Application of X-ray cephalometric analysis of adolescents in medicolegal investigation

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Abstract: We used cephalometric data obtained from X-ray images of adolescents to establish methods of inferring an adolescent's body height and age and provided new indices and novel methods for medicolegal investigation. Using random cluster sampling, 273 adolescents were scheduled to undergo projection of the skull for the harvesting of lateral cephalograms. The surveyed items were basic information of adolescents and 15 imaging data (SNA, SNB, ANB, NP-FH, Y-axis, NA-PA (angle of convexity), MP-FH (mandibular plane angle), SN-MP, 1-SN, 1-MP, 1-NA, 1-NB and 1-T angles as well as the 1-NA distance and 1-NB distance). SPSS 11.5 software was used to establish a database and stepwise multiple linear regression to establish the formula used to infer an individual's body height and age. The regression equation used for inferring an individual's body height was Y = 132.381 + 0.183X13 (1-T angle) + 0.178X12 (1-NB angle) and the regression equation for inferring an individual's age was Y = 16.402 – 0.024X13 (1-T angle) + 0.039X3 (ANB angle), obtained by taking the body height (cm) and age (year) as the Y-axis and 15 indices X1–X15 as the X-axis. The log-transformed results were used to infer an individual's body height and age using the formulas Y = 50.540 + 18.820X13(ln [1-T angle]) + 5.776X12(ln[1-NB angle]) and Y = 17.575 + 0.897X12(ln[1-NB angle]) – 1.237X4 (ln[NP-FH angle]), respectively. These findings demonstrate that an adolescent's body height was positively correlated to the size (or natural logarithm) of the 1-T angle and the 1-NB angle, and the 1-T angle had a stronger influence than the 1-NB angle on body height; an adolescent's age was positively correlated to the size (or natural logarithm) of the 1-NB angle but negatively correlated with the size (or natural logarithm) of the NP-FH angle, and the NP-FH angle had a greater influence than the 1-NB angle on an individual's age. We established methods of inferring an adolescent's body height and age from the cephalometric data of X-ray images of adolescents and provided new indices and methods of inferring an adolescent's body height and age in medicolegal investigation.

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1. Introduction

In medicolegal work, dead bodies that are difficult to identify in police investigations and dead bodies that require identification following major disasters should be technically appraised, and an important part of individual identification is to infer an individual's body height and age. Anthropologists engaged in medicolegal work use length indices including those of whole-body bone, upper-limb long bone, lower-limb long bone, cranial bone, thoracic bone, clavicle, scapula, hip bone, sacrum, metacarpus and digital bone to infer an individual's height. The method of inferring an individual's age according to their skeleton mainly depends on the ossification point, epiphyseal healing in the four limbs and skull, symphysial surface, auricular surface of the hip bone, thoracic bone, costal bone and pelvic bone（Zhang JZ，2009）. In this study, we used cephalometric data obtained from X-rays of adolescents to establish methods of inferring an adolescent's height and age and thus provide new indices and novel methods for medicolegal investigation.

2. Material and methods

2.1 Harvesting lateral cephalograms

Using random cluster sampling, 273 children/adolescent patients who received treatment at the Stomatology Hospital of Shanxi Medical University in July–September 2012 were scheduled to undergo projection of the skull in September 2012 for the harvesting of lateral cephalograms.

2.2 Measurement of lateral cephalograms

Through the use of the self-designed *X-ray Cephalometric Analysis Questionnaire for Shanxi Adolescents*, a postgraduate major in orthodontics surveyed the indices for each lateral cephalogram of each subject. The surveyed items were seven indices (gender, age, place of birth, race/ethnicity, body height (cm), body weight (kg), and detection time) and 15 imaging data (SNA, SNB, ANB, NP-FH, Y-axis, NA-PA (angle of convexity), MP-FH (mandibular plane angle), SN-MP, 1-SN, 1-MP, 1-NA, 1-NB and 1-T angles as well as the 1-NA distance and 1-NB distance).

2.3 Description of surveyed imaging data

The following indices of the maxilla and mandible were surveyed.

SNA angle: the angle formed by the sella–nasion plane and a line from the nasion to point A, which is an arbitrary measurement point on the innermost curvature from the maxillary anterior nasal spine to the crest of the maxillary alveolar process.

SNB angle: the angle formed by the sella–nasion plane and a line from the nasion to point B, which is the most anterior measurement point of the mandibular apical base.

ANB angle: the angle formed by point A, the nasion and point B.

NP-FH angle: the angle formed by the facial plane (NP) and the Frankfort horizontal plane (FH).

Y-axis angle: the angle formed by the Y-axis, which is the line connecting the sella to the gnathion, and FH.

NA-PA angle (angle of convexity): the angle formed by the intersection of the line that passes through the nasion and point A (NA) and another line from the most anterior point on the contour of the chin to point A (PA).

MP-FH angle (mandibular plane angle): the angle formed by the mandibular plane (MP) and FH.

SN-MP angle: the angle formed by the sella–nasion plane (SN) and MP.

The following indices of the maxillary and mandibular incisors were surveyed.

1-SN angle: the angle formed by the long axis of the maxillary central incisor and SN.

1-MP angle: the angle formed by the long axis of the mandibular central incisor and MP.

1-NA angle: the angle formed by the long axis of the maxillary incisors and NA.

1-NA distance: the perpendicular distance between the tip of the maxillary central incisor and NA.

1-NB angle: the angle formed by the long axis of the mandibular central incisor and the nasion–point B line (NB)

1-NB distance: the perpendicular distance between the tip of the mandibular central incisor and NB.

1-T angle the angle formed by the long axis of the maxillary incisors and the mandibular central incisor.

2.4 Statistical analysis

SPSS 11.5 software was used to establish a database and stepwise multiple linear regression to establish the formulas used to infer an individual's body height and age according to a previous report（Wang LH，1989）.

3. Results

3.1 General information of detected subjects

Among the 273 subjects surveyed, the youngest was 9.17 years old and the oldest was 18.93 years old. As per age division, the 11–12-year-old bracket accounted for the largest proportion (41.76%), followed by the brackets of ages of 9–12 (5.13%), 13–14 (35.90%), 15–16 (12.09%), and 17 years or older (5.13%). The subjects comprised 170 females (62.27%) and 103 males (37.73%). In terms of body weight, 39 subjects (14.29%) weighed 30–39 kg, 95 (34.80%) weighed 40–49 kg, 95 (34.80%) weighed 50–59 kg, 11 (4.03%) weighed 70–79 kg, and 11 (4.03%) weighed 80 kg or more. In terms of height, 21 (7.69%) subjects were 140–149 cm tall, 88 (32.23%) were 150–159 cm, 113 (41.39%) were 160–169 cm, 47 (17.22%) were 170–179 cm, and four (1.47%) were 180 cm or taller.

3.2 Descriptive analysis of surveyed maxillofacial indices

There were three categories of surveyed indices. The basic indices (the first category) were gender, age, body height (cm) and body weight (kg). The maxillofacial indices (the second category) were SNA, SNB, ANB, NP-FH, Y-axis, NA-PA (angle of convexity), MP-FH (mandibular plane angle), SN-MP, 1-SN, 1-MP, 1-NA, 1-NB and 1-T angles. The length indices (the third category) were the 1-NA distance and 1-NB distance. The maximum value, minimum value, mean and standard deviation of the above-mentioned indices are given in Table 1. The statistical descriptive results of the natural logarithm data are presented in Table 2.

3.3 Stepwise multiple linear regression for inferring an individual's body height and age

Inferring an individual's body height and age from originally surveyed indices

Stepwise multiple linear regression analysis was performed using SPSS 15.0 software by taking the body height (cm) and age (year) as the Y-axis and 15 indices as X_1–X_{15} [X_1 = SNA angle, X_2 = SNB angle, X_3 = ANB angle, X_4 = NP-FH angle, X_5 = NA-PA angle, X_6 = MP-FH angle, X_7 = Y-axis angle, X_8 = SN-MP angle, X_9 = 1-SN angle, X_{10} = 1-NA angle, X_{11} = 1-MP angle, X_{12} = 1-NB angle, X_{13} = 1-T angle, X_{14} = 1-NA distance (mm) and X_{15} = 1-NB distance (mm)].

X_{13} = (1-T angle) and X_{12} = (1-NB angle) were first introduced into the regression equation for inferring an individual's body height, $Y = 132.381 + 0.183X_{13} + 0.178X_{12}$. Analysis shows that $R^2 = 0.053$, F = 7.992, and there was statistical significance ($P < 0.01$). The results indicate that the adolescent's body height was positively correlated with the 1-T angle and 1-NB angle, and the1 -T angle had greater influence than the 1-NB angle on the adolescent's body height. Results are presented in Tables 3–5.

X_{13}= (1-T angle) and X_3 = (ANB angle) were then introduced into the regression equation for inferring an individual's age, Y = 16.402 – 0.024 X13 + 0.039 X3. Analysis shows that R^2 = 0.038, F = 5.702, and there was statistical significance (P < 0.01). The results indicate that the adolescent's age was positively correlated with the ANB angle but negatively correlated with the 1-T angle, and the ANB angle had a greater influence than the 1-T angle on the adolescent's age. Results are presented in Tables 6–8.

Table 1. Statistical descriptive results of surveyed maxillofacial indices

Index	n	Minimum value	Maximum value	Mean	Standard deviation
Years after birth	273	9.17	18.93	13.45	1.76
Body height (cm)	273	75.00	180.00	160.23	10.22
Body weight (kg)	273	30.00	86.00	49.14	11.57
SNA angle	273	18.00	94.00	79.97	6.53
SNB angle	273	68.00	89.00	77.97	3.97
ANB angle	273	0.15	79.00	4.84	7.34
NP-FH angle	273	2.50	99.50	83.19	9.84
NA-PA angle	273	0.50	115.00	9.69	12.02
MP-FH angle	273	3.00	89.00	31.01	11.12
Y-axis angle	273	7.00	112.00	65.40	8.56
SN-MP angle	273	4.00	78.50	35.75	8.14
1-SN angle	273	7.00	139.00	106.48	15.00
1-NA angle	273	4.00	78.00	28.40	8.64
1-MP angle	273	7.00	119.00	91.57	14.50
1-NB angle	273	5.00	130.00	28.81	11.30
1-T angle	273	18.00	160.00	120.41	14.65
1-NA distance (mm)	273	1.00	38.00	7.10	4.29
1-NB distance (mm)	273	1.00	91.50	7.00	6.00

Table 2. Statistical descriptive results of the natural logarithm data regarding surveyed maxillofacial indices

Index	n	Minimum value	Maximum value	Mean	Standard deviation
SNA angle	273	2.89	4.54	4.38	0.13
SNB angle	273	4.22	4.49	4.36	0.05
ANB angle	273	-1.90	4.37	1.19	0.83
NP-FH angle	273	0.92	4.60	4.40	0.26
NA-PA angle	273	-0.69	4.74	1.94	0.80
MP-FH angle	273	1.10	4.49	3.38	0.33
Y-axis angle	273	1.95	4.72	4.17	0.19
SN-MP angle	273	1.39	4.36	3.55	0.25
1-SN angle	273	1.95	4.93	4.65	0.28
1-NA angle	273	1.39	4.36	3.30	0.32
1-MP angle	273	1.95	4.78	4.49	0.30
1-NB angle	273	1.61	4.87	3.31	0.33
1-T angle	273	2.89	5.08	4.78	0.17
1-NA distance (mm)	273	0.00	3.64	1.79	0.63
1-NB distance (mm)	273	0.00	4.52	1.81	0.49

Table 3. Regression equation for inferring an individual's body height (original data)

Model	R	R square	Adjusted R square	Standard error of the estimated
1	0.179	0.032	0.029	13.07432
2	0.230	0.053	0.046	12.95435

Table 4. Analysis of variance of the regression equation for inferring an individual's body height (original data)

Model		Sum of squares	df	Mean square	F	Sig.
1	Regression	1621.583	1	1621.583	9.486	0.002
	Residual	48888.195	271	170.938		
	Total	50509.778	273			
2	Regression	2682.427	2	1341.214	7.992	0.000
	Residual	47827.351	270	167.815		
	Total	50509.778	272			

Table 5. Coefficients of the regression equation for inferring an individual's body height (original data)

Model		Unstandardized coefficients		Standardized coefficients	t	Sig.
		B	Standard error	Beta	B	Standard error
1	(Constant)	141.359	5.931		23.834	0.000
	X_{13}	0.151	0.049	0.179	3.080	0.002
2	(Constant)	132.381	6.877		19.251	0.000
	X_{13}	0.183	0.050	0.217	3.643	0.000
	X_{12}	0.178	0.071	0.150	2.514	0.012

Table 6.Regression equation for inferring an individual's age (original data)

Model	R	R square	Adjusted R square	Standard error of the estimated
1	0.156	0.024	0.021	2.36056
2	0.196	0.038	0.032	2.34766

Table 7. Analysis of variance of regression equation for inferring an individual's age (original data)

Model		Sum of squares	df	Mean square	F	Sig.
1	Regression	39.974	1	39.974	7.174	0.008
	Residual	1593.658	271	5.572		
	Total	1633.632	273			
2	Regression	62.854	2	31.427	5.702	0.004
	Residual	1570.778	270	5.512		
	Total	1633.632	272			

Table 8. Coefficients of the regression equation for inferring an individual's age (original data)

Model		Unstandardized coefficients		Standardized coefficients	t	Sig.
		B	Std. Error	Beta	B	Std. Error
1	(Constant)	16.617	1.071		15.518	0.000
	X_{13}	-0.024	0.009	-0.156	-2.678	0.008
2	(Constant)	16.402	1.070		15.326	0.000
	X_{13}	-0.024	0.009	-0.155	-2.671	0.008
	X_3	0.039	0.019	0.118	2.037	0.043

Inferring an individual's body height and age from log-transformed data

Stepwise multiple linear regression analysis was performed using SPSS 15.0 software by taking the body height (cm) and age (year) as the Y-axis and 15 indices as X_1–X_{15} [X_1 = ln (SNA angle), X_2 = ln (SNB angle), X_3 = ln (ANB angle), X_4 = ln (NP-FH angle), X_5 = ln (NA-PA angle), X_6 = ln (MP-FH angle), X_7 = ln (Y-axis angle), X_8 = ln (SN-MP angle), X_9 = ln ($\underline{1}$-SN angle), X_{10} = ln ($\underline{1}$-NA angle), X_{11} = ln (1-MP angle), X_{12} = ln (1-NB angle), X_{13} = ln ($\underline{1}$-T angle), X_{14} = ln ($\underline{1}$-NA distance (mm)) and X_{15} = ln (1-NB distance (mm))].

X_{13} = ln ($\underline{1}$-T angle) and X_{12} = ln (1-NB angle) were first introduced into the regression equation for inferring an individual's body height, $Y = 50.540 + 18.820X_{13} + 5.776X_{12}$. Analysis shows that $R^2 = 0.080$, $F = 12.317$, and there was statistical significance ($P < 0.01$). The results indicate that the adolescent's body height was positively correlated with the natural logarithm of the $\underline{1}$-T angle and the 1-NB angle, and the $\underline{1}$-T angle had a greater influence than the 1-NB angle on the adolescent's body height. Results are presented in Tables 9–11.

X_{12} = ln (1-NB angle) and X_4 = ln (NP-FH angle) were then introduced into the regression equation for inferring an individual's age, $Y = 17.575 + 0.897X_{12} - 1.237X_4$. Analysis shows that $R^2 = 0.057$, $F = 8.594$, and there was statistical significance ($P < 0.01$). The results indicate that the adolescent's age was positively correlated with the natural logarithm of the 1-NB angle but negatively correlated with the natural logarithm of the NP-FH angle, and the NP-FH angle had a greater influence than the 1-NB angle on the adolescent's age. Results are presented in Tables 12–14.

Table 9. Regression equation for inferring an individual's body height (log-transformed data)

Model	R	R square	Adjusted R square	Standard error of the estimated
1	0.246	0.060	0.057	12.88172
2	0.282	0.080	0.073	12.77212

Table 10. Analysis of variance of the regression equation for inferring an individual's body height (log-transformed data)

Model		Sum of squares	df	Mean square	F	Sig.
1	Regression	3051.334	1	3051.334	18.388	.000(a)
	Residual	47458.443	271	165.939		
	Total	50509.778	273			
2	Regression	4018.605	2	2009.302	12.317	.000(b)
	Residual	46491.173	270	163.127		
	Total	50509.778	272			

Table 11.Coefficients of the regression equation for inferring an individual's body height (log-transformed data)

Model		Unstandardized coefficients		Standardized coefficients	t	Sig.
		B	Standard error	Beta	B	Standard error
1	(Constant)	80.688	18.388		4.388	0.000
	X_{13}	16.511	3.850	0.246	4.288	0.000
2	(Constant)	50.540	22.038		2.293	0.023
	X_{13}	18.820	3.934	0.280	4.784	0.000
	X_{12}	5.776	2.372	0.143	2.435	0.016

Table 12. Regression equation for inferring an individual's age (log-transformed data)

Model	R	R square	Adjusted R square	Standard error of the estimated
1	0.187	0.035	0.032	2.34781
2	0.238	0.057	0.050	2.32508

Table 13.Analysis of variance of the regression equation for inferring an individual's age (log-transformed data)

Model		Sum of squares	df	Mean square	F	Sig.
1	Regression	57.141	1	57.141	10.366	0.001
	Residual	1576.491	271	5.512		
	Total	1633.632	273			
2	Regression	92.920	2	46.460	8.594	0.000
	Residual	1540.711	270	5.406		
	Total	1633.632	272			

Table 14.Coefficients of the regression equation for inferring an individual's age (log-transformed data)

Model		Unstandardized coefficients		Standardized coefficients	t	Sig.
		B	Standard error	Beta	B	Standard error
1	(Constant)	12.186	0.512		23.799	0.000
	X_{12}	0.872	0.271	0.187	3.220	0.001
2	(Constant)	17.575	2.155		8.154	0.000
	X_{12}	0.897	0.268	0.192	3.341	0.001
	X_4	-1.237	0.481	-0.148	-2.573	0.011

4. Discussion

Domestic and foreign scholars have acquired methods of inferring an individual's body height for different races of people according to different parameters including the long bone, dismembered long bone (Song HW et al, 1992), length of the second metacarpal bone（Wang LH，1989）, craniometric data (Holland TD, 1986), data of shoulder girdle and lower-limb girdle (Mohanty NK,1998), length of median metacarpal bone (Meadows L and Jantz RL, 1992), length of index finger and length of middle finger, length of hand and length of palm (Zhang HQ et al, 2005), data of thoracic bone (Meadows L,1992), epiphyseodiaphyseal fusion (Zhang HQ and Liu ZC., 2005), severely dismembered mandible (Zhang HQ et al, 2005), male humerus, male ulna, male radius, male femur, male fibula (Niu YL and Wang YY,2006), fingerprint (Li L,2005)and footprint (Liu YW and Liu JF, 2005). These methods provide novel ways of inferring an individual's body height. At present, a combined observation of multiple indices can accurately infer an individual's age. Because of its ease of implementation and high accuracy, this method has become a main means used to infer an individual's age and can provide accurate and reliable evidence for crime reconnaissance and court proceedings (Wang XY et al, 2008; Cameriere R and Ferrante L,2008; Cameriere R et al, 2008).

However, to the best of our knowledge, there have been no reports describing the application of X-ray cephalometric analysis in inferring an individual's body height and age. Results from this study demonstrate that an adolescent's body height is positively correlated with the size (or the natural logarithm) of the 1-T angle and 1-NB angle, and the 1-T angle has a greater influence than the 1-NB angle on an adolescent's body weight; the adolescent's age was positively correlated with the size (or the natural logarithm) of the 1-NB angle but negatively correlated with the size (or the natural logarithm) of the NP-FH angle, and the NP-FH angle has a greater influence than the 1-NB angle on the adolescent's age. This study used X-ray cephalometric analysis data to establish methods of inferring an adolescent's body height and age, thus providing new indices and novel methods for medicolegal investigation.

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