JOURNAL OF FORENSIC SCIENCES

J Forensic Sci, September 2013, Vol. 58, No. 5
doi: 10.1111/1556-4029.12192
Available online at: onlinelibrary.wiley.com

PAPER

ANTHROPOLOGY

Yaming Cui,[1,2] *B.Sc. and Jizong Zhang,*[3] *Ph.D.*

Stature Estimation from Foramen Magnum Region in Chinese Population*

ABSTRACT: Estimation of stature from body parts plays a vital role in identifying the dead. This study focused on dimensions of the foramen magnum region and examined the relationship between stature and the dimensions of the foramen magnum region in northern and southern Chinese populations. Measurements were taken on the skulls of 276 individuals (all male). Data on 48 individuals from northern China and 140 from southern China were used for further stature reconstruction of the above two populations in China. Statistical analyses indicate that bilateral variation is insignificant for all measurements except maximum length of condyle in the southern Chinese population ($p < 0.01$) and that the northern and southern populations differ significantly only in the minimum distance between condyles. Linear and multiple regression equations for stature estimation were established. The correlation coefficients between stature and the various measurements differed between the northern and southern Chinese populations.

KEYWORDS: forensic science, foramen magnum region, stature estimation, identification, forensic anthropology

Stature is an important parameter in forensic analysis because of its significant position in personal identification. A variety of methods, including both anatomical and mathematical ones, have been used to estimate living stature from skeletal remains. The anatomical methods involve summing up the proper measurements of the skull, vertebrae, femur, tibia, talus, and calcaneus. The mathematical method, which is easier to carry out and therefore more commonly used, is based on establishing equations that reflect linear relationships between stature and the dimensions of various individual bones. Measurements of limb bones, especially the long bones of lower limbs (femur, tibia, and fibula), are the most widely used parameters for stature estimation because correlation coefficients with respect to stature are greater for measurements of these bones than for measurements of other bones. Trotter and Gleser published regression formulae for long bones of American whites and blacks (1). Many authors have successfully estimated stature from isolated long and other bones. Badkur and Nath (2) proposed regression equations from ulna. Formicola and Franceschi (3) published a series of estimation equations from long bones of early Holocene European sample. Krogman made summarization of the work of several previous researchers who contributed to stature estimation from long bones (4).

Despite the significant correlations between limb long bone measurements and stature, it is necessary to establish regression formulae using other elements of the skeleton, because there are circumstances in which the limb bones mentioned above are not available in criminal cases. A broader range of regression formulae is also indispensible in paleoanthropological studies, which may involve attempts to reconstruct stature from fragmentary remains. More stature estimation researches have focused on cranial and facial dimensions for the significance of individual identification of skull. Krishan and Kumar (5) estimated stature of samples from North India from cephalo-facial dimensions. Sahni et al. (6) estimated stature from facial measurements in northwest Indians.

The foramen magnum region involves the foramen magnum, occipital condyles of both sides, and external hypoglossal canal openings and has never been included in former research. The purpose of this study is to analyze the anthropometric relationship between the dimensions of the foramen magnum region and stature and to establish regression equations to estimate stature from foramen magnum region measurements. The motivation for investigating this issue was the scarcity in the literature of attempts to reconstruct stature based on the cranial base region.

The land area of China is large. Scholars agree that a geographic demarcation between northerners and southerners exists in China, which brings about corresponding differences in the physical and genetic characteristics of residents of the two regions. The dividing line is drawn according to the location of Qinling Mountains and the Huai River. The stature regression equations involving different body parts have been demonstrated to vary among populations. Therefore, separate foramen magnum region regression equations for northern and southern Chinese are also provided.

Materials and Methods

The sample used in this study to establish regression equations consists of 276 individuals (all male) whose ages at the time of death ranged from 17 to 77, among which only 31 samples were 60–80, so the shrinking of stature in elderly individuals was not

[1]Key Laboratory of Evolutionary Systematics of Vertebrates, CAS at the Institute of Vertebrate Paleontology and Paleoanthropology (IVPP), Chinese Academy of Sciences (CAS), Beijing 100044, China.

[2]Graduate University of Chinese Academy of Science, Beijing 100039, China.

[3]Institute of Forensic Science of Ministry of Public Security, Beijing 100038, China.

*Funded by Key Laboratory of Evolutionary Systematics of Vertebrates, CAS at the Institute of Vertebrate Paleontology and Paleoanthropology (IVPP), Chinese Academy of Sciences (CAS).

Received 18 Aug. 2011; and in revised form 16 April 2012; accepted 4 Aug. 2012.

© 2013 American Academy of Forensic Sciences

TABLE 1—*Description and grouping method of the samples.*

Sample Groups	Sample Number
Samples for generating the equations (276)	
Northern Chinese	48
Southern Chinese	140
Excluded samples	88
Samples for blind test	49
Total	325

taken into account. An additional set comprised of 49 samples were put aside for blind test (not included in the 276 individuals). The samples were collected during the 1980s. These skeletal remains were obtained from the collection of Institute of Forensic Science of Ministry of Public Security, P.R.C. in Beijing. The collection was drawn from nine Chinese provinces: Jiangxi, Yunnan, Guizhou, Guangxi, Anhui, Shandong, Hebei, Qinghai, and Jilin. Crania with obvious pathologies such as signs of fracture, broken edges, basilar invagination, or atlanto-occipital fusion were excluded. Neither rickets nor humpbacks were recorded. The sex, birthplace, and stature of each individual in the collection were recorded prior to death.

Specimens from Jilin, Qinghai, Hebei, and Shandong provinces were classified as northern Chinese and those from Jiangxi, Guizhou, Yunnan, and Guangxi as southern Chinese. By these criteria, 48 individuals in the sample were northerners and 140 were southerners. Eight-eight samples were excluded. (The 14 samples that came from Anhui Province were excluded because the line of demarcation between northern and southern China passes through this province. The other 74 samples were also excluded because their birthplaces had not been recorded.) (Table 1).

Measurements of Foramen Magnum Region

On each cranium, 10 parameters were measured using sliding calipers. These were maximum length of occipital condyle (LC) for both sides, maximum width of condyle (WC) for both sides, maximum bicondylar breadth (BCB), minimum distance between condyles (MnD), maximum interior distance between condyles (MxID), distance between external hypoglossal canal openings (DEHC), maximum length of foramen magnum (FML), and maximum width of foramen magnum (FMB). An 11th parameter called area of foramen magnum (AFM) was the product of FML and FMB, representing the area of the foramen magnum (The true area of foramen magnum is AFM' = 4πFML $\times$ FMB, if we consider it as an ellipse. Here, the coefficient "4π" is left out, because it does not affect the linear relation between the area of foramen magnum and stature). Descriptions of the parameters are given, with citations, in Table 2.

The data were entered separately for northern and southern Chinese into a Microsoft Excel 2010 spreadsheet (Microsoft, Redmond, WA) and analyzed using the Statistical Product and Service Solutions (SPSS 18.0; released 2009, PASW Statistics for Windows, Version 18.0; SPSS Inc., Chicago, IL) program. Descriptive statistics, including minimums, maximums, means, and standard deviations, were obtained for each of the 11 foramen magnum parameters.

Simple regression analysis was performed to regress the various foramen magnum region measurements for each individual against stature for both northerners and southerners. A multiple regression analysis in which several combinations of the variables were regressed against stature for both populations was also carried out. From these analyses, the correlation coefficient (r) and standard error of the estimate (SEE) for each regression equation were calculated.

Results

Descriptive Statistics

Basic descriptive statistics for each of the 10 foramen magnum measurements used in this study except AFM for all crania are presented in Table 3.

Correlation Analyses

Table 4 presents the correlation coefficients between stature and foramen magnum region measurements for all samples. All of the measurements except maximum width of left condyle

TABLE 2—*Descriptions of the variables.*

Measurements (Abbreviation)	Description	Reference
Maximum length of condyle (LC)	Maximum length of the articular facets of the left and right occipital condyles, measured from the most posterior projecting point of the articular surface as shown in Fig. 1.	Droessler (7) Holland (8) Westcott and Moore Jansen (9) Gapert (13)
Maximum width of condyle (WC)	Maximum width of the articular facets of the left and right occipital condyles, measured approximately perpendicular to the LC and recorded at the widest part of the facet as shown in Fig. 1.	Droessler (7) Holland (8) Westcott and Moore Jansen (9) Gapert (13)
Maximum bicondylar breadth (BCB)	Distance between the most lateral parts of the left and right articular facets as shown in Fig. 2.	Holland (8) Westcott and Moore Jansen (9) Gapert (13)
Minimum distance between condyles (MnD)	Minimum distance between the anterior borders of the left and right articular facets, measured as shown in Fig. 3.	—
Maximum interior distance between condyles (MxID)	Maximum distance between the posterior borders of the left and right articular facets, measured as shown in Fig. 2.	—
Distance between external hypoglossal canal openings (DEHC)	Distance between the left and right external hypoglossal canal openings, measured between the medial edges of the openings as shown in Fig. 3.	Gapert (13)
Maximum length of foramen magnum (FML)	Distance between opisthion and endobasion, measured as shown in Fig. 4.	Brauer (10), M7
Maximum width of foramen magnum (FMB)	Maximum width of foramen magnum, measured perpendicular to FML as shown in Fig. 4.	Brauer (10), M16
Area of foramen magnum (AFM)	The product of FML and FMB.	

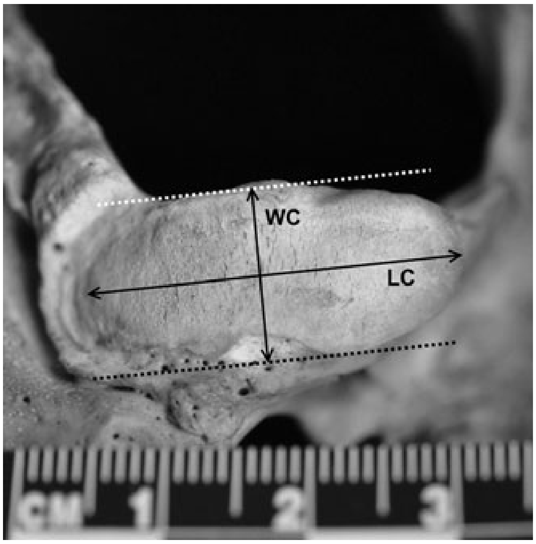

FIG. 1—*Occipital condyle showing maximum length of occipital condyle (LC) and maximum width of occipital condyle (WC).*

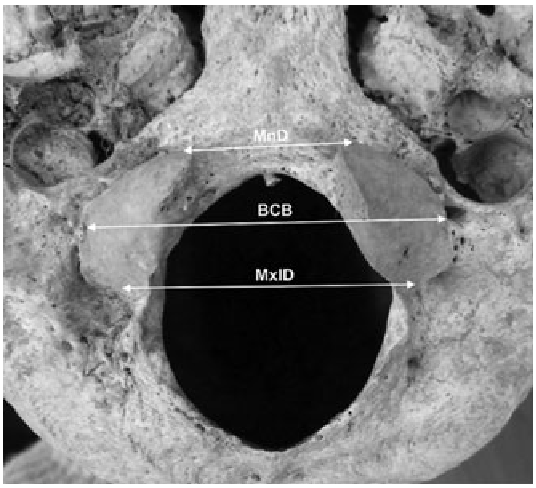

FIG. 2—*Occipital condyles showing maximum bicondylar breadth (BCB), minimum distance between condyles (MnD), and maximum interior distance between condyles (MxID).*

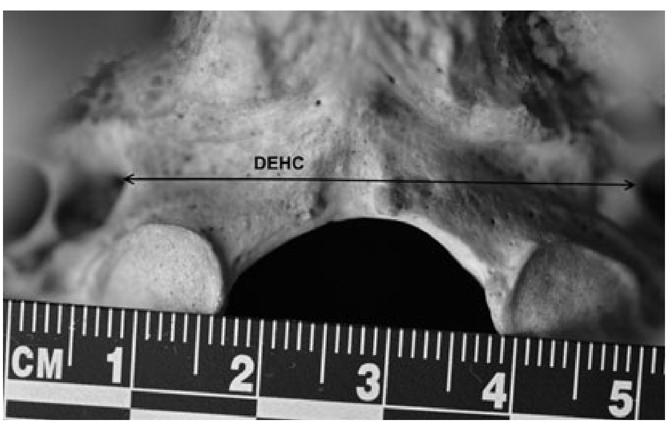

FIG. 3—*Cranial base showing distance between external hypoglossal canal openings (DEHC).*

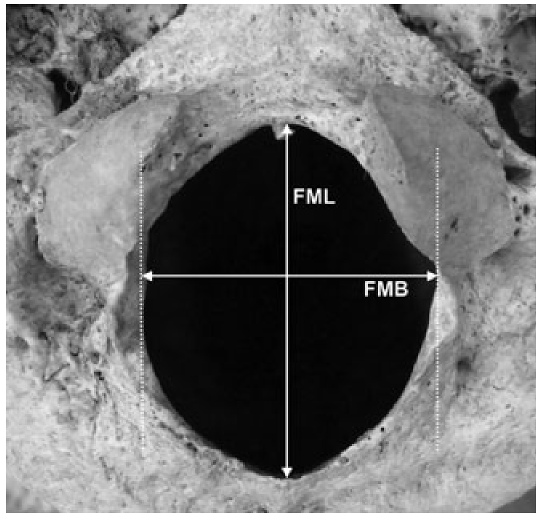

FIG. 4—*Foramen magnum showing length of foramen magnum (FML) and width of foramen magnum (FMB).*

exhibit statistically significant correlation coefficients with stature ($p < 0.05$). The highest correlation pertains to external hypoglossal canal distance ($r = 0.325$) and the lowest to maximum width of left condyle ($r = 0.135$). These correlation coefficients are lower than those calculated for dimensions of lower limb long bones. Variables whose correlation coefficients are lower than 0.2 are excluded from further regression analysis.

Regression Analyses

Table 5 contains information about the linear and multiple regressions for estimation of stature from those measurements of foramen magnum region whose correlation coefficients are higher than 0.2 for all samples. The regression equations, correlations, *F*-values, significance, and SEE for all the samples are listed.

Univariate—The variable that shows the highest correlation with respect to stature is external hypoglossal canal distance ($R = 0.34$) and the variable with the lowest is area of foramen magnum ($R = 0.26$), results consistent with the correlation coefficients obtained previously. SEE for the equations as presented in the upper part of Table 4 range from 6.96 to 7.18 cm.

Multivariate—Different combinations of parameters that best estimate skeletal height are presented in the lower part of

TABLE 3—*Measurements of foramen magnum region (cm).*

Variables ($n = 276$)	Minimum	Maximum	Average	Standard Deviation
LC(L)	1.17	3.53	2.35	0.28
LC(R)	1.07	3.39	2.32	0.29
WC(L)	0.78	1.71	1.19	0.16
WC(R)	0.76	1.62	1.18	0.16
BCB	3.85	6.05	4.89	0.36
MnD	1.06	4.85	1.92	0.36
MxID	1.14	5.53	4.04	0.40
DEHC	2.8	4.55	3.31	0.24
FML	2.32	4.51	3.57	0.26
FMB	2.51	4.03	3.03	0.22

TABLE 4—*Correlations between stature and foramen magnum region measurements.*

	LC(L)	LC(R)	WC(L)	WC(R)	BCB	MnD	MxID	DEHC	FML	FMB	AFM
Pearson correlation	0.186*	0.166*	0.135	0.167*	0.283**	0.157*	0.197**	0.325**	0.171*	0.287**	0.223**
Significance (two-tailed)	0.014	0.027	0.074	0.027	0	0.04	0.008	0	0.022	0	0.003

*Significant at 0.05 level.
**Significant at 0.01 level.

TABLE 5—*Linear regression equations for estimation of stature (cm) from measurements of foramen magnum region (cm).*

	Regression Equation	*R*	*F*	Sig.	SEE
Univariate equations	S = 132.483 + 6.095 BCB	0.29	17.357	0	7.09
	S = 127.118 + 10.633 DEHC	0.34	25.259	0	6.96
	S = 132.304 + 9.828 FMB	0.31	19.79	0	7.03
	S = 147.452 + 1.360 AFM	0.26	12.571	0.001	7.18
Multivariate equations	S = 132.676 + 1.03 FML + 8.53 FMB	0.29	7.948	0	7.05
	S = 117.136 + 3.515 BCB + 8.545 DEHC	0.37	13.195	0	6.90
	S = 123.214 + 10.099 DEHC + 1.588 FML	0.34	12.922	0	6.96
	S = 115.651 + 8.488 DEHC - 1.141 FML + 7.453 FMB	0.4	11.852	0	6.83
	S = 110.149 + 1.994 BCB + 7.916 DEHC + 5.368 FMB	0.4	12.01	0	6.84
	S = 112.287 + 2.206 BCB + 8.118 DEHC −1.575 FML + 5.955 FMB	0.4	9.112	0	6.85

Table 4. The correlation values for the multivariate regression equations are generally slightly higher than those for the univariate regression equations, ranging from 0.29 to 0.4. The SEE for these equations are consistently lower than those for the univariate equations, ranging from 6.83 to 7.05 cm.

Table 6 presents statistics on the bilateral differences in maximum occipital condyle length and width in northern and southern Chinese. Maximum condyle length exhibits statistically significant bilateral differences in the southern Chinese population ($p < 0.01$). No statistically significant bilateral differences were found for maximum condyle length in either population or maximum condyle width in the northern Chinese population. However, values of all four variables were higher on average for the left condyle than for the right.

Table 7 presents basic descriptive statistics for each anatomical parameter in both northern and southern Chinese separately, as well as *t*-values and significance levels for comparisons between northerners and southerners. The results reveal no statistically significant differences between northern and southern Chinese populations for any measurement except stature ($p < 0.001$) and distance between external hypoglossal canal openings ($p < 0.05$).

When correlation coefficients between stature and foramen magnum region measurements are calculated separately for northern and southern Chinese, notable differences emerge. The highest correlation coefficient among northerners pertains to maximum width of foramen magnum ($r = 0.4$) and the lowest to maximum length of foramen magnum ($r = -0.013$). The highest correlation coefficient among southerners likewise pertains to maximum width of foramen magnum ($r = 0.328$), but the lowest pertains to maximum breadth of condyle ($r = 0.124$). The correlation coefficients for northerners are higher than, or nearly the same as, those for the total sample with respect to most variables, the one exception being maximum length of foramen magnum.

Table 8 lists the linear and Table 9 the multiple, regression equations for estimation of stature from measurements of foramen magnum region for northern and southern Chinese populations. It is observed that the multivariate regression equations are associated with lower SEE values than are the univariate regression equations. This could be interpreted as an indication that multiple regression equations provide better estimates of stature.

Tests

Inter- and Intra-Observer Variability Tests—As the measurements involved in this paper have never been applied as parameters of stature estimation, it is necessary to perform inter- and intra-observer variability tests to check the credibility of these measurements.

The tests were performed on 15 adult modern human skulls housed at IVPP herbarium. Measurements were carried out by other other coworkers after reading the descriptions and pictures in this paper to evaluate intra-observer variability and repeated twice with a 15-day interval by the same observers to assess inter-observer variability. Data for each measurement were analyzed separately. For the inter- and intra-observer reliability, the intraclass correlation coefficient (ICC2, 1) was calculated. Data analysis was done using SPSS 18.0.

TABLE 6—*Bilateral differences in measurements (cm) of foramen magnum region in northern southern Chinese.*

	Variables	Average	Standard Deviation	*t*-Value	Sig. (Two-Tailed)
Northern Chinese	LC(L) – LC(R)	0.03262	0.24561	0.861	0.394
	WC(L) – WC(R)	0.02047	0.13668	0.982	0.332
Southern Chinese	LC(L) – LC(R)	0.05653	0.24115	2.813	0.006**
	WC(L) – WC(R)	0.0014	0.14372	0.116	0.908

**Significant at 0.01 level.

TABLE 7—*Descriptive statistics for stature in northern and southern Chinese (cm).*

	Northerners				Southerners					
Variable	Minimum	Maximum	Average	Standard Deviation	Minimum	Maximum	Average	Standard Deviation	*t*	Sig. (Two-Tailed)
Stature	146.2	180	165.22	7.55	135	183	161.01	7.08	3.297	0.001*
LC(L)	1.68	3.03	2.31	0.28	1.17	2.89	2.31	0.26	−0.052	0.959
LC(R)	1.71	2.78	2.27	0.26	1.07	2.86	2.24	0.28	0.641	0.524
WC(L)	0.82	1.66	1.22	0.15	0.8	1.53	1.17	0.14	1.792	0.075
WC(R)	0.92	1.54	1.20	0.14	0.76	1.62	1.17	0.16	1.05	0.295
BCB	4.31	5.84	4.94	0.36	4.05	5.65	4.86	0.32	1.378	0.17
MnD	1.28	2.6	1.98	0.30	1.17	4.85	1.95	0.40	0.466	0.642
MxID	3.59	4.76	4.12	0.31	1.14	5.53	4.03	0.43	1.236	0.218
DEHC	2.88	4.11	3.37	0.26	2.81	4.38	3.27	0.22	2.372	0.019*
FML	3.08	4.22	3.5662	0.26278	2.32	4.51	3.56	0.25	−0.03	0.976
FMB	2.57	4.03	3.0596	0.26439	2.62	3.68	3.04	0.22	0.454	0.65

*Significant at 0.01 level.

TABLE 8—*Univariate linear regression equations for estimation of stature from measurements of foramen magnum region in northern and southern Chinese (cm).*

	Number	Estimation Equation	*R*	*F*	Sig.	SEE
Northern Chinese	U-N-1	S = 145.700 + 16.265 WC(R)	0.3	4.17	0.048	7.48
	U-N-2	S = 131.151 + 6.936 BCB	0.33	5.25	0.027	7.34
	U-N-3	S = 125.331 + 11.750 DEHC	0.39	7.7	0.008	7.23
	U-N-4	S = 127.582 + 12.265 FMB	0.4	8.37	0.006	7.19
Southern Chinese	U-S-1	S = 132.181 + 5.946 BCB	0.27	11.2	0.001	6.85
	U-S-2	S = 131.759 + 8.624 DEHC	0.29	12.4	0.001	6.8
	U-S-3	S = 137.797 + 6.524 FML	0.23	7.7	0.006	6.91
	U-S-4	S = 128.772 + 10.613 FMB	0.33	16.71	0	6.71
	U-S-5	S = 149.063 + 1.112 AFM	0.25	9.69	0.002	6.84

TABLE 9—*Multivariate linear regression equations for estimation of stature from measurements of foramen magnum region in northern and southern Chinese (cm).*

	Number	Estimation Equation	*R*	*F*	Sig.	SEE
Chinese northerners	M-N-1	S = 116.441 + 4.607 BCB +7.834 DEHC	0.44	4.68	0.015	6.88
	M-N-2	S = 138.745 + 13.668 DEHC −5.481 FML	0.45	5.2	0.01	6.91
	M-N-3	S = 106.433 + 9.540 DEHC +8.715 FMB	0.5	7.08	0.002	6.68
	M-N-4	S = 130.053 + 6.426 BCB +8.927 DEHC −7.376 FML	0.5	4.27	0.011	6.71
	M-N-5	S = 93.304 + 3.968 BCB +9.415 DEHC +16.282 FMB −2.648 AFM	0.55	4.14	0.007	6.54
Chinese southerners	M-S-1	S = 117.012 + 5.807 DEHC +8.234 FMB	0.37	10.89	0	6.62
	M-S-2	S = 119.012 + 3.382 BCB +8.415 FMB	0.36	10.11	0	6.67
	M-S-3	S = 114.472 + 2.207 BCB +4.793 DEHC +5.620 FMB +0.285 AFM	0.38	5.65	0	6.66
	M-S-4	S = 111.259 + 2.206 BCB +4.766 DEHC +6.589 FML +0.970 FMB	0.38	5.66	0	6.66

The results of this test indicate that the use of these measurements in forensic practice could be stable. The average scores of the measurements are good. But the scores of width of condyle of both sides (WC) and maximum interior distance between condyles (MxID) are not so reliable as the other measurements (Table 10).

Test of the Accuracy of Stature Estimation from the Dimensions of the Foramen Magnum Region—Further, to test the reliability of the formulae, 49 samples were put aside in advance to perform a blind test of the 10 regression formulae in Table 5. The results of the test are listed in Table 11. Depending on the regression formula, the magnitude of the difference between actual and estimated stature is < 5 cm in 55–69% of all cases and < 7 cm in 67–80% of all cases. The results of these tests show that the 10 proposed equations for estimating stature based on the foramen magnum region are of practical value.

The relationship between dimensions of foramen magnum and occipital condyle has not been previously studied. According to

TABLE 10—*Inter- and intra-observer variability tests for the measurements of foramen magnum region (cm).*

	Inter-Observer (ICC2, 1)	Intra-Observer (ICC2, 1)
LC(L)	0.81	0.81
LC(R)	0.85	0.76
WC(L)	0.62	0.72
WC(R)	0.69	0.68
BCB	0.74	0.85
MnD	0.87	0.84
MxID	0.52	0.56
DEHC	0.91	0.86
FML	0.89	0.82
FMB	0.86	0.84

the data collected in the present study, foramen magnum length has statistically significant correlation coefficients with respect to the following variables: maximum length of right condyle, maximum width of left condyle, maximum bicondylar breadth, maximum interior distance between condyles, and external hypoglossal canal distance. Foramen magnum breadth has statistically significant correlation coefficients with respect to the following variables: maximum length of left condyle, maximum bicondylar breadth, minimum distance between condyles, maximum interior distance between condyles, and external hypoglossal canal distance (Table 12).

Tests of Formulae for Estimating Stature from Foramen Magnum Region Measurements Between Northern and Southern Chinese Populations—Cross tests of the stature estimation equations based on foramen magnum region for northern and southern Chinese were performed by comparing the actual stature values for individuals in each population with stature estimates from both the geographically appropriate (northern or southern) set of equations and the "opposite" set of equations. *t*-Tests were carried out to determine whether statistically significant differences exist between the errors produced using the geographically appropriate and geographically inappropriate equations. The results are listed in Table 13.

As shown in Table 10, there are major differences between the errors produced using the different sets of estimation formulae, which implies that it is necessary to use different estimation equations for southern and northern Chinese populations. It is advisable to distinguish between individuals from northern and southern China. However, the estimation formulae in Table 4 could be applied if the exact birthplace of a deceased person was unknown.

Discussion

Stature Estimation from Dimensions of Foramen Magnum Region

The results of the present study show that the dimensions of the foramen magnum region can be successfully used for estimation of stature by legal medical experts, anthropologists, and paleoanthropologists working on male Chinese individuals or populations. The correlation values of the dimensions of foramen magnum region are lower compared with the error from those using limb lower long bones, but approximately the same as, or even higher than those from other cranial dimensions (5,6). The equations should be chosen according to actual circumstances when the birthplace of the deceased person is available. The low accuracy of stature estimation when the foramen magnum is included may be partially explained by the early termination of the basi-exoccipital junction and foramen magnum region (11,12), and the dimensions of foramen magnum region receive little influence in pubertal development.

Angel (14) suggested that skull base is sensitive to nutrition, as the weight of the head is transmitted through the atlanto-occipital joint, and it is possible that loading of the condylar facets as well as stresses in the frontal, lateral, and posterior neck musculature contribute to the dimensions of the foramen magnum region (13). Hoyte (15) and Scheuer and Black (12) proposed that bone resorption causes a slight increase in foramen magnum region dimensions after overall growth has ceased. Furthermore, rickets and hunchbacks cause

TABLE 11—*Blind test of equations for estimation of stature from measurements of foramen magnum region (cm).*

	BCB	DEHC	FMB	AFM	FML, FMB	BCB, DEHC	DEHC, FML	DEHC, FML, FMB	BCB, DEHC, FMB	BCB, DEHC, FML, FMB
0 to ±3	35	37	39	35	39	39	41	39	43	43
±3 to ±5	22	33	20	20	20	29	27	22	18	18
±5 to ±7	10	10	12	18	12	8	10	16	12	14
> +7 or < −7	33	20	29	27	29	24	22	22	27	24
0 to ±5	57	69	59	55	59	67	67	61	61	61
0 to ±7	67	80	71	73	71	76	78	78	73	76

TABLE 12—*Correlations between foramen magnum region and occipital condyle measurements.*

	LC(L)	LC(R)	WC(L)	WC(R)	BCB	MnD	MxID	DEHC
FML								
Pearson correlation	0.164**	0.157**	0.071	0.088	0.332**	0.071	0.226**	0.257**
Significance (two-tailed)	0.005	0.007	0.227	0.132	0	0.229	0	0
FMB								
Pearson correlation	0.129*	0.1	0.095	0.190**	0.484**	0.152**	0.428**	0.352**
Significance (two-tailed)	0.027	0.088	0.103	0.001	0	0.01	0	0

*Significant at 0.05 level.
**Significant at 0.01 level.

TABLE 13—*Tests for stature estimation equation based on foramen magnum region for northern and southern China.*

	Northern Equations				Southern Equations						
SEE	U-N-1	U-N-2	U-N-3	U-N-4	U-S-1	U-S-2	U-S-3	U-S-4	U-S-5	*t*	Sig.
Tests for univariate estimation equations											
Northern data	6.09	5.50	5.28	5.65	6.45	6.65	7.11	6.53	6.82	−5.386	0.001
Southern data	6.10	6.14	5.56	5.92	5.06	5.27	5.20	5.17	5.17	6.176	0.000
Tests for multivariate estimation equations											
Northern data	5.28	5.17	5.10	5.16	4.89	6.01	6.33	5.99	5.76	−7.145	0.000
Southern data	5.85	5.85	5.59	5.93	5.82	5.08	4.98	4.97	5.60	4.429	0.003

deformation of the cranial base. Therefore, other information such as nutritional status should be taken into account in practical applications.

Differences Between Northern and Southern Chinese Populations in the Relationships Between Stature and Foramen Magnum Region Measurements

The anatomical and genetic differences between northern and southern Chinese populations have been a focus of many previous literatures (16–21). The present study can be considered to further support the viewpoint that important differences exist between northern and southern Chinese people. Regression equations developed for the two populations exhibit differences. The correlations between stature and the dimensions of the foramen magnum region are generally higher in northern Chinese populations than in southern ones, which may imply that the southern Chinese have multiple ancestral origins.

There are measurements that differ extraordinarily in their relationship to stature between the two populations, such as breadth of foramen magnum. The correlation coefficient between stature and breadth of foramen magnum shows extreme significance ($p = 0.006$) in the southern Chinese population, but is not statistically significant ($p = 0.932$) in the northern Chinese population. Furthermore, differences also exist between the two populations in the correlations between stature and measurements of maximum condyle length on both sides of the skull, maximum width of condyle on the right side, and minimum distance between condyles. The standard errors estimated show no reduction in multivariate regression equations than in univariate equations, which implies that there exist other elements that influence stature variance other than independent variances in the equations. It is possible that this is a reflection of genetic differences between northern and southern Chinese populations or is caused by discrepancies in nutritional status and behavior patterns. Further anthropological and genetic research is needed to distinguish between these possibilities.

Conclusion

Linear and multiple regression equations for stature estimation based on occipital condyle region were established in this study. The correlation coefficients between stature and the various measurements were significant but not strong enough, which made the basio-cranial region not a very reliable predictor of stature. However, in incidences when only the skull is available, the method in this paper can still provide an estimation.

References

1. Trotter M, Gleser GC. Estimation of stature from long bones of American whites and negroes. Am J Phys Anthropol 1952;10(4):463–514.
2. Badkur P, Nath S. Use of regression analysis in reconstruction of maximum bone length and living stature from fragmentary measures of ulna. Forensic Sci Int 1990;45:15–25.
3. Formicola V, Franceschi M. Regression equations for estimating stature from long bones of early Holocene European samples. Am J Phys Anthropol 1996;100:83–8.
4. Krogman WM. The human skeletons in forensic medicine, 2nd edn. Springfield, IL: Charles C. Thomas Publication, 1978;302–52.
5. Krishan K, Kumar R. Determination of stature from cephalo-facial dimensions in a North Indian population. Leg Med 2007;9:128–33.
6. Sahni D, Sanjeev, Sharma P, Harjeet, Kaur G, Aggarwal A. Estimation of stature from facial measurements in northwest Indians. Leg Med (Tokyo) 2010;12(1):23–7.
7. Droessler J. Craniometry and biological distance. Evanston, IL: Centre for American Archeology at Northwestern University, 1981.
8. Holland TD. Sex determination of fragmentary crania by analysis of the cranial base. Am J Phys Anthropol 1986;70:203–8.
9. Westcott D, Moore-Jansen P. Metric variation in the human occipital bone: forensic anthropological applications. J Forensic Sci 2001;46:1159–63.
10. Brauer G. Osteometrie. In: Knussman R, editor. *Anthropologie, handbuch der vergleichenden biologie des menschen, band I, wesen und methoden der anthropologie, auflage des lehrbuchs des anthropologie begrundet von R. Martin*. Stuttgart, Germany: Gustav Fischer Verlag, 1988;160–232.
11. Hoyte D. Growth of the cranial base. In: Dixon AD, Hoyte DAN, Rönning O, editors. Fundamentals of craniofacial growth. Boca Raton, FL: CRC Press, 1997;257–333.
12. Scheuer L, Black S. Developmental juvenile osteology. London, UK: Academic Press, 2000.
13. Gapert R, Black S, Last J. Sex determination from the foramen magnum: discriminate function analysis in an eighteenth and nineteenth century British sample. Int J Legal Med 2009;123(1):25–33.
14. Angel JL. A new measure of growth efficiency: skull base height. Am J Phys Anthropol 1982;58(3):297–305.
15. Hoyte D. The cranial base in normal and abnormal skull growth. Neurosurg Clin N Am 1991;2:515–37.
16. Zhang Z, Wang L, Ouyang L. Physical patterns of Neolithic skulls in China in view of cluster analysis. Vertebrata Palasiatica 1982;(1):72–80. (in Chinese)
17. Zhang Z. An analysis of the physical characteristics of modern Chinese. Acta Anthropologica Sinica 1988;(4):314–23. (in Chinese)
18. Liu W, Yang M, Wang Y. Study of metric traits and geographical variations of modern Chinese skulls. Acta Anthropologica Sinica 1991;(2):96–106. (in Chinese)
19. Zhao T. Principle and application of HLA typing. Shanghai, China: Shanghai Scientific & Technical Publishers, 1984;121–6. (in Chinese)
20. Zhao T, Zhang G, Zhu Y, Zheng S, Gu W. Study on immunoglobulin allotypes in the Chinese: a hypothesis of the origin of the Chinese nation. Atca Genetica Sinica 1991;18(2):97–108. (in Chinese)
21. Su B, Xiao J, Underhill P, Deka R, Zhang W, Akey J, et al. Y-chromosome evidence for a northward migration of modern humans into eastern Asia during the last ice age. Am J Hum Genet 1999;65:7.

Additional information and reprint requests:
Yaming Cui, B.Sc.
Key Laboratory of Evolutionary Systematics of Vertebrates
CAS at the Institute of Vertebrate Paleontology and Paleoanthropology (IVPP)
Chinese Academy of Sciences (CAS)
142 Xizhimenwai Street
Beijing 100044
China
E-mail: cuiyaming@ivpp.ac.cn