.6	−1.0
Function24	WC	♀ < 166.02 < ♂	83.2	88.3	−5.1
Function25	1D2C	♀ < 64.82 < ♂	83.2	79.9	3.3
Function26	2D2C	♀ < 61.55 < ♂	79.6	79.9	−0.3
Function27	3D2C	♀ < 62.99 < ♂	83.2	76.6	6.6
Function28	4D2C	♀ < 58.84 < ♂	80.2	76.6	3.6
Function29	5D2C	♀ < 51.64 < ♂	79.0	77.9	1.1

observed. In both male and female, finger proximal and distal joint breadth increases slightly as age range increases. The finger proximal and distal joint breadth of the 60 and 70 year olds were the greatest. On the other hand, those of the 20 and 30 year old subjects were the smallest. Among the variables related to circumference, the proximal joint circumference of all fingers also significantly differed according to age for both men and women, and tended to increase as the subject's age increased. The value was maximum for the 60 and 70 year old group, but minimum for the 20 and 30 year old group.

Table 6
Discriminant analysis results using stepwise method.

Variables	Coefficient		Canonical correlation	Wilk's lambda	Group centroids	Sectioning Point	Accuracy (%)			Cross-validated (%)
	Unstandardized	Standardized					Male	Female	Pooled	
PL	0.149	0.712	0.678	0.541	♂ 0.882	−0.038	80.8	85.7	83.2	81.9
1DL	0.159	0.593			♀ −0.957					
2DL	−0.155	−0.669								
3DL	0.105	0.472								
(constant)	−21.872									
MHB	0.160	0.786	0.772	0.404	♂ 1.158	−0.054	88.6	88.2	88.4	87.5
5D2B	0.275	0.319			♀ −1.265					
(constant)	−20.798									
HT	0.282	0.546	0.724	0.475	♂ 1.006	−0.043	88.0	86.4	87.2	86.3
MHT	0.181	0.707			♀ −1.091					
(constant)	−15.693									
MHC	0.065	0.774	0.791	0.374	♂ 1.239	−0.053	87.4	91.6	89.4	88.8
WC	0.034	0.343			♀ −1.344					
(constant)	−21.272									
PL	0.075	0.357	0.765	0.414	♂ 1.145	−0.004	91.0	88.9	90.0	89.1
MHT	0.131	0.511			♀ −1.228					
HB	0.112	0.459								
(constant)	−22.772									
2DL:4DL	31.34	1.000	0.128	0.984	♂ −0.123	0.006	67.1	40.3	54.2	54.2
(constant)	−29.89				♀ 0.134					

Table 7
Effect of age range and interaction effect on hand measurement by ANOVA.

Variables	20's–30's (a)		40's–50's (b)		60's–70's (c)		Range of age		Range of age × sex	
	Male (n = 76)	Female (n = 60)	Male (n = 66)	Female (n = 62)	Male (n = 25)	Female (n = 32)	F-value	P-value	F-value	P-value
HL	184.1	171.3	183.6	170.6	180.1	170.1	1.923	0.148	0.713	0.491
PL	105.6	98.0	104.8	96.8	104.0	97.3	1.820	0.164	0.307	0.736
1DL	61.3	55.7	61.8	56.7	59.7	55.8	3.328	0.037*	1.000	0.369
2DL	70.5	66.6	70.8	66.6	69.5	64.9	2.493	0.084	0.132	0.876
3DL	78.8	73.8	79.1	73.8	76.5	72.5	4.196	0.016*	0.417	0.659
4DL	74.2	69.2	75.0	69.8	72.8	68.4	3.297	0.038*	0.156	0.855
5DL	58.8	55.0	59.8	54.6	57.5	53.6	2.702	0.069	0.867	0.421
HB	85.7	77.2	86.2	78.0	86.0	79.7	2.372	0.095	1.582	0.207
MHB	107.0	94.8	108.0	95.4	106.4	98.4	2.146	0.119	4.173	0.010**
WB	60.9	54.3	62.2	55.5	61.1	57.3	7.163	0.001**	4.411	0.013*
1D2B	22.0	18.9	22.8	19.8	23.0	21.1	25.773	0.000***	3.496	0.032*
2D2B,	20.3	17.7	20.8	18.5	20.8	19.2	19.492	0.000***	3.579	0.029*
3D2B	20.4	17.8	21.0	18.7	21.1	19.4	24.735	0.000***	3.228	0.041*
4D2B	19.3	16.7	19.8	17.5	19.9	18.0	19.818	0.000***	2.132	0.120
5D2B	17.1	14.8	17.8	15.4	17.8	16.2	23.664	0.000***	2.623	0.074
2D1B,	17.7	15.5	18.4	16.3	18.5	17.1	28.201	0.000***	2.906	0.056
3D1B	17.9	15.5	18.5	16.4	18.7	17.2	29.154	0.000***	2.982	0.052
4D1B	16.5	14.4	17.1	15.0	17.2	15.9	24.643	0.000***	2.949	0.054
5D1B	15.2	12.9	15.7	13.7	15.9	14.8	36.668	0.000***	7.038	0.001***
HT	27.2	24.1	28.3	24.8	27.6	25.5	8.948	0.000***	2.479	0.085
MHT	49.2	41.0	49.1	42.7	49.1	43.5	2.452	0.088	2.945	0.054
HC	207.1	182.4	209.0	186.7	208.6	191.7	6.696	0.001**	2.958	0.053
MHC	252.0	220.4	254.1	223.5	250.3	228.3	2.199	0.113	3.634	0.028*
WC	175.9	153.3	176.4	156.7	174.2	160.8	2.191	0.113	4.314	0.014*
1D2C	67.5	58.8	69.5	60.9	69.6	65.5	24.444	0.000***	7.485	0.001***
2D2C	63.8	56.4	65.8	58.2	65.8	62.0	24.993	0.000***	6.059	0.003***
3D2C	64.9	57.5	67.5	59.6	68.0	63.5	32.784	0.000***	4.349	0.014*
4D2C	60.4	53.9	63.2	55.5	63.9	59.1	32.087	0.000***	3.315	0.038*
5D2C	53.0	47.1	55.8	48.9	55.7	51. 8	338.367	0.000***	4.339	0.014*

* $P < 0.05$ is significant, ** $P < 0.01$ is significant, *** $P < 0.001$ is significant.

No interaction effect was observed on the length related variables, but the interaction effect was shown in the breadth related variables (MHB, WB, 1D2B, 2D2B, 3D2B, and 5D1B), and the circumference related variables (MHC, WC, 1D2C, 2D2C, 3D2C, 4D2C, and 5D2C) with statistical significance. According to the result of the interaction effect, there was a tendency for the difference between the phalange breadth and circumference for both gender's to reduce in the 60 and 70 year old age group because female's phalange breadth and circumference increases as female's age increases (Fig. 2).

4. Discussion

The purpose of this study is to determine reliable sex discriminators with various hand parts and verifying age effect on gender estimation using hand dimensions. Some hand parts such as hand or wrist circumference showed higher accuracy; however, the breadth and circumference of the finger joints and the wrist were affected by the subject's age. All hand dimensions were greater with statistical significance in males than in females ($P < 0.001$). Therefore, all of the dimensions are possible sex

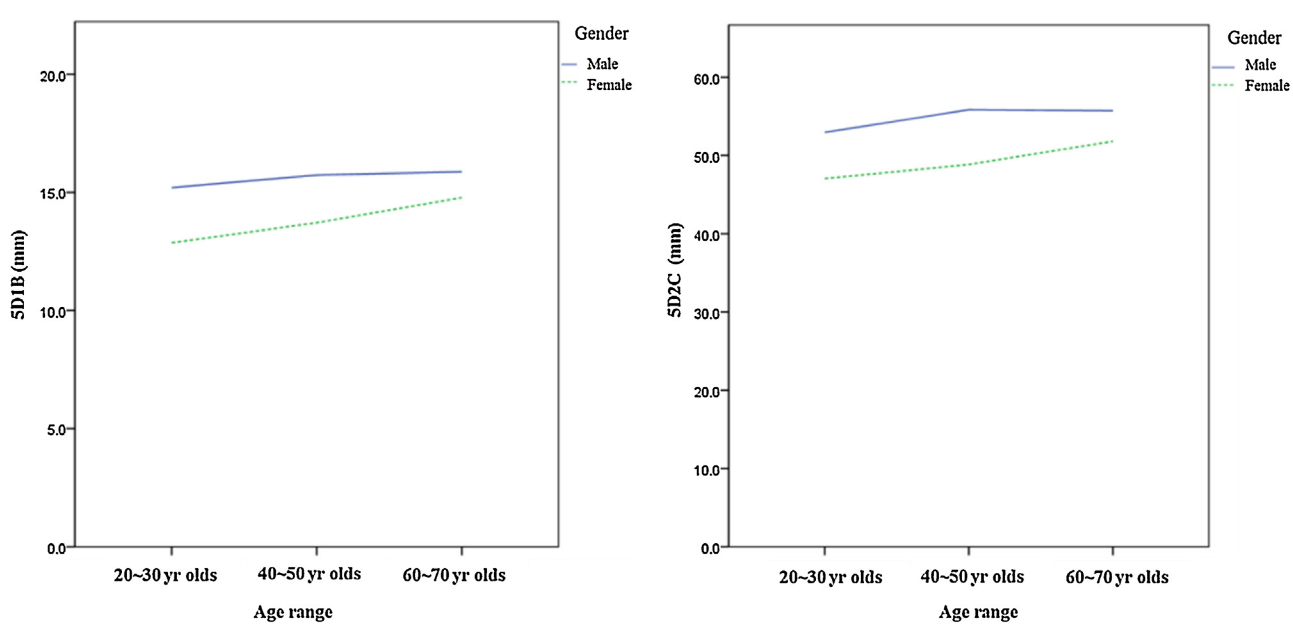

Fig. 2. Interaction effects on hand measurement according to age and sex.

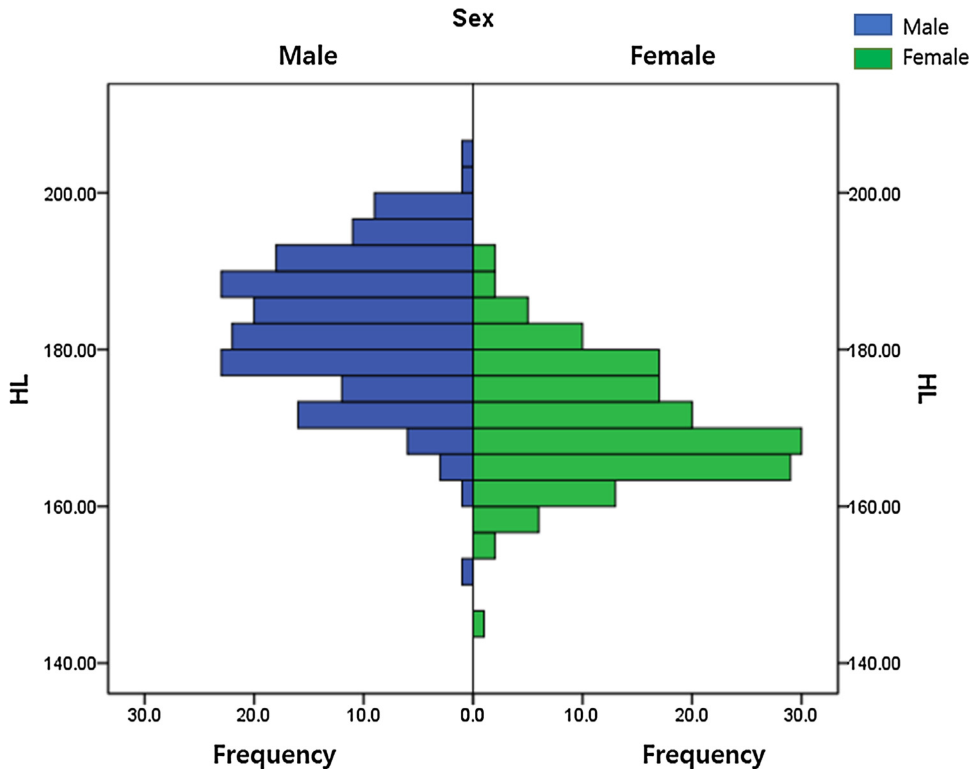

Fig. 3. Hand length is a relatively unreliable sex discriminator in Korean population (length dimension).

indicators [26]. The single variables that showed highest determination accuracy were the maximum hand circumference (88.6%), the maximum hand breadth (86.2%) for males, and the maximum circumference (89.6%) and wrist circumference (88.3%) for females. The result of the study confirmed that the breadth and lengths of hand and palms can be used for sex determination in accordance with the results of the previous study by Ishak that showed 94% and 91.5% accuracy using hand breadth and lengths of West Australian subjects, respectively [12]. Similar studies on Indian subjects showed 89% and 85% accuracy, respectively [11]. In the present study, the sex determination accuracy on Korean subjects based on hand breadth and length showed 85.7% and 76.8%, which are lower than the accuracy for Australian or Indian subjects. The possible reason is that the hand lengths of Koreans are 12 mm and 16 mm shorter than those of Australians and Indians for males, and 6 mm and 12 mm shorter for females, which resulted in greater overlapping of demarking points of males and females and consequently lowered the accuracy of sex determination of Korean subjects (Fig. 3). Therefore, for sex determination based on the hand dimensions of Korean subjects, using hand dimensions other than hand length such as hand breadth and circumference may improve the accuracy.

While the previous studies mainly determined sex based on the length and breadth of the hand, this study attempted to discriminate sex by utilizing the thickness and circumference of hand parts. The accuracy of the thickness and circumference of hand parts cannot be compared directly because there are few previous studies that applied breadth and circumference for sex determination. In this study, the breadth, circumferences, and thicknesses of hand parts generally showed higher accuracy than the lengths (Figs. 4 and 5). A similar trend was observed in the study of Mahakkanukrauh in which an attempt was made to distinguish sex based on the breadths and lengths of metacarpals and phalanges [21]. Moreover, the sex determination using the breadth and circumference of each finger joint, which were not considered in previous studies, showed a minimum accuracy of 76% and maximum accuracy of 89.4% as a sex discriminator. Thus, an improved sex determination accuracy will be achieved when the breadth of finger joints and palm, the thickness of hand, and the circumferences of wrist are considered in addition to hand length and breadth.

In this study, the dimensional changes of the hand parts in accordance with the age range, which was rarely studied in the previous studies, was examined. Among the length related variables, the length of the thumb, middle finger, and ring finger significantly differed according to the age range. These differences seem to occur because some subjects of the 40 and 50 year old age group have longer thumbs and middle fingers. No certain tendency was shown in the differences depending on the age range. In the variables related to phalange breadth, all the variables have significant difference except for hand breadth and maximum hand breadth. As age increases, the phalange joint breadth tended to increase slightly for both male and female. MHB, WB, and some measurements of phalange breadth showed interaction effects according to age and gender, where female's phalange breadth tended to increase as age increased. Therefore, due to this interaction effect, it is recommended that the phalange joint breadth should be used only as a reference for distinguishing the sex in the investigation for wide age range pooled suspects. Among the circumference related variables, the phalange joint circumference also tended to increase slightly for both male and female as age increased. An interaction effect according to age and gender was also observed. As age increases, female's phalange circumference increases, thus a tendency is shown whereby the difference between the male's phalange circumference and the female's phalange circumference was reduced. Thus, the phalange joint circumference related variables may yield lower prediction accuracy than the other variables when they are used for an older age group. Therefore, the variables such as HL, PL, HB, and MHT which are not affected by age or interaction effect are recommended to be used first in sex determination for a wide age range group.

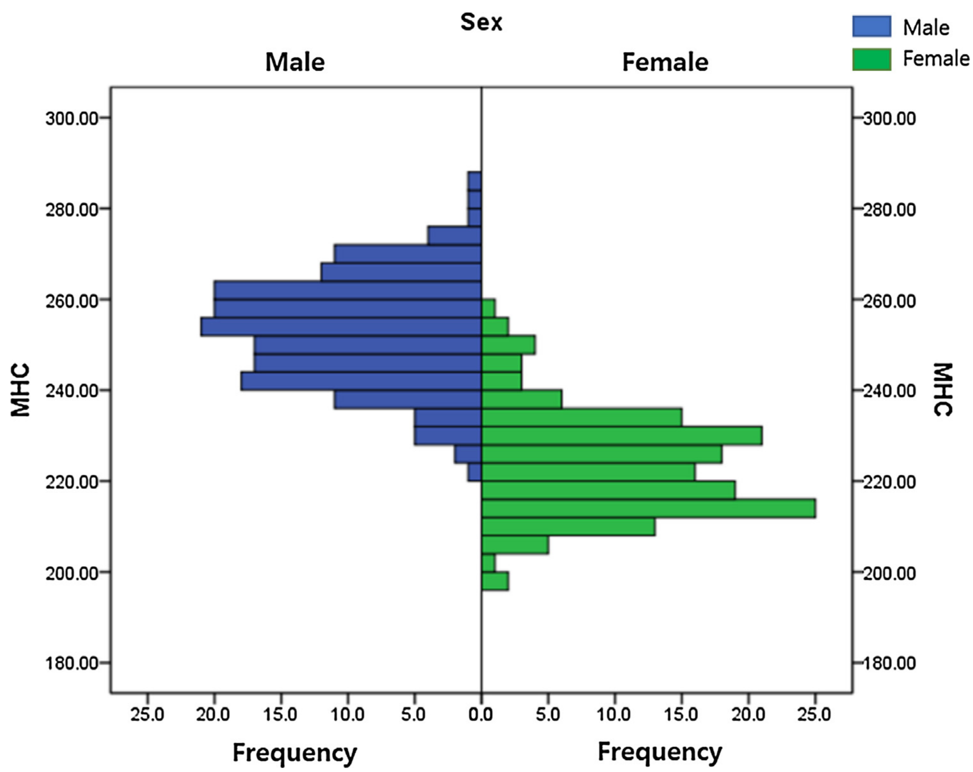

Fig. 4. Maximum hand circumference is a reliable discriminator in hand dimension (circumference dimension).

In this study, we also compared the predictive accuracy when using a variety of hand parts for each age range group (Table 8). Lower prediction accuracy was shown in the 60–70 year old age group than in the other age groups because there was a size difference in the phalange breadth (1D2B, 2D2B, 3D2B, 4D2B, 5D2B, 2D1B, 3D1B, 4D1B, and 5D1B) and phalange circumference-related variables (1D2C, 2D2C, 3D2C, 4D2C, and 5D2C) depending on age range. In accordance with the increasing age, the difference between the male's and female's phalange breadth and circumference reduced. Therefore, when examining the wide age group, it is

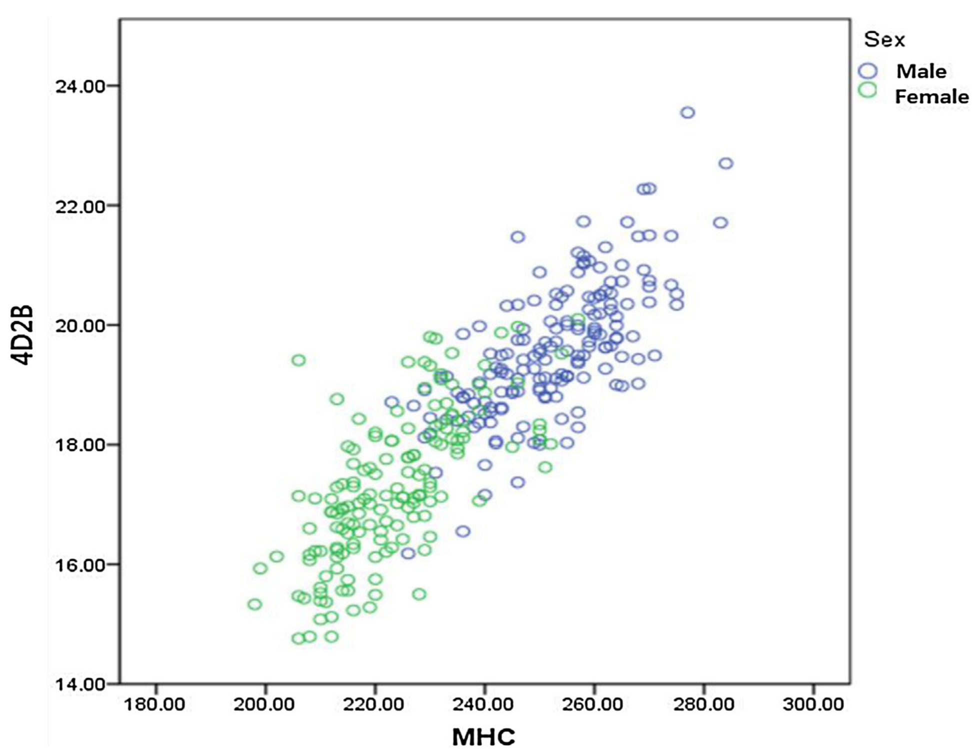

Fig. 5. Circumference and breadth of various hand dimensions can be used for sex estimation.

Table 8
Prediction accuracy (%) in each age group.

Variables	20's–30's			40's–50's			60's–70's		
	Male	Female	Pooled	Male	Female	Pooled	Male	Female	Pooled
HL	77.0	80.0	78.4	81.8	77.4	79.7	64.0	71.9	68.4
PL	75.0	81.4	77.8	80.3	82.3	81.3	72.0	84.4	78.9
1DL	78.9	76.7	77.9	75.8	74.2	75.0	68.0	77.4	73.2
2DL	65.8	68.3	66.9	68.2	69.4	68.8	72.0	71.9	71.9
3DL	65.8	73.3	69.1	72.7	79.0	75.8	60.0	62.5	61.4
4DL	68.4	74.6	71.1	72.7	75.8	74.2	72.0	68.8	70.2
5DL	65.8	61.7	64.0	81.5	69.4	75.6	72.0	65.6	68.4
HB	85.3	86.7	85.9	87.9	87.1	87.5	68.0	78.1	73.7
MHB	86.8	91.5	88.9	90.9	91.8	91.3	72.0	78.1	75.4
WB	84.2	81.7	83.1	90.9	88.7	89.8	76.0	71.9	73.7
1D2B	78.9	90.0	83.8	87.9	85.5	86.7	68.0	81.3	75.4
2D2B	89.5	86.7	88.2	86.4	87.1	86.6	72.0	75.0	73.7
3D2B	89.5	86.7	88.1	86.4	83.9	85.2	68.0	81.3	75.4
4D2B	92.1	83.3	88.2	90.9	85.5	88.3	72.0	75.0	73.7
5D2B	88.2	83.3	86.0	90.9	75.5	88.2	80.0	68.8	73.7
2D1B	76.3	86.7	80.9	89.4	85.5	87.5	72.0	71.9	71.9
3D1B	80.3	88.3	83.8	84.8	88.7	86.7	72.0	75.0	73.7
4D1B	81.6	85.0	83.1	84.8	85.5	85.2	64.0	71.9	68.4
5D1B	86.8	86.7	86.8	83.3	83.9	83.6	72.0	75.0	73.7
HT	78.9	88.3	83.1	83.3	87.1	85.2	60.0	68.8	64.9
MHT	86.8	86.7	86.8	86.4	82.3	84.4	76.0	84.4	80.7
HC	89.5	90.0	89.7	90.9	88.7	89.8	76.0	87.5	82.5
MHC	89.5	95.0	91.9	92.4	90.3	91.4	72.0	84.4	78.9
WC	84.2	85.0	84.6	87.9	88.7	88.3	76.0	90.6	84.2
1D2C	80.3	90.0	84.6	84.8	88.7	86.7	52.0	62.5	57.9
2D2C	80.3	90.0	84.5	90.9	87.1	89.1	76.0	71.9	73.7
3D2C	81.6	88.3	94.6	87.9	85.5	86.7	60.0	75.0	68.4
4D2C	73.7	81.7	77.2	87.9	87.1	87.5	72.0	75.0	73.7
5D2C	80.3	86.7	83.1	84.8	88.7	86.7	76.0	75.0	75.4

possible to provide higher prediction accuracy in even age group by using variables such as HL, PL, HB, and MHT. Using these variables, the discriminant analysis yielded higher accuracy for the 20–30 year olds (90.3%), 40–50 year olds (92.2%) and 60–70 year olds (82.5%), respectively.

The performance of sex determination using the hand anthropometrics seems to differ between different nationalities. Although Manning and Kanchan proposed a method based on a 2D to 4D ratio and confirmed its reliability [17] [27], the method showed only 54.2% accuracy in the present study, which is not higher than the other indicators. This study result is similar to the result of Voracek's study (Table 6) [19]. The reason that hand lengths or 2D:4D ratio-based sex determination accuracy in Korean subjects appeared lower than the other ethnic groups may be associated with the nationalities characteristics [15]. Overall, the Korean subjects showed short hand lengths and breadths, and small differences of 2D and 4D lengths between male and female groups compared to the West Australian and Indian subjects. Thus, the ethnic difference may have an impact on the accuracy of the methods proposed in the previous studies.

The result of this study is obtained by measuring only the Korean hand dimensions, who were born and raised in Korea. Therefore, when applied to other ethnic groups, the sectioning points derived in this study may not provide high accuracy because each ethnic group has different hand size variations. The investigation on the hand dimensions of different age groups is in the cross-sectional case study. In order to generalize the aging effect on hand parts, more longitudinal case studies need to be conducted.

5. Conclusion

This study on Korean subjects confirmed that the length, breadth, thickness and circumference of various parts of the hand can be used for more accurate sex determination. In addition to the length and breadth, which have mainly carried out in previous studies, been circumference and thickness can especially be used as reliable sex discriminators, however the breadth and circumference of finger joints and wrist only can be served as references in wide age range groups due to the effect of age on hand size. In the previous studies, as the subjects were mainly in their 20s, they were unable to confirm the effect of age on the measurements of hand parts. In the present study, the age effect on the hand parts was possible to be verified by examining wide age range groups. The results of this study showed that first the utilized hand dimensions of Korean subjects for sex determination may serve as a useful reference for future forensic studies based on the hand anthropometrics.

Acknowledgment

This study was supported by the National Research Foundation of Korea (Grant Numbers: NRF-2014R1A1A1003446) and engineering research institute at the college of engineering in Seoul National University.

References

[1] C. Cattaneo, E. Baccino, A call for forensic anthropology in Europe, Int. J. Legal Med. 116 (2002) N1–N2.
[2] T. Kanchan, K. Krishan, Anthropometry of hand in sex determination of dismembered remains-A review of literature, J. Forensic Legal Med. 18 (2011) 14–17.
[3] C. Cattaneo, Forensic anthropology: developments of a classical discipline in the new millennium, Forensic Sci. Int. 165 (2007) 185–193.
[4] K.R. Patil, R.N. Mody, Determination of sex by discriminant function analysis and stature by regression analysis: a lateral cephalometric study, Forensic Sci. Int. 147 (2005) 175–180.
[5] C. Villa, M.N. Hansen, J. Buckberry, C. Cattaneo, N. Lynnerup, Forensic age estimation based on the trabecular bone changes of the pelvic bone using post-mortem CT, Forensic Sci. Int. 233 (2013) 393–402.
[6] C. Champod, C.J. Lennard, P. Margot, M. Stoilovic, Fingerprints and other Ridge Skin Impressions, CRC Press, 2004.
[7] N.M. Egli, C. Champod, P. Margot, Evidence evaluation in fingerprint comparison and automated fingerprint identification systems—Modelling within finger variability, Forensic Sci. Int. 167 (2007) 189–195.

[8] R. DeSilva, A. Flavel, D. Franklin, Estimation of sex from the metric assessment of digital hand radiographs in a Western Australian population, Forensic Sci. Int. 244 (2014) 314.e1–314.e7.
[9] T. Kanchan, K. Krishan, A. Sharma, R.G. Menezes, A study of correlation of hand and foot dimensions for personal identification in mass disasters, Forensic Sci. Int. 199 (2010) 112, e1-. e6.
[10] K. Krishan, T. Kanchan, A. Sharma, Sex determination from hand and foot dimensions in a North Indian population, J. Forensic Sci. 56 (2011) 453–459.
[11] T. Kanchan, P. Rastogi, Sex determination from hand dimensions of North and South Indians, J. Forensic Sci. 54 (2009) 546–550.
[12] N-I. Ishak, N. Hemy, D. Franklin, Estimation of sex from hand and handprint dimensions in a Western Australian population, Forensic Sci. Int. 221 (2012) 154, e1-. e6.
[13] V. Jowaheer, A.K. Agnihotri, Sex identification on the basis of hand and foot measurements in Indo-Mauritian population–a model based approach, J. Forensic Legal Med. 18 (2011) 173–176.
[14] D.T. Case, A.H. Ross, Sex determination from hand and foot bone lengths*, J. Forensic Sci. 52 (2007) 264–270.
[15] K.E. Aboul-Hagag, S.A. Mohamed, M.A. Hilal, E.A. Mohamed, Determination of sex from hand dimensions and index/ring finger length ratio in Upper Egyptians, Egypt. J. Forensic Sci. 1 (2011) 80–86.
[16] R. Trivers, J. Manning, A. Jacobson, A longitudinal study of digit ratio (2D:4D) and other finger ratios in Jamaican children, Hormones Behav. 49 (2006) 150–156.
[17] J.T. Manning, A. Stewart, P.E. Bundred, R.L. Trivers, Sex and ethnic differences in 2nd to 4th digit ratio of children, Early Human Dev. 80 (2004) 161–168.
[18] K. Krishan, T. Kanchan, N. Asha, S. Kaur, P.M. Chatterjee, B. Singh, Estimation of sex from index and ring finger in a North Indian population, J. Forensic Legal Med. 20 (2013) 471–479.
[19] M. Voracek, Why digit ratio (2D:4D) is inappropriate for sex determination in medicolegal investigations, Forensic Sci. Int. 185 (2009) e29–e30.
[20] D.A. El Morsi, A.A. Al Hawary, Sex determination by the length of metacarpals and phalanges: X-ray study on Egyptian population, J. Forensic Legal Med. 20 (2013) 6–13.
[21] P. Mahakkanukrauh, P. Khanpetch, S. Prasitwattanseree, D.T. Case, Determination of sex from the proximal hand phalanges in a Thai population, Forensic Sci. Int. 226 (2013) 208–215.
[22] İ. Ali, N. Arslan, Estimated anthropometric measurements of Turkish adults and effects of age and geographical regions, Int. J. Indust. Ergon. 39 (2009) 860–865.
[23] E. Perissinotto, C. Pisent, G. Sergi, F. Grigoletto, G. Enzi, Anthropometric measurements in the elderly: age and gender differences, Br. J. Nutr. 87 (2002) 177–186.
[24] S.J. Ulijaszek, D.A. Kerr, Anthropometric measurement error and the assessment of nutritional status, Br. J. Nutr. 82 (1999) 165–177.
[25] M.R. Dayal, M.A. Spocter, M.A. Bidmos, An assessment of sex using the skull of black South Africans by discriminant function analysis, HOMO – J. Comp. Hum. Biol. 59 (2008) 209–221.
[26] D-I. Kim, Y-S. Kim, U-Y. Lee, S-H. Han, Sex determination from calcaneus in Korean using discriminant analysis, Forensic Sci. Int. 228 (2013) 177.e1–177.e7.
[27] T. Kanchan, G.P. Kumar, R.G. Menezes, Index and ring finger ratio—A new sex determinant in south Indian population, Forensic Sci. Int. 181 (2008) 53.e1–53.e4.