Rom J Leg Med [21] 299-304 [2013]
DOI: 10.4323/rjlm.2013.299

Value of the appearance of left hand wrist ossification centres to age estimation in Roma population

Catalin Dogaroiu[1], Lucina Hackman[2,], Elena Gherghe[3], Eugenia Panaitescu[4], Marian Avramoiu[5]*

Abstract: The continuous movement of people across borders has resulted in an increase in children who are unable to prove their age when challenged by authorities. The use of the left hand-wrist radiograph for age estimation, especially in younger children has been shown to be an effective method of assessing skeletal age. This study looks at a population of Roma children aged between 1 year and 9 years of age and examines the relationship between the appearance of the ossification centres of the hand-wrist and the age of the child with a view to understanding which of these ossification centres is most predictive of age. The radiographs of 388 children (214 boys, 174 girls) were examined and each ossification centre scored on their appearance in the radiograph. Discriminant function analysis was undertaken on the results to understand the relationship between the appearance of each ossification centre and chronological age. The results showed that there were a number of ossification centres which could be considered to be more predictive of age for both boys and girls including the ossification centres of the distal ulna, the scaphoid and the 5th distal phalanx.

Key Words: left hand-wrist ossification centres, age estimation, roma population.

Cross border migration has increased on a worldwide scale in recent decades with the movement of large numbers of people between states for economic or humanitarian reasons. Countries which have experienced this growing influx of people have also encountered a number of related issues, including the problem of assigning a chronological age to individuals who are either unable or unwilling to prove their age. Many children do not have their birth registered and even if they do, documents can become lost as the result of conflict or natural disaster. Yet for many of the countries that these children are entering, the ability to prove age becomes vitally important as without it they may be stopped from accessing resources or become vulnerable to exploitation [1].

The Study Group of Forensic Age Diagnostic recommends a set of methods for establishing age in the living population [2]. The X-ray examination of the left hand/wrist complex is one of the three areas which are recommended for analysis, especially for younger individuals. The skeletal maturity of the left hand-wrist is considered to be representative of the skeletal maturity of the individual and its use in age estimation has been studied extensively, most recently in relation to forensic age

1) "Carol Davila" University of Medicine and Pharmacy, Department of Legal Medicine and Bioethics, Bucharest, Romania
2) University of Dundee, Scotland, United Kingdom
** Corresponding author: Lecturer in Human Identification, CAHID, University of Dundee, Scotland, United Kingdom E-mail: L.Hackman@dundee.ac.uk*
3) "Mina Minovici" National Institute of Forensic Medicine, Bucharest, Romania
4) "Carol Davila" University of Medicine and Pharmacy, Department of Medical Statistics, Bucharest, Romania
5) Forensic Medicine Laboratory, Rm. Valcea, Romania

estimation methods for the living [3-10]. Morphological changes in the bones of the hand-wrist complex have been shown to be representative of skeletal age and have been shown to be of use in establishing the chronological age of an individual [3,4,10,11]. Skeletal age is assessed by comparing the X-ray of the individual whose age is in question with a radiograph from a prepared reference collection. There are a number of these available for those who are undertaking age estimation processes [12-17]. The most commonly utilised of these is the Greulich and Pyle atlas which was based upon an American population of the 1900's, despite this research has shown that it is still relevant to the age estimation of children today [8,10,11,13,18].

MATERIALS AND METHODS

This research examined the appearance of secondary ossification centres and examined their relationship with chronological age for a selected population of Roma children. The study was carried out within the Laboratory of Medico-Legal Identification of the "Mina Minovici" National Institute of Forensic Pathology, Bucharest, Romania.

In total 388 children aged between 1 – 9 years of age (215 boys, 174 girls) had a left hand/wrist radiograph taken. The examination was under the direction of the Court who required that the radiograph was taken to allow a birth certificate to be issued to the child. The numbers of children in each age group is listed in Table 1.

Only the cases where the child's chronological age was known precisely were selected for this study, whilst the children did not have a birth certificate, the date of birth (day, month, year) was registered in the maternity certificate provided by the parents or social worker. As this medical document does not have legal value in the Romanian legislation, the child's age had to be established by forensic assessment.

Forensic assessment consists of a clinical examination which includes: anthropometric measurements (size, weight, cranial perimeter, cranial index, maximum opened arms, arm, forearm and left hand lengths, chest and abdominal circumference, thigh and left leg circumference); examination of secondary sexual characteristics, dental formula and radiological examination of the left hand/ wrist.

Table 1. Number of radiographs by sex and age

Age groups (yrs)	Boys	Girls
1 -1½	17	11
1½ - 2	18	11
2 – 2½	15	10
2½ – 3	17	7
3 – 3½	13	15
3½ -4	17	11
4 – 4½	13	8
4½ -5	17	11
5 -5½	11	9
5½ -6	15	11
6 -6½	13	14
6½ -7	10	16
7 -7½	15	14
7½ -8	11	10
8 -8½	9	12
8½ -9	3	4
Total	214	174

The X-rays were taken with a Primax – Riviera Blade machine. 13 x 18 cm or 18 x 24 cm X-ray films were used, given the hand size. The exposure dose was 42 kV, 25 mA and 0.1 sec. The exposure was postero-anterior and the x-ray machine was centred 1 m above the head of metacarpal III.

The x-rays were divided into three groups; group 1: 1 – 2 year of age, group 2: 3 – 5 year of age year group 3: 6 – 8 years of age. Each group of X-rays was separately examined by a pathologist. Unclear X-rays taken, especially in the case of the children who moved their hands during the X-ray exposure and those which showed possible artefacts caused by the x-ray machine and the ancillary equipment and which could be considered to be an ossification centre were not taken into consideration.

The presence or absence of ossification centres of the following bones was recorded: the distal epiphysis of the ulna and the radius, the carpal bones (the scaphoid, lunate, triquetral, pisiform, trapezoid and capitate, the base of the first metacarpal, the head of metacarpal II – V, the base of the phalanges) (Table 2). The ossification centres were recorded as "1" indicating the presence of the ossification centre and "0" indicating its absence. The ossification centre was considered present if it was visible on the X-ray even if its size was small. Each sex was examined separately due to the well recorded differences that exist between the rates of development in girls and boys [19,20]. The radiographs were analysed independently by

Table 2. Ossification centres which were scored during this study and their abbreviation

Ossification centres scored:
Distal epiphisys of the radius (DER)
Distal epiphisys of the ulna (DEU)
Scaphoid
Lunate
Triquetral
Trapezium
Trapezoid
Metacarpal 1 (MC1)
Metacarpal 2 (MC2)
Metacarpal 3 (MC3)
Metacarpal 4 (MC4)
Metacarpal 5 (MC5)
Proximal phalanx 1 (PP1)
Proximal phalanx 2 (PP2)
Proximal phalanx 3 (PP3)
Proximal phalanx 4 (PP4)
Proximal phalanx 5 (PP5)
Middle phalanx 2 (MP2)
Middle phalanx 3 (MP3)
Middle phalanx 4 (MP4)
Middle phalanx 5 (MP5)
Distal phalanx 1 (DP1)
Distal phalanx 2 (DP2)
Distal phalanx 3 (DP3)
Distal phalanx 4 (DP4)
Distal phalanx 5 (DP5)

3 forensic pathologists, if any differences of opinion were identified these were discussed and a consensus opinion was reached.

For each case, the age at the time of the examination was expressed in days and each case was included in year age group expressed every six months (for example 1 – 1½ yr, ½ yr – 2 yrs etc). The child whose age was expressed in "number of years" and 6 months was included in the next age group.

To test the possibility that the claimed dates of birth were not accurate the radiographs were assigned a skeletal age using the Greulich and Pyle atlas. Spearman's correlation was used to test the correlation between assigned skeletal age and chronological age. The results of the tests were analysed using SPSS.

RESULTS

The presence or absence of each ossification centre was examined in relation to the age of each child. Table 3 gives the time of the first appearance of each ossification centre for each sex. The table shows that for most ossification centres, except those of the ulna, the trapezium and the trapezoid, the intial appearance of the secondary ossification centres was the similar for both boys and girls at between 1 - 1½ yr of age. However, the age at which these ossification centres were seen consistently in all radiographs was older for boys than it was for girls, the secondary ossification centre of the 3rd metacarpal was seen in all individuals in the 2 yrs to 2½ yrs age group for girls but not until a year later in the 3 yrs to 3½ yrs age group for boys. The timing of the first appearance of the trapezoid and trapezium was later for boys being 4 yrs to 4½ yrs for the trapezoid and 3 yrs to 3½ yrs for the trapezium whereas for girls the initial appearance of both of these carpal bones was between 2½ yrs and 3 yrs of age. The timing of the appearance for the secondary ossification centre of the distal ulna was earlier in boys than in girls, however care has to be taken in relation to this observation. One male child had a secondary ossification centre for the distal ulna at the age of 3 yrs 1 month however the ossification centre was not observed again in boys until 5 yrs 3 months of age. The age that this ossification centre was first observed in girls was 4 yrs 7 months.

Tables 4-7 give the percentage of children in each age group for whom each ossification centre was observed. These tables clearly show that for many of the ossification centres, the age range over which they develop is relatively limited in relation to the age range of the children whose radiographs were observed. Ossification centres such as the distal radius, the metacarpals and most of the phalanges are all present by the 3rd year for boys and the 4th year for boys. The appearance of other ossification centres, such as the lunate, scaphoid, trapezium and trapezoid have a much wider spread in their appearance times and can be seen to ossify across a number of years. All of the secondary ossification centres observed had appeared in the female group by between 7 yrs and 7½ yrs, however the male group lagged behind and the complete appearance of all of the ossification centres was not found until between 8½ yrs and 9 yrs of age.

In any age estimation from the skeleton where as many different factors are taken into account as is possible in order to come to a final conclusion it is useful to be able to understand what weight to put on each observation. Discriminant function analysis was conducted on the

Table 3. Appearance of ossification centres by age group and sex

	Boys – OC (age groups – yrs)		Girls - OC (age group - yrs)	
	1st appearance	has appeared for all children	1st appearance	has appeared for all children
DEU	3 -3½	8 -8½	4½ -5	8½ -9
DER	1 - 1½	2 - 2½	1 -1½	2 - 2½
Triquetral	1 - 1½	6 – 6½	1 – 1½	6 – 6½
Lunate	1 - 1½	7½ - 8	1½ – 2	6 – 6½
Trapezium	3 -3½	8½ - 9	2½ - 3	8½ -9
Trapezoid	4 – 4½	8 -8½	2½ - 3	6½ - 7
Scaphoid	4 – 4½	8 -8½	4 – 4½	6½ -7
MC 1	1½ – 2	5 – 5½	1 - 1½	3 -3½
MC 2	1 - 1½	3 -3½	1 - 1½	2 - 2½
MC 3	1 - 1½	3 -3½	1 - 1½	2 - 2½
MC 4	1½ – 2	4 – 4½	1 - 1½	2 - 2½
MC 5	1½ – 2	4 – 4½	1 - 1½	2 - 2½
PP1	1½ – 2	5 - 5½	1 - 1½	3 -3½
PP2	1 - 1½	3½ - 4	1 - 1½	2 - 2½
PP3	1 - 1½	3 -3½	1 - 1½	1½ – 2
PP4	1 - 1½	4 – 4½	1 - 1½	1½ – 2
PP5	1½ – 2	4 – 4½	1 - 1½	2 - 2½
MP 2	1 - 1½	4 – 4½	1 - 1½	2½ -3
MP 3	1 - 1½	3 -3½	1 - 1½	2 - 2½
MP 4	1 - 1½	3 -3½	1 - 1½	2 - 2½
MP 5	1½ – 2	6 – 6½	1 - 1½	2½ -3
DP 1	1 - 1½	4 – 4½	1 - 1½	2 - 2½
DP 2	2 - 2½	6 – 6½	1 - 1½	3 -3½
DP 3	1½ – 2	3½ - 4	1 - 1½	2½ -3
DP 4	1½ – 2	3½ - 4	1 - 1½	2½ -3
DP 5	2½ -3	5 - 5½	1 - 1½	3 -3½

Table 4. Percentage of boys in which the ossification centres for the radius, ulna and carpals was identified by age group

Age group	Distal ulna	Distal radius	Triquetral	Lunate	Trapezium	Trapezoid	Scaphoid
1 -1½	0	47	5.88	11.76	0	0	0
1½ -2	0	83.33	27.77	0	0	0	0
2 – 2½	0	100	26.66	13.33	0	0	0
2½ – 3	0	100	29.4	5.88	0	0	0
3 – 3½	7.69	100	69.23	30.76	7.69	0	0
3½ -4	0	100	70.58	41.17	5.88	0	0
4 – 4½	0	100	84.61	46.15	7.69	7.69	7.69
4½ -5	0	100	76.47	47	35.29	11.76	11.76
5 -5½	9.09	100	90.9	63.63	18.18	9.09	27.27
5½ -6	0	100	80	60	20	20	13.3
6 -6½	30.76	100	100	76.92	53.84	53.84	61.53
6½ -7	20	100	100	100	60	60	80
7 -7 ½	53.33	100	100	93.33	53.33	73.33	73.33
7½ -8	72.72	100	100	100	81.81	90.90	90.90
8 -8 ½	100	100	100	100	77.77	100	100
8½ -9	100	100	100	100	100	100	100

Table 5. Percentage of boys in which the ossification centres for the metacarpals and phalanges was identified by age group

Age yrs	MC 1	MC 2	MC 3	MC 4	MC 5	PP 1	PP 2	PP 3	PP 4	PP 5	MP 2	MP 3	MP 4	MP 5	DP 1	DP 2	DP 3	DP 4	DP 5
1 -1½	0	17.65	5.88	0	0	0	23.52	23.52	23.52	0	5.88	11.76	11.76	0	11.76	0	0	0	0
1½ -2	5.55	55.55	50	50	33.33	11.11	61.11	55.55	50	22.22	11.11	22.22	22.22	11.11	61.11	0	11.11	11.11	0
2 – 2½	6.66	86.66	66.66	60	40	6.66	93.33	93.33	86.66	66.66	46.66	53.33	46.66	6.66	66.66	6.66	46.66	53.33	0
2½ – 3	29.4	76.5	64.7	52.94	47	11.76	94.11	94.11	88.23	52.94	58.82	64.7	70.58	35.29	64.7	11.76	35.29	35.29	11.76
3 – 3½	53.84	100	100	92.3	92.3	46.15	92.3	100	100	100	92.3	100	100	61.53	92.3	61.53	76.92	76.92	46.15
3½ -4	70.58	100	100	94.11	88.23	64.7	100	100	94.11	94.11	94.11	100	100	64.7	94.11	82.35	100	100	52.94
4 – 4½	84.61	100	100	100	100	92.3	100	100	100	100	100	100	100	100	100	92.3	100	100	100
4½ -5	94.11	100	100	100	100	94.11	100	100	100	100	100	100	100	94.11	100	88.23	100	100	88.23
5 -5½	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
5½ -6	100	100	100	100	100	100	100	100	100	100	100	100	100	86.66	100	100	100	100	100
6 - 9	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Table 6. Percentage of girls in which the ossification centres of the radius, ulna and carpals was identified by age group

Age -yrs	Distal ulna	Distal radius	Triquetral	Lunate	Trapezium	Trapezoid	Scaphoid
1 -1½	0	72.72	27.27	0	0	0	0
1½ -2	0	81.81	18.18	9	0	0	0
2 – 2½	0	100	60	30	0	0	0
2½ – 3	0	100	85.71	14.28	14.28	14.28	0
3 – 3½	0	100	86.66	60	6.66	6.66	0
3½ -4	0	100	90.90	27.27	16.18	27.27	0
4 – 4½	0	100	75	50	37.5	25	12.5
4½ -5	9.9	100	100	100	81.81	72.72	45.45
5 -5½	22.22	100	100	77.77	77.77	66.66	66.66
5½ -6	36.36	100	100	100	72.72	81.81	63.63
6 -6½	50	100	100	100	85.7	85.7	85.7
6½ -7	75	100	100	100	100	100	100
7 – 9	100	100	100	100	100	100	100

Table 7. Percentage of females in which the ossification centres for the metacarpals and phalanges was identified by age group

Age - yrs	MC 1	MC 2	MC 3	MC 4	MC 5	PP 1	PP 2	PP 3	PP 4	PP 5	MP 2	MP 3	MP 4	MP 5	DP 1	DP 2	DP 3	DP 4	DP 5
1 -1½	27.27	72.72	63.63	45.45	45.45	18.18	72.72	72.72	72.72	45.45	18.18	18.18	18.18	18.18	18.18	18.18	18.18	18.18	18.18
1½ -2	27.27	81.81	72.72	72.72	45.45	36.36	90.9	100	100	72.72	63.63	63.63	63.63	45.45	72.72	36.36	45.45	45.45	27.27
2 – 2½	70	100	100	100	100	60	100	100	100	100	90	100	100	60	100	60	80	80	60
2½ – 3	85.7	100	100	100	100	85.7	100	100	100	100	100	100	100	100	100	85.7	100	100	85.7
3 – 9	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

data. The discriminant function revealed a significant association between groups and ossification centres as a predictor of chronological age, for boys these accounted for 65.8% of between group variability and for girls 72.5% of variation. Closer analysis of the structure matrix shows that in reality a limited number of the ossification centres could be considered significant predictors. The stepwise discriminant analysis showed that for boys the five most significant appearance times were for the ossification centres for the distal phalanges 3 and 5, the proximal phalanx 3, the scaphoid and that of the distal ulna. For the female group the most significant appearance times of ossification centres in relation to the prediction of age was for those of the scaphoid, the distal ulna the middle phalanx 3 and the distal phalanx 5 (Table 9).

All of the radiographs were compared to the Greulich and Pyle atlas and age estimation was undertaken using a straight comparison method between the atlas and the radiograph. The individual was assigned the skeletal age by the plate which it most closely resembled. The results of the analysis were compared to chronological age, for both boys and girls the correlation was high, the R value for boys was 0.927 and for girls 0.895, both these results were significant (p<0.0001) (Table 9).

DISCUSSION

These radiographs comprise images from children of known sex and chronological age. Roma groups have a tendency to be nomadic and therefore in many countries are less likely to have the appropriate paperwork with which to prove chronological age when requested. This puts them at a decided disadvantage since that they are unable to access age appropriate resources including education and housing.

Whilst Schmeling *et al.* [21,22] have argued that the most important influence on maturational progression is based on socio-economic factors, the Roma form a significant minority in both Romania and many of the Eastern European countries and as a transitional population they are less likely to have access to the same standard of health care and nutritional intake as the more established local populations. This means that a population specific understanding of the skeletal development of Roma children is vital to anyone who might be attempting to undertake a forensic age estimation on them.

The results of this study show that there is a strong correlation between chronological age and age estimated using the Greulich and Pyle atlas. The correlations coefficients are similar for boys (R=0.909, p<0.0001) and girls (R=0.900, p<0.0001). This indicates that for this group of children there is some supporting evidence that in cases where chronological age is unknown, that the Greulich and Pyle atlas can be used to assess age, however this relationship does need to be examined further. Care also has to be taken in extrapolating this conclusion to older age groups without testing. The children in the groups which were tested were aged from 1 year of age to 9 years of age and few, if any, in these groups would be expected to have commenced the pubertal growth spurt [23,24]. Studies have shown that this is when children experience the greatest differences in growth velocity which in turn means that children reach maturational stages at different times [23-26].

Table 8. Most discriminatory ossification centres for boys and girls

Most discriminatory ossification centres after stepwise discriminant analysis			
Boys		Girls	
DP 5	0.657	Scaphoid	0.799
DP 3	0.582	Distal ulna	0.570
Scaphoid	0.438	DP 5	0.398
PP 3	0.427	MP 3	0.344
Distal ulna	0.336		

Table 9. Spearman's correlation for comparison of chronological age and estimated age using Greulich and Pyle

Spearman's correlation (R) for comparison of chronological age and age estimated using Greulich and Pyle	
Boys	0.927 (p<0.0001)
Girls	0.895 (p<0.0001)

The relationship between chronological age and the appearance of ossification centres showed that whilst the relationship between age and appearance was robust, there were a number of ossification centres for which the relationship was stronger. This study classed the first appearance of ossification seen on a radiographic image as the beginning of ossification, it is not possible to compare these timings with the ossification detected in dry bone studies because the identification of this stage will be different due to the different methods of detection which in dry bone studies would rely either on the ossification centre becoming big enough to differentiate or on histological detection [27-30].

In this population there were a number of ossification centres whose appearance was spread over a number of years, amounting to a longer period of time for both sexes. These ossification centres included the distal ulna epiphysis, the scaphoid, the 5th distal phalanx and the trapezium and trapezoid. Discriminant function analysis showed all of these were good predictors of age compared to other ossification centres such as the triquetral or the 2nd metacarpal. Three of the ossification centres which were considered to be most discriminatory after stepwise analysis were common to both boys and girls; the scaphoid, the distal ulna epiphysis and the 5th distal phalanx. The other three ossification centres were the 3rd distal and the 3rd proximal phalanges for boys and was the 3rd middle phalanx for girls. Whilst these were all different phalanges, they were all from the same digit. Garn identified the scaphoid and distal ulna epiphysis to be amongst the ossification centres which he identified as having the most obviously different maturity values for the different sexes [31]. This agrees with the discriminant function analysis of these ossification centres which demonstrate the strength of the relationship of the appearance of the ossification centre of the scaphoid and the distal ulna with age for each sex.

There are limitations to an analysis such as this which is based only on the appearance of the ossification centres rather than the changes in morphology which is the basis for most age estimation methods [12,13,17]. For example, the ossification centre of the distal radius scores low in predictive value for both boys and girls within this study whilst it plays an important role for other age estimation methods. The increase in the importance of the distal radius is based on the fact that whilst it appears at a relatively young age, it is the last of the epiphyses to fuse much later in the maturation process [13-17]. In a cohort as young as the one tested here, fusion of any of the secondary ossification centres which are developing within the skeleton of the hand wrist is not expected, removing this as a factor in the age estimation process. Age estimation in these younger children is therefore dependent on the appearance of both the primary ossification centres of the carpal bones and the secondary ossification centres of the digital rays. When examining the relationship of age of appearance and ossification centres Garn *et al.* concluded that ossification centres which were of high predictive value should be employed when utilised for age estimation [32]. This study identifies the most predictive ossification centres of the hand by sex for this population.

References

1. UNICEF (2007) Child protection from violence, exploitation and abuse. UNICEF. http://www.unicef.org/media/media_45451.html. Accessed 26.03.2013.
2. Schmeling A, Grundmann C, Fuhrmann A, Kaatsch HJ, Knell B, Ramsthaler F, Reisinger W, Riepert T, Ritz-Timme S, Rösing F, Rötzscher K, Geserick G. Criteria for age estimation in living individuals. Int J Legal Med 2008;122(6):457-460.
3. Schmidt S, Koch B, Schulz R, Reisinger W, Schmeling A. Comparative Analysis of the Applicability of the Skeletal Age Determination Methods of Greulich-Pyle and Thiemann-Nitz for Forensic Age Estimation in Living Subjects. Int J Legal Med 2007;121(4):293-296.
4. Schmidt S, Koch B, Schulz R, Reisinger W, Schmeling A. Studies in the use of the Greulich-Pyle skeletal age method to assess criminal liability. Leg Med 2008;10(4):190-195.
5. Büken B, Erzengin ÖU, Büken E, Safak AA, YazIcI B, Erkol Z. Comparison of the three age estimation methods: Which is more reliable for Turkish children? Forensic Sci Int 2009;183(1-3):103.e1-7.
6. Kim SY, Oh YJ, Shin JY, Rhie YJ, Lee KH. Comparison of the Greulich-Pyle and Tanner Whitehouse (TW3) methods in bone age assessment. J Korean Soc Pediatr Endocrinol 2008;13(1):50-55.
7. Tisè M, Mazzarini L, Fabrizzi G, Ferrante L, Giorgetti R, Tagliabracci A. Applicability of Greulich and Pyle method for age assessment in forensic practice on an Italian sample. Int J Legal Med 2011;125:411-416.
8. Van Rijn RR, Lequin MH, Robben SGF, Hop WCJ, Van Kuijk C. Is the Greulich and Pyle atlas still valid for Dutch Caucasian children today? Pediatr Radiol 2001;31 (10):748-752.
9. Zafar AM, Nadeem N, Husen Y, Ahmad MN. An appraisal of Greulich-Pyle Atlas for skeletal age assessment in Pakistan. J Pak Med Assoc 2010;60(7):552-555.
10. Hackman L, Black S. The Reliability of the Greulich and Pyle Atlas When Applied to a Modern Scottish Population. J Forensic Sci 2013;58 (1):114-119.
11. Bull RK, Edwards PD, Kemp PM, Fry S, Hughes IA. Bone age assessment: a large scale comparison of the Greulich and Pyle, and Tanner and Whitehouse (TW2) methods. Arch Dis Child 1999;81(2):172-173. doi:10.1136/adc.81.2.172.
12. Gilsanz V, Ratib O. Hand Bone Age. A Digital Atlas of Skeletal Maturity. Berlin (Germany):Springer;2005.
13. Greulich WW, Pyle SI. Radiographic Atlas of Skeletal Development of the Hand and Wrist. 2nd ed. Stanford (USA): Stanford University Press; 1959.
14. Tanner JM, Healy MJR, Goldstein H, Cameron N. Assessment of Skeletal Maturity and Prediction of Adult Height (TW3 method). London (UK):Saunders; 2001.
15. Tanner JM, Whitehouse RH, Healy MJR. A New System for Estimating Skeletal Maturity from the Hand and Wrist with Standards Derived from a Study of 2600 Healthy British Children. Part II. The Scoring System. International Child Centre, Paris; 1962.
16. Tanner JM, Whitehouse RH, Marshall WA, Healy MJR, Goldstein H. Assessment of Skeletal Maturity and Prediction of Adult Height. London (UK):Academic Press;1975.
17. Thiemann H-H, Nitz I, Schmeling A. Rontgenatlas der normalen Hand im Kindesalter. Leipzieg (Germany):Thieme;2006
18. Calfee R, Sutter M, Steffen J, Goldfarb C. Skeletal and chronological ages in American adolescents: current findings in skeletal maturation. J Child Orthop 2010;4 (5):467-470.
19. Pryor JW. Differences in the time of development of centres of ossification in the male and female skeleton. Anat Rec 1923;25:257-273.
20. Pryor JW. Time of ossification of the bones of the hand of the male and female. Am J Phys Anthropol 1925;8(4):401-410.
21. Schmeling A, Reisinger W, Loreck D, Vendura K, Markus W, Geserick G. Effects of ethnicity on skeletal maturation: consequences for forensic age estimations. Int J Legal Med 2000;113:253-258
22. Schmeling A, Schulz R, Danner B, Rosing FW. The impact of economic progress and modernization in medicine on the ossification of hand and wrist. Int J Legal Med 2006;120:121-126.
23. Tanner JM. Growth at Adolescence. 2nd ed Oxford (UK): Blackwell Scientific;
24. Tanner JM. Foetus into Man. London(UK):Open Books Publishing;1978
25. Hagg U, Taranger J. Maturation indicators and the pubertal growth spurt. Am J Orthod 1982; 82:299
26. Helm S, Siersbaek-Nielsen S, Skieller V, Björk A. Skeletal maturation of the hand in relation to maximum pubertal growth spurt in body height. Tandlaegebladet 1971;75:1223.
27. Scheuer L, Black S. Developmental Juvenile Osteology. 1st ed. London(UK): Academic Press;2000.
28. Fazekas IG, Kosa F. Forensic Fetal Osteology. Budapest (Hungary):Akademiai Kiado;1978.
29. Hellman M. Ossification of epiphysial cartilages in the hand. Am J Phys Anthropol 1928;11 (2):223-257.
30. Hill AH. Fetal Age Assessment by Centres of Ossification. Am J Phys Anthropol 1939;24(8):251-272.
31. Garn SM, Poznanski AK, Nagy JM. The Operational Meaning of Maturity Criteria. Am J Phys Anthropol 1971;35:319-326.
32. Garn SM, Rohmann, C.G., Blumenthal, T. and Silverman, F.N. Ossification Communalities of the Hand and Other Body Parts: Their implication to skeletal assessment. Am J Phys Anthropol 1967;27:75-82.