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Forensic age estimation of living persons from the knee: Comparison of MRI with radiographs

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ABSTRACT

To perform a study to clarify how strong the chronological age relates to ossification of the knee in Chinese on X-rays and the MRI when a similar four-stage grading system was used. 322 individuals with conventional radiographs and MRI were collected from routine medical investigations and evaluated retrospectively. Bland Altman plots were performed to reveal the agreement of grading of MRI and radiograph. Regression analysis was conducted to establish a mathematical model for age estimation. The ossification process of the knee occurs earlier in females than in males for about 1–2 years. The process on X-ray grading is consistently higher than that of MRI. The chronological age is well correlated with both grading of MRI and radiograph (all p values were less than 0.001). By comparison, the R-square of grading of MRI were relatively higher than that of radiograph. Finally, the chronological age is well correlated with the ossification of the knee when both grading of MRI and radiograph were used, with the R-square for MRI were relatively higher than that of radiograph. Furthermore, the use of MRI will reduce exposure to X-ray radiation as much as possible.

1. Introduction

Forensic age estimation of living adolescents and young adults is becoming increasingly important nowadays. This forensic problem mostly relates to persons without valid identification documents, whose exact age needs to be established for asylum, criminal or civil proceedings [1–5]. Forensic age estimation is one of the main tasks of forensic anthropology, which is affected by the unavoidable limits concerning difficulties in standardization of methods and procedures [6].

The search for the best anatomical growth markers which provide the most reliable age assessments has been ongoing for decades [6]. According to the recommendations of the International Study Group on Forensic Age Diagnosis, age estimations of living adolescents and young adults should firstly consist of a physical examination which also records anthropometric data, signs of sexual maturation and any age-relevant developmental disorders; an X-ray examination of the left hand; a dental examination which records dentition status and evaluates an orthopantomogram [1,2]. Some authors state that to establish whether an individual has reached the age threshold of 18 years or 21 years, an additional conventional X-ray or computed tomography (CT) scan of the medial epiphyses of the clavicle is recommended [7–12].

A combination of multi-factorial methods with multi-anatomical growth markers can provide the most accurate age estimate with the smallest possible error [6]. At present, age estimation was obtained from the skeleton development of hand [13,14], medial epiphysis of the clavicle [8,15–17], cervical vertebra [18], temporal bone [19], mandibular ramus [20], teeth development [21–23], the apophysis of the iliac crest [24–26] and the ischial tuberosity [27–29] and so on. There are many anthropological studies of skeletal maturation of the knee, based on dry bone, X-ray examinations and magnetic resonance imaging (MRI), but they differ with regard to numerous variables: study population, gender, number of individuals, age range and number of bone fusion stages [30–36].

The aim of the present study was to perform a study to clarify how strong the chronological age relates to ossification of the knee in Chinese on X-rays and the MRI when a similar four-stage grading system was used.

2. Materials and methods

322 individuals with conventional radiographs and MRI at the West China Hospital of Sichuan University between February 2014 and September 2015 were collected from routine medical

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Table 1
Frequency distribution by biological sex and age cohort.

Age (year)	Male	Female	Total
11.00–11.99	8	5	13
12.00–12.99	15	15	30
13.00–13.99	15	9	24
14.00–14.99	17	21	38
15.00–15.99	21	13	34
16.00–16.99	23	9	32
17.00–17.99	18	10	28
18.00–18.99	9	8	17
19.00–19.99	5	7	12
20.00–20.99	6	8	14
21.00–21.99	4	6	10
22.00–22.99	9	6	15
23.00–23.99	6	4	10
24.00–24.99	6	8	14
≥25.00	21	10	31
Total	183	139	322

investigations and evaluated retrospectively. The radiographs and MRI sequences were performed on the same day. All the individuals were seeking for medical treatment with the symptom of knee pain syndrome. The radiographs and MRI sequences were both taken because the radiographs showed no injury and then MRI was performed to find the injury of soft tissue.

All participants were from the West China Han group, the ones taking drugs and/or suffering diseases affecting their skeletal development were excluded intentionally from our research. The population with reliable examination included 139 female (43.2%) and 183 male (56.8%) individuals. The subjects were aged between 11 and 30 years. Table 1 shows sample sizes by sex and age group for the 322 cases in which reliable assessment of the ossification status was possible. 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 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 MRI examinations were performed using two 1.5 T MRI system (Achieva, Philips Medical Systems, Netherlands; Siemens, Germany) with knee coil. For analysis of the scans, a T1-weighted turbo spin-echo (T1-TSE) sequence in sagittal orientation was used.

A stage grading system modified from Kramer et al. [33] was used for assignment of the union when both MRI and radiographs were applied, according to the age range of the population in this study. The stage 1–stage 4 were morphologically defined as follows:

Stage 1: The epiphyseal–metaphyseal has not yet fused.

Stage 2a: Epiphyseal–metaphyseal fusion completes one third or less of the former gap between epiphysis and metaphysis.

Stage 2b: Epiphyseal–metaphyseal fusion completes between one third and two thirds of the former gap between epiphysis and metaphysis.

Stage 2c: Epiphyseal–metaphyseal fusion completes over two thirds of the former gap between epiphysis and metaphysis.

Stage 3: The epiphyseal cartilage is fully ossified, and the epiphyseal scar is visible.

Stage 4: The epiphyseal cartilage has fused completely, and the epiphyseal scar is no longer visible.

All the images were evaluated by two examiners with wide experience in imaging diagnosis independently. Intra- and inter-class correlation coefficients were determined in order to evaluate intra- and inter-observer agreement. The ossification status for the distal femoral, proximal tibial and proximal fibular epiphyses of stage 1 was scored as 1, the stage 2 was scored as 2–4 according to the developmental status, the stage 3 was scored as 5, and the stage 4 was scored as 6. The sum of all scores in the individual image was defined as X. Bland Altman plots were performed to reveal the agreement of grading of MRI and radiograph. Regression analysis was conducted with age as dependent variable and X as independent variable to establish a mathematical model for age estimation. Eleven regression models were used which were Linear, Logarithmic, Inverse, Quadratic, Cubic, Compound, Power, S-Curve, Growth, Exponential and Logistic. Each regression model will produce R-square value which represents the correlation between age and X. Statistical analyses were performed using SPSS (VERSION 19.0 for Windows). A level of significance of 0.05 ($p < 0.05$) was adopted for all the tests.

3. Results

In all the cases included in the analysis, determination of the ossification stage of the knee was possible. Fig. 1 shows

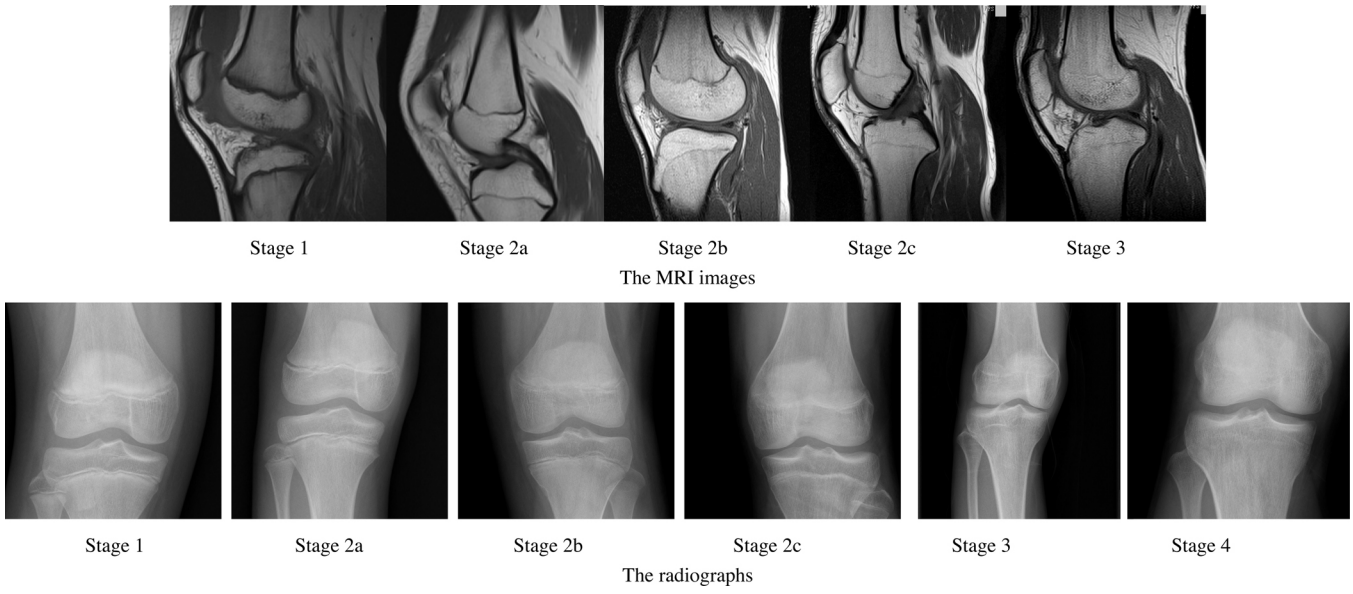

Fig. 1. The ossification stages of the distal femoral epiphyses.