



Forensic anthropology population data

Forensic age estimation through evaluation of the apophyseal ossification of the iliac crest in Western Chinese

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ABSTRACT

The criminal age estimation procedures have gained greatest significance to date, a reliable age diagnostics may depend on data of skeletal maturation from different socioeconomic status. In order to establish the iliac crest apophysis as a possible criterion for forensic age estimation in a different socioeconomic status, and to examine the pace of ossification for the iliac crest apophysis in Western Chinese, one thousand seven hundreds and seventy-seven conventional pelvic radiographs relating to West China Han group routinely taken between January 2010 and June 2012 have been sighted. The data was analysed with separation of the sexes. The results indicated that stage 2a was last observed in females at the age of 17.00 and in males at the age of 18.01, stage 3a was first achieved in females at the age of 14.46 and in males at the age of 15.31, stage 4 was observed between 17.95 and 25.98 years for male and between 18.36 and 25.95 years for female. By comparison with previous studies, our research indicated that Western Chinese presents a delaying development for the iliac crest apophysis. Furthermore, the present study with eight stages of ossification for the iliac crest offers a valuable alternative method of estimation of 18 years of age for Western Chinese.

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1. Introduction

The criminal age estimation procedures have gained greatest significance to date, in which they serve both to safeguard legal certainty within the state as well as to protect the individual interests of a defendant. In the age of globalization, it is of the utmost importance to verify whether the subjects who do not possess proper identification documents should be accepted as juveniles or adults during criminal proceedings [1–6]. Thus, the research field of forensic age diagnostics in living adolescents and young adults has being a well established sector within the medicolegal sciences due to the increasing significance of forensic age estimations. Moreover, it was reported that the socioeconomic status does have an impact on the pace of ossification [7]. Hence, a reliable age diagnostics may depend on data of skeletal maturation from different socioeconomic status.

The international Study Group on Forensic Age Diagnostics (AGFAD), consisting of forensic physicians, radiologists, dentists, and anthropologists, has developed recommendations for age

diagnostics in criminal proceedings and other relevant legal fields. The measures proposed comprising radiological assessments of the left hand, the teeth, and, if hand ossification is complete, the clavicles [8]. Besides the clavicle and the skeletal elements of the hand, the apophysis of the iliac crest [9–12] and the ischial tuberosity [13–15] could be such a suitable criterion due to a comparatively late completion of osseous maturation.

Our previous study [16] established a classification scheme for apophyseal iliac crest ossification by referring to the previous classification systems [10,17] and differentiating eight stages of ossification for the iliac crest. Hence, in order to establish the iliac crest apophysis as a possible criterion for forensic age estimation in a different socioeconomic status, further fundamental research appeared to be necessary. For that reason, in the present study, we aimed at investigating conventional pelvic radiographs by means of forensically established grading system for skeletal maturation of the iliac crest apophysis in the West China Han group.

2. Materials and methods

One thousand seven hundreds and seventy-seven conventional pelvic radiographs at the West China Hospital of Sichuan University between January 2010 and June 2012 were evaluated retrospectively. All participants are West China Han group, the

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Table 1
Frequency distribution by biological sex and age cohort.

| Age (year) | Male | Female | Total |
|-------------|------|--------|-------|
| 14.00–14.99 | 49 | 38 | 87 |
| 15.00–15.99 | 71 | 35 | 106 |
| 16.00–16.99 | 78 | 59 | 137 |
| 17.00–17.99 | 71 | 49 | 120 |
| 18.00–18.99 | 84 | 46 | 130 |
| 19.00–19.99 | 91 | 51 | 142 |
| 20.00–20.99 | 110 | 58 | 168 |
| 21.00–21.99 | 81 | 76 | 157 |
| 22.00–22.99 | 116 | 80 | 196 |
| 23.00–23.99 | 107 | 75 | 182 |
| 24.00–24.99 | 116 | 76 | 192 |
| 25.00–25.99 | 86 | 74 | 160 |
| Total | 1060 | 717 | 1777 |

ones taking drugs and/or suffering diseases affecting their skeletal development were excluded intentionally from our research. The population with reliable examination included 717 female (40.3%) and 1060 male (59.7%) individuals. Table 1 shows sample sizes by biological sex and age cohort for the 1777 cases in which reliable assessment of the ossification status was possible. The subjects were aged between 14 and 26 years. The present study was performed with the approval of the ethics committee of the West China Hospital of Sichuan University and all the participants provided written informed consent.

The pelvic radiographs were done according to standard procedures: lying patient, anterior/posterior path of rays, approx. 81 kV on average, and usage of a digital luminescence radiography system. Image evaluation was done on screen using a workstation at syngo fast view.

The developmental status of the ossification for the iliac crest were evaluated referring to the previous classification systems

[10,17] differentiating eight stages of ossification for the iliac crest as follows:

- Stage 1: Ossification centre not ossified.
- Stage 2a: Ossification centre ossified, the lengthwise apophyseal measurement is one third or less compared to the maximal lengthwise measurement of the iliac wing.
- Stage 2b: The apophyseal ossification extending into two thirds.
- Stage 2c: The lengthwise apophyseal measurement is over two thirds of the maximal lengthwise measurement of the iliac wing, the apophyseal cartilage has not ossified yet.
- Stage 3a: The apophyseal cartilage has partially ossified, the apophyseal fusion to the iliac crest is completed in one third or less.
- Stage 3b: The apophyseal fusion to the iliac bone is completed in over one third and less than two thirds.
- Stage 3c: The apophyseal fusion to the iliac bone is completed in over two thirds.
- Stage 4: Apophyseal cartilage has fully ossified.

Fig. 1 shows the findings that correspond to each of the stages 1–4. An ossification stage was determined for both the right and the left pelvic side. All evaluations were made twice by one examiner. The examiner was blinded to the age of the individuals before and during the examinations.

Results are expressed as minimum, maximum, mean \pm standard deviation and 95% confidence index. A receiver operating characteristic (ROC) analysis was performed to measure the value of estimation of 18 years of age for Western Chinese with the present eight stages of ossification for the iliac crest. Statistical analyses were performed using SPSS (VERSION 19.0 for Windows). To cope with outliers and/or skew distributions, sexual differences were analysed using Mann–Whitney *U* test for two independent groups. Significance was assessed at $p < 0.05$, exact, two-sided. Intra-class correlation

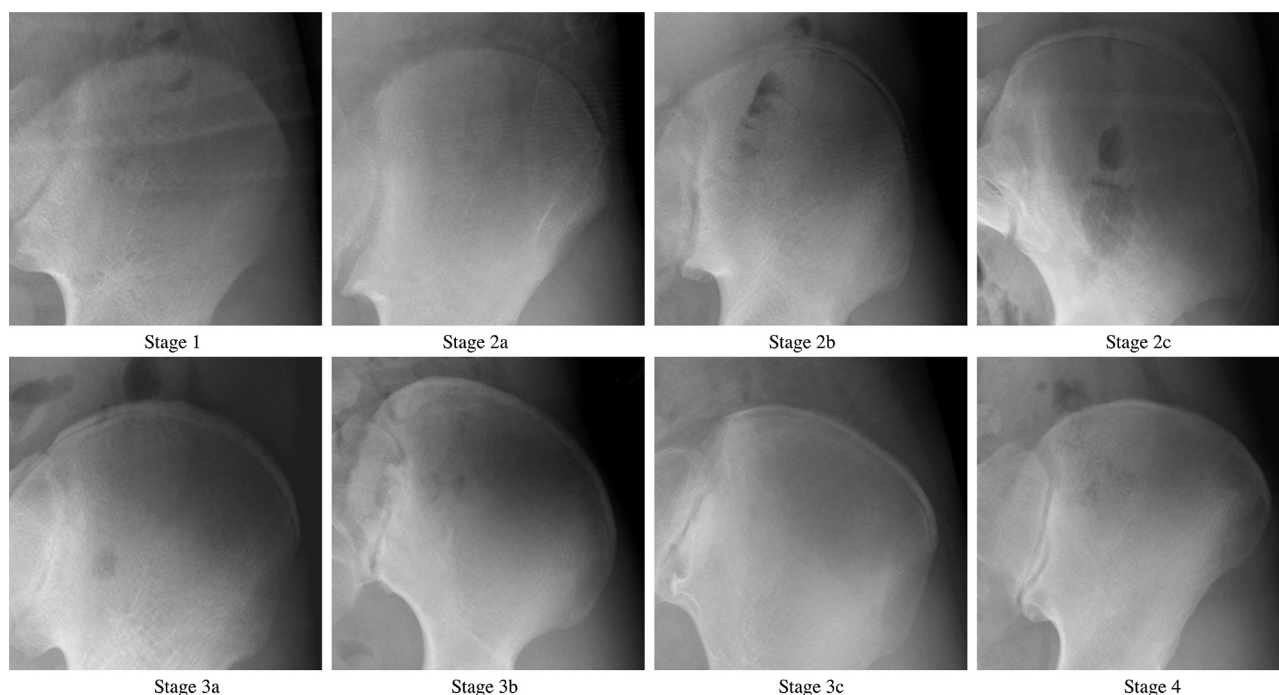


Fig. 1. Ossification stages of the iliac crest and radiographic examples. Stage 1: Ossification centre not ossified. Stage 2a: Ossification centre ossified, the lengthwise apophyseal measurement is one third or less compared to the maximal lengthwise measurement of the iliac wing. Stage 2b: The apophyseal ossification extending into two thirds. Stage 2c: The lengthwise apophyseal measurement is over two thirds of the maximal lengthwise measurement of the iliac wing, the apophyseal cartilage has not ossified yet. Stage 3a: The apophyseal cartilage has partially ossified, the apophyseal fusion to the iliac crest is completed in one third or less. Stage 3b: The apophyseal fusion to the iliac bone is completed in over one third and less than two thirds. Stage 3c: The apophyseal fusion to the iliac bone is completed in over two thirds. Stage 4: Apophyseal cartilage has fully ossified.

coefficients were determined in order to evaluate intra-observer agreement.

3. Results

No statistical significant differences were found between the right and left pelvic sides ($p = 0.331$). Hence, in the following paragraphs, only the left pelvic side is regarded.

Mann–Whitney's U -test revealed no statistic difference between the sexes ($p > 0.05$) for stage 1–4. Calculation of intra-class correlation coefficients revealed very good intra-observer agreements ($R = 0.912$).

Table 2 presents the minimum, maximum, mean \pm standard deviation and 95% confidence index for stages 1–4 separately subdivided according to sex.

While stage 2a was last observed in females at the age of 17.00 and in males at the age of 18.01, stage 3a was first achieved in females at the age of 14.46 and in males at the age of 15.31, stage 4 was observed between 17.95 and 25.98 years for male and between 18.36 and 25.95 years for female.

Fig. 2 shows the ROC curve for the eight stages of ossification for the iliac crest to estimate the age of 18 years for Western Chinese. The area under the ROC curve was 0.955 (95% CI 0.945–0.966, $p < 0.001$), indicating a good prediction of the grading system.

4. Discussion

Numerous studies referring to the ossification of the iliac crest apophysis with respect to clinical [9,18–20] and anthropological aspects [21,22], only few studies are applicable for forensic purposes. The iliac crest apophysis provides very good preconditions for determining skeletal age due to a relatively late completion of maturation [9–11,17,23]. One of the earliest radiographic descriptions of the apophyseal ossification of the iliac crest dates from 1934 [24]. The first fundamental knowledge about the assessment of maturity of the osseous pelvis and iliac crest apophysis, in particular, derives from the orthopaedic surgeon Risser whose studies led to the development of the so-called Risser sign [18–20]. For the last time in 1998, the standard values of the Risser sign grading system have been updated for clinical purposes [19]. A sonographic pilot study demonstrated the iliac crest apophysis to be principally suitable for forensic age estimation in the living [17]. In 2013, two more studies investigated different classification systems applied to pelvic radiographs in order to further establish the iliac crest apophysis as a possible criterion for forensic age estimation [10,11]. However,

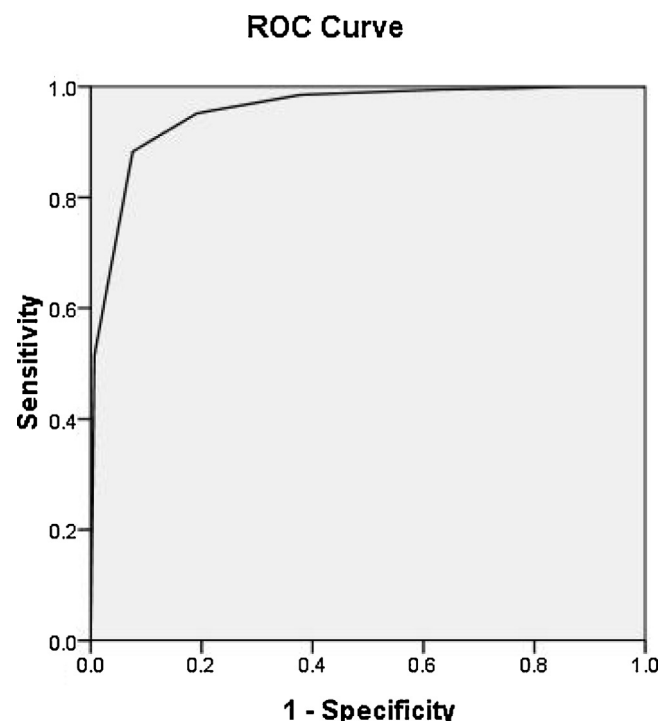


Fig. 2. ROC curve for the eight stages of ossification for the iliac crest to estimate the age of 18 years for Western Chinese (AUC = 0.955, 95% CI 0.945–0.966, $p < 0.001$).

all present studies dealing with the iliac crest apophysis for forensic age estimation were relating to German.

Owing to that the socioeconomic status does have an impact on the pace of ossification [7], 1777 conventional pelvic radiographs relating to West China Han group routinely taken between January 2010 and June 2012 have been sighted. Our results indicated that stage 2a was last observed in females at the age of 17.00 and in males at the age of 18.01, stage 3a was first achieved in females at the age of 14.46 and in males at the age of 15.31, stage 4 was observed between 17.95 and 25.98 years for male and between 18.36 and 25.95 years for female. By comparison with the previous studies relating to German, as shown in Table 3, the Western Chinese presents a delaying development for the iliac crest apophysis. For stage 3, our results presents a minimum age of 14.46 years in female and a minimum age of 15.31 years in male, however, Wittschieber et al. [10] reports a minimum age of 13.88 years in female and a minimum age of 14.39 years in male. Moreover, we observed a maximum age of 25.71 years in female and a maximum age of 25.84 years in male for stage 3. Schmidt et al. [17] reports a maximum age of 23.6 years in female and a maximum age of 22.4 years in male, and Wittschieber et al. [10] observed a maximum age of 20.67 years in female and a maximum age of 24.57 years in male. Furthermore, our result was deviant to the result of Wittschieber et al.'s research [10], with minimum age of 18.36 years for stage 4 in female, and Wittschieber et al. reports a minimum age of 16.42 years for stage 4 in female.

The earliest radiographic descriptions of the apophyseal ossification of the iliac crest in 1934 found the iliac crest apophysis between the 13th and 14th year of age, regularly existed at the age of 15 and 16, and began to fuse between 16 and 18 years [24]. Risser whose studies led to the development of the Risser sign [18–20]. According to the Risser sign grading system the iliac crest ossification begins at the age of 12 and 13 (girls/boys) and ends at the age of 17 and 18 (girls/boys). The method of examination does have an impact on the pace of ossification [7]. A recent research reports that the Risser sign grading system for the iliac crest are suitable for forensic age diagnostics, especially to determine

Table 2
Statistical parameters in years by sex for ossification stages 0–7.

| Stage | Sex | n | Min | Max | Mean \pm SD | 95%CI |
|-------|--------|-----|-------|-------|------------------|-------------|
| 1 | Male | 50 | 14.00 | 17.93 | 15.11 \pm 0.97 | 14.86–15.39 |
| | Female | 6 | 14.00 | 15.03 | 14.36 \pm 0.51 | 14.01–15.00 |
| 2a | Male | 47 | 14.00 | 18.01 | 15.46 \pm 1.11 | 15.15–15.79 |
| | Female | 8 | 14.00 | 17.00 | 15.24 \pm 1.08 | 14.45–16.11 |
| 2b | Male | 37 | 14.14 | 18.26 | 16.18 \pm 1.09 | 15.92–16.55 |
| | Female | 22 | 14.00 | 17.68 | 15.12 \pm 1.11 | 14.67–15.62 |
| 2c | Male | 68 | 14.02 | 19.00 | 16.10 \pm 1.18 | 15.82–16.39 |
| | Female | 60 | 14.00 | 18.29 | 15.68 \pm 1.11 | 15.40–15.97 |
| 3a | Male | 63 | 15.31 | 20.47 | 17.39 \pm 1.28 | 17.07–17.71 |
| | Female | 65 | 14.46 | 21.83 | 17.07 \pm 1.60 | 16.69–17.48 |
| 3b | Male | 65 | 16.00 | 24.66 | 18.85 \pm 1.84 | 18.43–19.32 |
| | Female | 79 | 14.95 | 24.01 | 18.59 \pm 1.89 | 18.20–19.00 |
| 3c | Male | 295 | 16.34 | 25.84 | 20.78 \pm 2.05 | 20.55–21.01 |
| | Female | 223 | 16.00 | 25.71 | 21.65 \pm 2.17 | 21.36–21.92 |
| 4 | Male | 433 | 17.95 | 25.98 | 23.09 \pm 1.79 | 22.91–23.26 |
| | Female | 254 | 18.36 | 25.95 | 23.27 \pm 1.74 | 23.06–23.49 |

Min: minimum, Max: maximum, SD: standard deviation, 95%CI: 95% confidence index.

Table 3
Comparison of studies dealing with the ossification of iliac crest.

| Study | Case number | Age (age in years) | Sex | Pelvic side | Stage 1 (age in years) | Stage 2a (age in years) | Stage 2b (age in years) | Stage 2c (age in years) | Stage 3a (age in years) | Stage 3b (age in years) | Stage 3c (age in years) | Stage 4 (age in years) |
|--------------------------------|-------------|--------------------|--------|-------------|------------------------|-------------------------|-------------------------|-------------------------|-------------------------|-------------------------|-------------------------|------------------------|
| Schmidt ^a [17] | 613 | 10–26 | Female | | 10.1–14.4 | 11.2–18.5 | | | 14.7–23.6 | | | 17.9–26.0 |
| | | | Male | | 10.0–14.0 | 10.5–20.4 | | | 15.6–22.4 | | | 17.4–25.9 |
| Wittschieber ^b [10] | 643 | 10–30 | Female | Right | 10.02–13.89 | 12.36–14.72 | 12.55–17.56 | 14.27–18.57 | 13.88–22.49 | 13.83–19.30 | 15.96–20.67 | 16.42–30.85 |
| | | | Male | Left | 10.02–13.89 | 12.36–14.72 | 12.55–15.68 | 14.27–15.17 | 13.88–20.02 | 13.83–22.49 | 15.73–20.67 | 16.42–30.85 |
| | | | Female | Right | 10.19–15.34 | 12.21–14.28 | 12.77–15.29 | 12.92–17.12 | 14.39–20.41 | 16.16–21.12 | 15.00–24.57 | 17.90–30.93 |
| | | | Male | Left | 10.19–15.34 | 12.21–14.28 | 13.66–15.84 | 13.89–14.91 | 15.70–19.88 | 12.92–24.57 | 15.00–20.27 | 17.90–30.93 |
| Present study ^b | 1777 | 14–26 | Female | | 14.00–15.03 | 14.00–17.00 | 14.00–17.68 | 14.00–18.29 | 14.46–21.83 | 14.95–24.01 | 16.00–25.71 | 18.36–25.95 |
| | | | Male | | 14.00–17.93 | 14.00–18.01 | 14.14–18.26 | 14.02–19.00 | 15.31–20.47 | 16.00–24.66 | 16.34–25.84 | 17.95–25.98 |

Classification systems for stages of iliac crest in previous studies: ^a Stage I: no ossification of the apophyseal ossification centre; Stage II: ossification of the apophyseal ossification centre; no ossification of the apophyseal plate; Stage III: partial ossification of the apophyseal plate; Stage IV: complete ossification of the apophyseal plate.

^b Stage 1: Ossification centre not ossified. Stage 2a: Ossification centre ossified, the lengthwise apophyseal measurement is one third or less compared to the maximal lengthwise measurement of the iliac wing. Stage 2b: The apophyseal ossification extending into two thirds. Stage 2c: The lengthwise apophyseal measurement is over two thirds of the maximal lengthwise measurement of the iliac wing, the apophyseal cartilage has not ossified yet. Stage 3a: The apophyseal cartilage has partially ossified, the apophyseal fusion to the iliac crest is completed in one third or less. Stage 3b: The apophyseal fusion to the iliac bone is completed in over one third and less than two thirds. Stage 3c: The apophyseal fusion to the iliac bone is completed in over two thirds. Stage 4: Apophyseal cartilage has fully ossified.

whether the 14th year of life has been completed or not, and the French Risser sign system additionally allows for statements as to the completion of the 16th year of age [10]. Our study established a grading system for skeletal maturation modified for specific characteristics of the iliac crest apophysis and differentiating eight stages of ossification for the iliac crest, this system makes it possible to determine completion of the 18th year of life in both sexes when an ossification stage 4 is present. This was applicable in China where the age thresholds of relevance for criminal proceedings was 18 years, reaching the age of 18 years the most significant step for the legal assessment of numerous aspects of criminal, civil and asylum law.

To conclude, our research indicated that Western Chinese presents a delaying development for the iliac crest apophysis when compared with previous studies. And the present study with eight stages of ossification for the iliac crest offers a valuable alternative method of estimation of 18 years of age for Western Chinese.

Competing interest

No competing financial interests exist.

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