Age estimation of teenage boys during puberty

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Abstract:

Background: Age estimation of a minor whose identity is unknown must be accurate enough to respond to judicial requests. The main objective of this study is to accurately determine a teenager's age from simple and reproducible criteria.

Samples and methods: The first reference sample consists of 1720 measurements collected from 170 teenagers aged 11 to 16, over a period of five years. A second validation sample of 735 teenage boys aged 11 to 16 made it possible to verify the relevance of our estimates. The degree of maturation was determined using 4 pubertal stages: the stage below the age of puberty; the pre-pubescent stage; the para-pubescent stage and the pubescent stage.

For each pubertal stage an optimization of the values of the age was carried out in order to reduce the differences between the estimated and the actual age at the different age groups.

Results: The mean differences between estimated age and actual age from this values was -0.06 ± 0.91 years for the reference group and -0.49 ± 0.73 years for validation group.

Conclusions: Our method of age estimation is simpler and accurate. It could be used routinely in a forensic frame to respond to judicial requests.

KEY-WORDS: Forensic anthropology, age estimate, teenager, pubertal stages.

Age estimation of minor boys concerns often occur when individuals whose identity is unknown are involved in legal proceedings (1,2). In France, minors between 13 and 16 years of age can be placed under judicial control by order of a children's judge or an examining magistrate. They can also be placed in custody in the case of an indictment. In France, there is no age of penal responsibility, but reference is made to the notion of discernment. Thus the penal responses that can be made, vary according to the age of the minor. Between 10 and 13 years: educational measures or educational sanctions and between 13 and 16 years: educational measures, or educational sanctions, or punishments.

For these reasons, knowing the age of minors who are under 17 years old can be useful. Beyond the age of 17, most adolescents are pubescent, which does not allow us to differentiate them from pubertal stages.

During puberty, there is sometimes a large gap between the chronological age and the age of peak growth velocity, particularly in individuals with advanced or delayed puberty. In a National Research Agency program, we developed new growth curves of stature using age and maturation from a longitudinal data. In this study, we observed that the mean age of peak height velocity is 12.9 years for advanced puberty, 13.9 years for standard puberty and 14.8 years for delayed puberty (3).

Age estimation methods based on bone tests present the most difficulty in adolescence and mainly between the ages of 13 and 15 years. In this pubertal period, age estimation of minors presents a genuine problem for forensic scientists. Most of the time, magistrates or judges, through the intermediary of a physician, order the examination of hand and wrist radiography of teenagers whose civil status is uncertain. To date, bone age using hand and wrist radiography is the most commonly employed measure of biological age to estimate chronological age. The radiological images are compared with those of the Greulich-Pyle atlas (4). This method cannot accurately estimate the age of the minors in this pubertal period because the variability of age increases significantly at peak age velocity. For this reason, this age assessment method of minors with a reliability of ± 2 years still remains too imprecise (5-7). Furthermore, there is a large intra and inter observer variability with the use of the Greulich-Pyle atlas (8). The accuracy of age estimation was greater for younger children than for older children (9). The role of the doctor is to give an accurate age range estimation (10).

In addition, the age of a minor boy having committed an offence must be quickly established so as not to exceed the deadline of 48 hours of surveillance. Furthermore, no criterion can be revealed by a doctor without the agreement of the person concerned (11).

For all these reasons, it was necessary to develop a new age estimation method based on non-invasive pubertal criteria and to show the importance of sampling criteria in the accuracy of these estimates. The main objective of this study is to estimate the chronological age from biological maturation in teenage boys with high variability of age at peak growth velocity.

A cross-validation study was also performed from the model established on the reference group of teenage boys. This study is the only one that estimates age using secondary pubertal criteria. Currently this clinical methodology is not used in the courts.

Materials and Methods

We collected data from two different samples G1 and G2: the reference sample (G1) was carried out during the school years 2009 and 2010 in three secondary schools in the region of the town of Soissons, in the Aisne administrative department in agreement with the head teachers, the supervisory physician for school health services and the governing body of the academic authorities of the Aisne department.

This sample was made up of 170 boys aged 11 to 16 years who were followed-up over 5 consecutive years. We chose this age range which includes the extreme age range at the peak of growth between 12.9 and 14.8 years (3). Respecting the inclusion criteria of individuals in good health and in a particular age group led to the undertaking of this study in schools in the Soissons area. The boy's parents came from three different socioprofessional groups: workers and employees; skilled workers; and middle managerial staff. Moreover, we stated the ethnicity of the group studied. Therefore the sample was considered to be very homogeneous with a totality of Caucasian boys. Among the exclusion criteria, we excluded boys from other ethnic groups because the ethnic difference should be a cause of advanced or retarded maturation (2,12).

The permission of the advising doctors and the regional education authority of Aisne was also procured, all in accordance with the Helsinki Declaration and was approved by the ethical committee of the Medical authorities. All participants and parents gave their oral and written informed consent to participate in this study.

Longitudinal data were collected twice every school year. The database was made up of 1720 measurements which focused on chronological age and biological maturation, estimated using a simplification of the Tanner stages (13). The pubertal stage is only based on a non-invasive visual observation of the teenager in accordance with the absence of the examination of the genitalia advocated by French law. These puberty stages were assessed based on facial and axillary pilosity as well as voice change. Each pubertal stage is based on three qualitative criteria that allow us to differentiate the subjects The physician should check two boxes corresponding to the axillary hair, then the face pilosity with the voice change (Table1). The different stages of axillary hair according to the Wolfsdorf classification are illustrated in Figure 2 . The degree of maturation was thus determined using 4 different stages based on facial and axillary pilosity as well as voice changes: the stage below the age of puberty (ST1), pre-pubescent (ST2), para pubescent (ST3) and pubescent (ST4) (Table 1). However, although puberty follows an individual chronology growing with the age from ST1 to ST4, there is sometimes a gap between the axillary hair and the face pilosity. When there was concordance between the axillary and the face pilosity, we retained the indicated stage. In case of conflict between stages, we kept the higher stage. In practice, the majority of stages concerned no more than two consecutive stages.

Table 1: Classification of the subjects by pubertal stage

	ST1 Below the age of puberty Stage 0 of Tanner	ST2 Pre-pubescent Stage 1 and 2 of Tanner	ST3 Para-pubescent Stage 3 of Tanner	ST4 Pubescent Stage 4 and 5 of Tanner
Axillary hair	No hair	Start of hair growth	Very visible	Thick hair growth
Face pilosity and voice change	No facial hair and soft voice	Facial hair and voice instability	Moustache and deep voice	abundant beard hair and deep voice

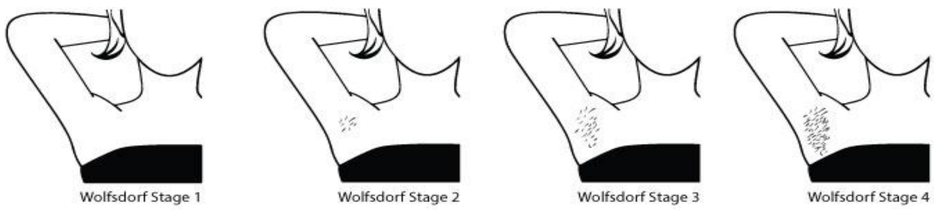

Figure 1: Wolfsdorf stages of axillary hair conforming to our pubertal stages.

The pubertal stages grid helps to bridge some gaps between physicians by retaining the highest pubertal stage between the axillary hair and the face pilosity with voice change (14) So, there are very specific differences between a child who has no facial hair (ST1) and a teenager who has a beginning of facial hair (ST2). As for the voice change, it is enough that the individual talk.

The two physicians who participated in our study received preliminary training in the collection of pubertal stages. They were not influenced by the age and educational level of the children as they observed differences in biological maturation within each age group.

The main objective of this study is to accurately determine a teenager's age from simple and reproducible criteria. We established our age estimation model from this sample of teenage boys.

A second validation sample of 735 regional Caucasian teenage boys aged 12 to 16 years (G2) made it possible to verify the relevance of our estimates. Chronological age and pubertal stages were systematically recorded for every boys. Age estimations were obtained from a cross-validation method using the model based on the first reference sample made up of 1720 measures. Age distribution by pubertal stages of the teenage boys is grouped in Table 2.

Table 2: The study sample: number of individuals per age class

Age (years)	Reference group G1	Validation group G2
[11-12[	292	6
[12-13[	453	124
[13-14[	488	266
[14-15[	342	226
[15-16[	145	113
Total	1720	735

Age estimation model

The linear regression line giving an estimate of age by pubertal stage passes by the mean values of age at the different pubertal stages. So we get 11.9 years at ST1, 12.9 years at ST2 , 13.9 years at ST3 et 14.9 years at ST4. Due to a very uneven distribution of pubertal stages in the extreme age groups of 11-12 and 15-16, there is an overestimation of the age estimate at

11-12 and an underestimation of the age estimate at 15-16 years. For this reason, we did not use this linear model to estimate the chronological age.

The chosen model consists in establishing a correspondence between the pubertal stages and the chronological age. The best fitted model was obtained by weighted line squares procedures using quantile-quantile plot as showed Figure 2. Under these conditions an optimization of age according to the pubertal stage in the different age classes led us to retain the following values: 11.3 years for ST1, 12.8 years for ST2, 14.3 years for ST3 and 15.6 years for ST4.

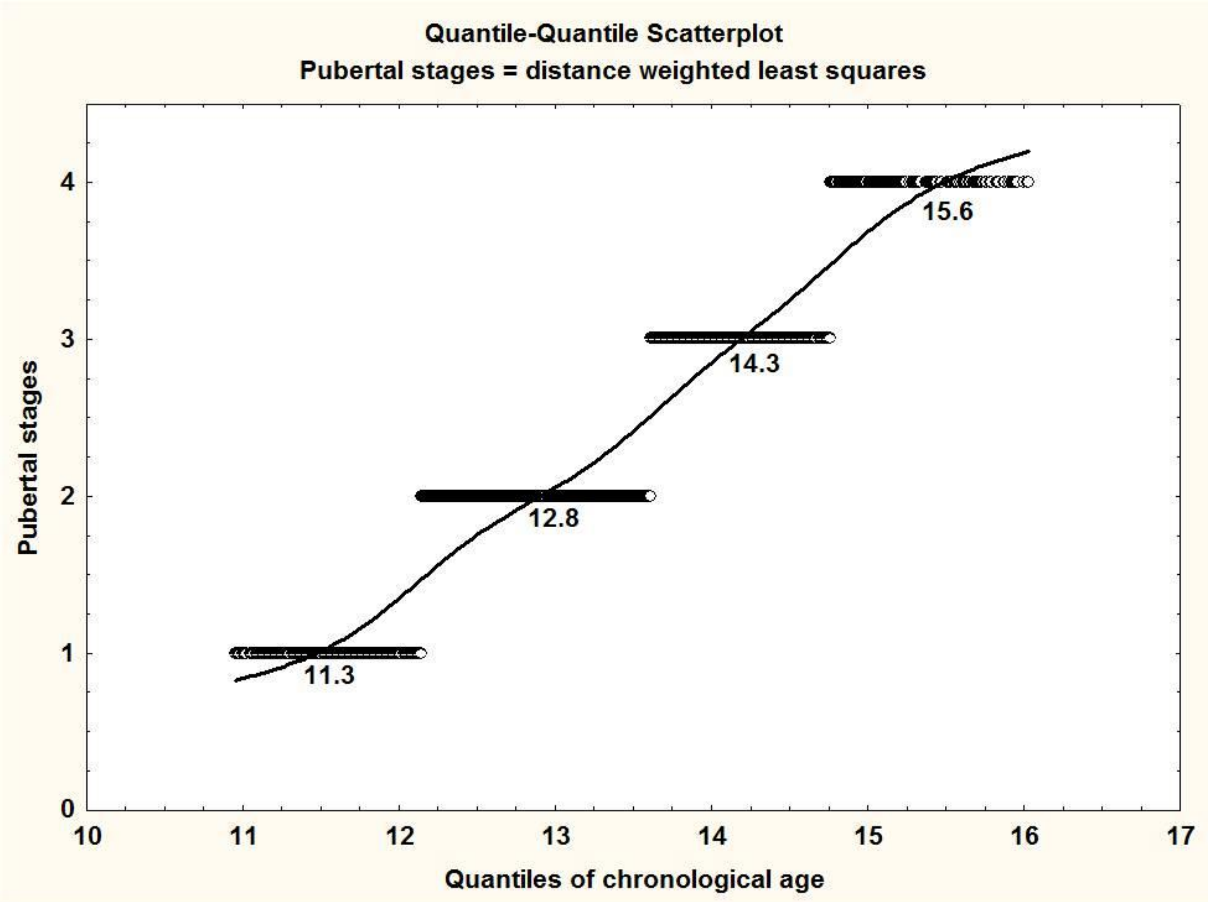

Figure 2: Fitted model establishing between the pubertal stages and the chronological age (in year).

Statistical analysis

The normality of the pubertal stages was verified by the skewness and kurtosis test.

Mean differences (d) in years between the chronological age (CA) and the estimated age (EA), standard deviation of mean difference (S.D.d) and 95% confidence interval of individual age (95% CI= m ± t $\sigma/\sqrt{n}$) with t=1.96 was calculated. Mean comparisons of the differences between the estimated age and the chronological age were made from the Student t-test.

For all tests, $P<0.05$ was considered significant. Statistical tests were performed using Statistica software (version 6; StatSoft, Tulsa, Okla, USA).

Results

Age and distribution by puberty stages of the sample studied were represented in Table 3. We did not observe any significant differences in the distribution of adolescents by pubertal stages.

Table 3: the study sample: age and puberty stages

Variables	Reference group G1 n=1720 Mean±SD	Validation group G2 n=735 Mean±SD	percentage comparison P value
Age (years)	13.3 ± 1.2	13.9 ± 1.1	
Puberty stages	%	%	
ST1	16.9	12.5	0.31
ST2	41.9	42.6	0.83
ST3	28.1	30.9	0.44
ST4	13.1	14.0	0.82

The distribution of pubertal stages is Gaussian with the coefficient of Skewness (γ_1 =0.2) and the coefficient of Kurtosis (γ_2 =-0.8). Estimates of the chronological age obtained from the different optimal age values corresponding to each pubertal stage are grouped in Table 4. Mean and standard deviation of the differences (d) between the (CA) and the estimated age (EA) and the 95% confidence interval of mean accuracy are also shown in Table 4. In the totality of each group, 89% of reference group G1 and 88% of validation group G2 have an age estimate of ± 1.5 years.

Table 4: Mean differences (d) in years between the chronological age (CA) and the estimated age (EA), standard deviation of mean difference (S.D.d) and 95% confidence interval of individual age (95% CI)

Samples	N	d	S.D.d	Lower bound 95%CI	Upper bound 95% CI
Reference groupe G1	1720	0.06	0.91	0.017	0.103
Validation group G2	735	-0.49	0.73	-0.54	-0.44

The difference (d) distribution data are normally distributed for the reference sample: skewness γ_1 =0.1 and the coefficient of Kurtosis γ_2 = 0.17 and for the validation sample: skewness γ_1 =0.06 and Kurtosis γ_2 = 0.3. Mean differences between the CA and the EA for each age group are indicated in Table 5.

Table 5: Mean difference ± standard deviation (d ±S.D.d) in years between the chronological age (CA) and the estimated (EA) for age cohort (G1=reference group and G2=validation group)

Age groups (in years)	Cohort	n	d ± S.Dd (in years)	Median	average comparison G1 vs G2 P-value	Average comparison G1 vs Total
[11-12[	G1	292	0.28 ± 0.74	0.07	<0.01	<0.01
	G2	6	-0.6 ± 0.04			
[12-13[	G1	453	0.18 ± 0.90	0.17	<0.01	0.01
	G2	124	-0.57 ± 0.82			
[13-14[	G1	488	0.09 ± 0.94	-0.24	<0.01	0.52
	G2	266	-0.33 ± 0.69			
[14-15[	G1	342	-0.08 ± 0.94	-0.06	<0.01	0.01
	G2	226	-0.70 ± 0.80			
[15-16[	G1	145	-0.5 ± 0.79	-0.35	0.11	<0.01
	G2	110	-0.37 ± 0.37			

We observe significant differences in age estimation in favor of G1 in all age groups except 15-16 years. Moreover, mean difference between CA and EA are higher than the mean value obtained on the G1 total group. These differences in age estimates are due to the fact that the mean ages are significantly larger in the G2 group than G1 for the same pubertal stage. The group G2 is older than G1 in all pubertal stages. (Table 6).

Table 6: Mean comparison of age in each pubertal stage between G1 and G2

	n	Age (year) G1 (n=1720) m ± SD	n	G2 n=(735) m ± SD	Mean comparison P value G1 vs G2
ST1	292	11,9 ± 0.6	92	12.4 ± 0.4	<0.01
ST2	720	12.9 ± 0.8	313	13.6 ± 0.6	<0.01
ST3	484	14.0 ± 0.8	227	14.3 ± 0.6	<0.01
ST4	224	14.6 ± 0.8	103	15.7 ± 0.4	<0.01

Discussion

Age estimation of minor boys whose identity is unknown is frequently required by magistrates or judges. On the scientific and medical level, age estimations are based on biological criteria. In our study accurate age estimation can be obtained from an age corresponding to the pubertal stage. Mean difference and standard deviation between age estimated and chronological age was 0.06 ± 0.91 years for the reference group (G1) and -0.49 ± 0.73 years for the validation group (G2).

In our study the adolescents of group G2 have a delayed puberty versus group G1. Age differences at the same pubertal stage are statistically significant. Consequently, there are significant difference in the mean age estimate between these two groups.

A new model developed in the G2 group giving the pubertal stage as a function of the quantile of age would indicate the following values: ST1 : 12.2 years; ST2: 13.4 years; ST3: 14.7 years et ST4: 15.9 years. A mean age estimate of 0.06 ± 0.64 years, equivalent to that obtained with the G1 group, would then be obtained.

These observations show the importance of the representativeness of the sample or population studied. We know that there are significant differences in age with the maturity according to the ethnicity. To overcome these differences, it would be desirable to establish a database on age and pubertal stages in order to correct the model developed by introducing ethnicity as a selective criterion. In this way, age estimates based on pubertal stages will be consistent with the various samples studied. In addition, our method of age estimate from pubertal stages can be performed on a large number of subjects in contrast to the Greulich and Pyle method which requires more restrictive clinical investigations.

The association between chronological age and pubertal Tanner stages has been developed in previous studies in which the authors analysed the timing of puberty in a contempory Brithish cohort of 8-14 year old boys. This study showed a strong association between physical growth and timing of pubertal development (15).

The most frequently employed method of bone age calculation is the Greulich &Pyle Atlas (16-19). This atlas is a qualitative method using reference radiographic images of the left wrist and hand from birth until 19 years of age. Bone age is calculated by comparing the degree of ossification in various hand and wrist bones using the Greulich & Pyle Atlas. The use of the Greulich & Pyle method in a forensic setting must take into account individual variability which also depends on the age of the minor (8). It appears that the Geulich and Pyle technique is the simplest and fastest method with good reliability for Australian and Middle Eastern ethnicity (20).

Age estimation using the Greulich and Pyle method was carried out by different authors in this pubertal period between 11 and 16 years (5-7,16, 19). The mean differences between the age estimate and the actual age are between -0.65 and +1.72 years with a standard deviation between 0.4 and 1.8. In most cases individual errors are greater than +2 years and sometimes more than 3 years.

Other methods were also used to estimate the chronological age.

-De Luca et al.(21) established a linear regression giving the chronological age from the ratio between the total bone area and the area of the carpal bones. However, mean deviations of the differences between chronological age and estimated age remain high: -1.25 ± 0.19 years at 12-13 years old and -1.35 ± 0.57 years at 13-14 years old.

-Cameriere et al. (22) calculated the ratio between the total area of carpal bones and epiphyses of the ulna and radius (Bo) and (Ca) on 150 Italian children and adolescents aged between 5 and 17. The regression model, describing age as a linear function of the ratio Bo/Ca gives a median of the absolute values of residuals of 0.08 and a standard error of estimate of 1.19 years.

-Remy et al. (23) made age estimations from radiography of the hand with a mean standard error which never exceeds 1 year for the 95% confidence interval. Between 13 and 18 years old, 95% CI was ± 0.69 years with an 81% probability. This value remains larger than that of

Buken with the Greulich &Pyle method 95% CI =(0.23; 0.19) and larger than that of our sedentary sample 95%CI=(0.017;0.103).

-Garamendi et al. (24) showed that the Greulich and Pyle and dental age methods gives a mean error ± SD of 1.07 ± 1.76 years on 114 immigrant Moroccan males aged between 13 and 18. They indicated that the degree error in the results has to be considered by the physician as considerable.

-Serinelli et al. (25) indicated that Greulich &Pyle method is not as accurate a method as TW2 or TW3 for both Caucasian people and Mongoloids, even if it is the one most often used.

In most cases, the uncertainty of age estimations among teenagers aged between 13 and 16 remains high. Thus, it would seem that the Greulich and Pyle atlas is unsuitable for the populations studied, with an underestimation of age before puberty and an overestimation of age after puberty (26). Greulich &Pyle remains however the reference method to estimate bone age regardless of the geographical origin of the population (6, 27).

In France, the recommendations of the National Consultative Committee of Ethics (28) must be applied when there is a requisition to determine bone age for forensic purposes. These recommendations require an age estimation accurate within one year. Thus, it is not possible to obtain an accurate estimate of chronological age using bone age. Judicial requests concerning the age of teenagers have penal implications. This necessitates a prompt medical answer as minors cannot be held in detention for more than 48 hours (29).

However, the Advisory Committee of ethics (28) criticized age estimation obtained from radiographic examination of the left wrist and hand using the Greulich and Pyle Atlas or the Tanner and Whitehouse method.

The present study provides answers to various questions relating to teenagers' chronological age in the pubertal period from both a scientific and a legal point of view. Indeed, these pubertal stages rely solely on non invasive visual observation of the teenager without, examination of genitalia, as recommended by French law.

Furthermore, our method of age estimation is simpler and more accurate than the current radiological techniques. It can be easily used on large samples with an immediate result.

The simple and non invasive practices used in our model largely respond to the various requirements of the judicial authorities.

Conclusions

During puberty among boys aged between 11 and 16 years, we observed a significant gap between chronological age and puberty maturation. Radiographic techniques are quite constraining because they require a large collection of data and provide an age estimation over ± 2 years at teenager. For this reason, it was therefore necessary to use a faster, non invasive method in order to give a better age estimation.

The present study allowed us to determine the chronological age of Caucasians teenagers aged 11 to 16 based on a simple, reproducible and non invasive method using pubertal stage. A qualitative examination was carried out based on facial and axillary pilosity as well as voice change. A cross-validation study was then validated on a teenage boys with a good accuracy. Our method can be extrapolated to other ethnicities provided that the optimal age values are modified according to pubertal stages.

The simplicity and accuracy of this method means that it could well be used shortly within a medico-legal framework in response to legal requests.

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