EXERCISE AND SPORTS MEDICINE CLINIC

ORIGINAL ARTICLE

PREDICTION EQUATION OF BONE AGE IN SPORTS INITIATION THROUGH ANTHROPOMETRIC VARIABLES

Breno Guilherme de Araújo T. Cabral[1,4]
Suzet de Araújo Tinôco Cabral[1,4]
Roberto Vital[2]
Kenio Costa de Lima [3]
Tabata Alcantara[5]
Victor Machado Reis[6,7]
Paulo Moreira Silva Dantas[1,4]

1. Physical Education. Federal Univeristy of Rio Grande do Norte – Natal, RN, Brazil.
2. Medicine. Federal University of Rio Grande do Norte – Natal, RN, Brazil.
3. Dentistry. Federal University of Rio Grande do Norte – Natal, RN, Brazil.
4. Laboratory of Physical Activity and Health, AFISA-UFRN, Natal – RN, Brazil.
5. Medicine. Potiguar University – UNP.
6. Physical Education. University of Trás os Montes and Alto Douro – UTAD-PT.
7. Investigation Center in Sports, Health and Development – CIDESD- PT.

Mailing address:
Campus Universitário, UFRN - Departamento de Educação Física
Av. Sen. Salgado Filho, 3000
59078-970 – Potilandia, Natal, RN, Brasil
E-mail: brenotcabral@gmail.com

ABSTRACT

Introduction: Sports performance has currently developed in a fast and concrete way, requiring hence an efficient evolution of different areas of sports sciences, offering scientific support necessary to the continuity of this phenomenon. Objetive: The present study aimed to develop a prediction mathematical equation for bone age of young athletes, based on anthropometric variables. Methods: In order to achieve the final result, skinfolds, body circumferences and bone diameters, chronological age and bone age have been measured. The statistical treatment used correlation between variables, a multiple linear regression model with backward. Results: The study presented as final result a model equation which explains 75.4% ($r = 0.868$; $R^2 = 0.754$) of the variation of the bone age using chronological age, height, triceps skinfold, arm corrected perimeter and femur and humerus diameters. Conclusion: It was concluded from the results that this type of model shows approximate values to those observed through hand and wrist radiography, which makes it important in the observation of maturational stage through tests of easy application performed by professionals of the sports field.

Keywords: maturation, morphology, volleyball.

INTRODUCTION

The literature has mentioned that knowing the moment at which children and adolescents are within the maturational development process is an important instrument to enable suitable sports initiation, minimizing hence possible errors in the detection, selection and promotion of young athletes[1].

The maturational process can be evaluated in many different ways. However, despite the reliability of the different evaluation alternatives, bone maturation deserves special attention for being the most reliable and efficient, since the changes in shape and density of the bone allow the measurement of the trajectory throughout the growth period[2]. The different health fields have tried to find less costly and invasive methods to identify maturation. However, the development of such methods is considered of great value for the sorts sciences due to the confirmed correlation between maturational stage and athlete's performance as well as the importance of implementing this kind of evaluation in the selection, discovery and guidance of sports talents[3].

The development of a less invasive and costly equation which can be applied in the sports scenario for maturational analysis of novices in the sports practice, and uses only variables of easy measurement and low cost, which allow the observation of the maturational stage of an individual, becomes extremely relevant. Within this context and in the face of the need of practical identification of early guidance of young sports talents, in a trail to avoid errors in the process of formation of these novice athletes, the main goal of this study was to develop a prediction mathematical equation for bone age, from anthropometric variables.

METHODS

The research was descriptive with transversal typology, with a sample with 149 subjects of both sexes and aged between 8 and 14 years, intentionally chosen in a non- probabilistic way among students of a project which works with sports initiation in the city of Natal, RN, Brazil. The tests performed strictly followed the protocols chosen for observation of the variables under question, according to the procedures previously authorized by the Ethics Committee (legal opinion # 071/071/2010) in the items proposed by the resolution 196/96-CNS-Brazil and respecting the international guidelines for experimentation with human beings (Declaration of Helsinki, 1975).

The anthropometric variables were observed on the week following the performance of the X-ray examination to avoid interference of the maturational process, since this process is continuous. In the present study, bone age was considered the dependent variable, while the other variables were independent. In an attempt to minimize to the most any interference in the measurement of the anthropometric measures, we were careful in observing the intra-evaluator Measurement Technical Error (MTE), since all the measurements were performed by the same evaluator. The 0.7% to 4.6% and 9.52% to 43.25% of MTE intervals were observed in the Coefficient of Variation[4].

For the anthropometric evaluation, the subjects were measured barefoot and wearing light clothes and the following measures were observed:

Body mass: individual at standing position on the center of the platform of the scale, mass was recorded in kilograms. A 110V Filizola electronic scale with capacity for 150 kg and divisions of 1/10 of kg was used.

Body stature: Distance between the sole of the feet and the highest point of the head (vertex), in apnea, with head oriented at the Frankfurt plane. The measurement was recorded in cm and a Sanny ES2020 stadiometer was used.

Perimeters, diameters and lengths: in order to check perimeters, diameters and lengths the Marfell-Jhones *et al.*[5] procedures were followed and a SANNY tape measure was used as instrument (precision of 0.1 mm) for perimeters and lengths measurement, and a SANNY small pachymeter for the diameters, both made in Brazil. The measures taken were: upper and lower limbs, foot and hand length; Arm perimeter (AP); Arm corrected perimeter (ACP), which refers to the arm perimeter in centimeters, subtracted by the tricipital skinfold value (TR) transformed in centimeters; leg perimeter (LP) and the leg corrected perimeter (LCP), which refers to the leg perimeter (calf) in centimeters, subtracted by the leg skinfold value transformed in centimeters; bi-crista iliac diameter (Bi.cr di), Biacromial diameter (Bi.ac. di), Femoral Biepicondyle (FD) and Humeral Biepicondyle (HD).

Skinfolds: The skinfolds measurement were taken on the right side of the subjects and repeated three successive times on each site following the protocol by Marins and Giannichi[6]. Mean value or two coincidence values were used as measure value. Mean or two coincidence values were used as measurement values. SANNY scientific skinfolds calipers were used to measure the skinfolds. The skinfolds used were namely: tricipital (TR); leg (ML); supraspinal (SS) and subscapular (SS).

Chronological age in years was determined by the sum of months of life of the individual, from his date of birth divided by 12, resulting hence in his chronological age in years.

Bone age, the dependent variable of the study, was determined with a medical report diagnosed through a hand and wrist X-ray. A single radiographic dose was individually administered and the X-rays were taken with a Rhos equipment with a Toshiba tube of 60 Kvp and 9 mA, at focus-film distance of 75 cm. The film used was a 18 x 24 cm Kodak TMATX on a chassi with rare-earth ecran, developed on a DENTXR automatic processor, with chemical components for Kodak. Subsequently, the pelicules were independently analyzed by three radiologists, through the Grave and Brown method (1976)[7], which observes the sequence of events of the ossification through the X-ray, using the atlas proposed by Pyle, Waterhouse, Greulich (1971) for bone age comparison and determination. Using the mentioned method, the Kappa statistical test was then applied with the aim to evaluate reproducibility and reliability of the observers and optimum value of inter-evaluator concordance was obtained (0.88).

The Stata 10.0 software was used for the statistical analysis and model designing, where descriptive statistics was observed and measurements of central tendency and dispersion were established. The assumption of data normal distribution was verified through the Kolmogorov-Smirnov test, and the Pearson correlation coefficient between bone age and the remaining variables with significance level of $P < 0.05$ was applied. A multiple linear regression with backward model from the results found, while in the final model, all the independent variables which presented correlation significance with bone age < 0.20 were included. Prior to the variables inclusion in the multiple linear regression model, the existence of multi colinearity between the independent variables through the variance inflation factor (CIF) and tolerance was tested, which demonstrated there is no multi colinearity between them. The values were also analyzed through the concordance thresholds of the Bland and Altman plot.

RESULTS

In a first moment in table 1, for effective mathematical model which could predict bone age, the calculation of the linear correlation coefficients was performed among the bone age variables, anthropometry and chronological age.

In the sequence, multiple regression analysis with backward model was used, where mathematical models were developed for bone age estimation. According to the regression analysis, the best parameters obtained for the bone age model prediction, following the significance level criteria of the models, highest multiple correlation coefficient (r), highest determination coefficient (R^2) and practicality in using the prediction model, were described

Table 1. Correlation of the bone age and the anthropometric variables.

	BONE AGE N = 149	
	r	p
Chronological age	0.774	< 0.001
Body mass	0.589	< 0.001
Stature	0.732	< 0.001
Biacromial diameter	0.645	< 0.001
Bi-crista iliac diameter	0.483	< 0.001
Lower limb length	0.659	< 0.001
Upper limb length	0.538	< 0.001
Foot length	0.447	< 0.001
Hand length	0.171	0.037
Tricipital skinfold	0.142	0.090
Supraspinal skinfold	0.206	0.013
Leg skinfold	0.122	0.146
Humeral diameter	0.241	0.004
Femoral diameter	0.287	< 0.001
Arm perimeter	0.428	< 0.001
Leg perimeter	0.524	< 0.001
Arm corrected perimeter	0.461	< 0.001
Leg corrected perimeter	0.552	< 0.001

below in the parameters described in table 2 and the model described in equation 1.

After the parameters obtained in the linear regression have been observed, the multi colinearity among the independent variables was tested in an attempt to avoid errors caused by the results bias between variables, making any estimation impossible. The results demonstrated there is no multi colinearity among variables, being its absence one of the premises for the establishment of a correct multiple linear regression model, making the development of the mathematical equation for estimation of bone age in children aged between eight and 14 years possible, described as the main aim of this study.

Table 2. Parameters obtained for multiple linear regression.

	Non-standard coefficient		Standard coefficient			Confidence interval for the beta (95.0%)	
	Beta	Standard error	Beta	t	p	Lower threshold	Upper threshold
(Constant)	-11.620	1.570		-7.399	0.000	-14.726	-8.514
Stature	7.004	1.402	0.314	4.995	0.000	4.231	9.777
Sex	1.226	0.230	0.243	5.324	0.000	0.771	1.682
CA	0.749	0.098	0.447	7.630	0.000	0.555	0.943
Tricipital	-0.068	0.024	-0.181	-2.811	0.006	-0.117	-0.020
ACP	0.214	0.057	0.289	3.790	0.000	0.102	0.326
Humeral diam	-0.588	0.260	-0.144	-2.256	0.026	-1.103	-0.073
Femoral diam	0.388	0.164	0.150	2.371	0.019	0.064	0.712

Equation

$$\text{Bone age} = -11.620 + 7.004\,(\text{stature}) + 1.226.D_{sex} + 0.749\,(\text{age}) - 0.068\,(\text{Tr}) + 0.214\,(\text{ACP}) - 0.588\,(\text{HD}) + 0.388\,(\text{FD})$$

Where: for the male sex: $D_{sex} = 0$, for the female sex: $D_{sex} = 1$, Stature (m), Age (years), Tr = tricipital skinfold (mm), ACP = arm corrected perimeter (cm), HD = humeral diameter (cm), FD= femoral diameter (cm).

For the mathematical equation model developed in the present study (r = 0.868) all the independent variables which presented correlation significance with bone age < 0.20 were included, where 75.4% of the bone age variation ($R^2 = 0.754$) could be explained, with an adjusted $R^2 = 0.741$, established from the sample size of the variables included in the model. Estimation standard error for the model was = 1.243.

Figure 1 presents the results of bone age calculated through the hand and wrist X-ray, confronted with the values estimated by the prediction equation derived from the variables developed in the present study, where they were evaluated by the concordance thresholds of the Bland and Altman plot.

The difference between bone age in the two methods (X-ray and proposed equation) was demonstrated in figure 2, where it was observed that bone age presented only 4.16% of the points outside the thresholds (± 2SD).

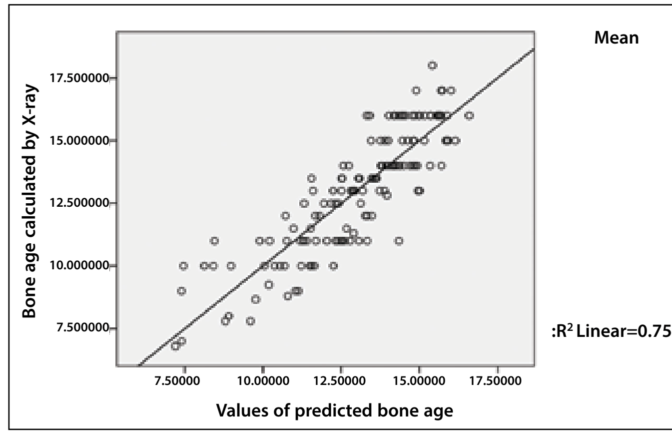

Figure 1. Linear regression between bone age and predicted bone age.

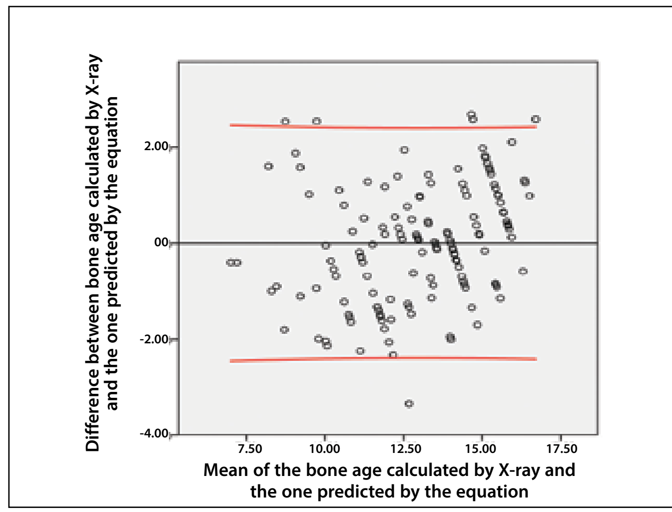

Figure 2. Bland Altman plot.

DISCUSSION

Table 1 demonstrates the existence of correlation between different variables and bone age, corroborating studies by Malina *et al.*[8] and Frainer *et al.*[9], where, from the results inserted there, the components which will compose the mathematical model proposed as general aim of this study will be able to be determined.

The alterations experienced by the body under growth concerning the anthropometric variables become latent in the correlations indicated in the study, with special attention to the structures which involve diameters, lengths and mass, corroborating results found in the literature, which observe an important correlation of the morphological alterations[10,11].

Bone age has been considered a reference in the determination of biological age and maturation, justifying hence its use, since the bone tissue differentiates, develops and matures along determined lines, which enables that from the center of primary ossification the development status of an individual can be more safely determined[12]. Table 1 presents the results of the present study as well as the high correlation between bone age and chronological age, being chronological age a variable of proved influence concerning bone age, corroborating the studies by Malina *et al.* [8] and Frainer *et al.*[9].

However, in the sports field, chronological age has still been used as a reference standard, since the categories are normally guided by it, besides the acknowledgement that there is correlation between it and the maturational stage of the individual, and consequently, in the motor development, as the correlation studies evidence[13]. Such studies indicate a strong tendency with significant results ($p < 0.01$) of the young subjects with heavier body mass and taller stature, thus older and more mature to present higher scores in the motor performance tests. Therefore, due to the easiness of use, many sports entities when working with selection and promotion of young athletes, still use the chronological age as a criterion or its association with stature as a pre-requisite[14.]

Such statements may still be reinforced with the studies by Veiga[15], who confirm the high correlation between bone age and maturation analyzing different methods, from the prediction of the relative age (RWT = 0.53, KR = 0.71 and TW3 = 0.98), and studies by Linhares *et al.*[1] with sexual maturation, which reveal gradual increase of bone age (9.4 - 11.4 - 12.3 - 13.7 - 14.5) according to the stages of pubertal development (I – II – III – IV), respectively, presenting significant difference between them.

Thus, it is confirmed that the results found in the literature, when they show that chronological age and stature cannot be independently observed when working with spots talents[16]. Different studies in Brazil and the UUA with volleyball athletes associate late maturation with high performance athletes, even presenting positive correlations which associate the taller athletes and with high sports performance with a delayed maturation process, as in the studies by Borjikian *et al.*[17], which evidence that the women athletes of the Brazilian adult team (high performance) presented significantly late menarche age (13.0), if compared with the ones from the youth Brazilian team (10.5) or even with the adult athletes from clubs in Brazil (11.1). Such study also mentions that the taller female athletes are also the ones with late maturation, agreeing with the studies by Castilho *et al.*[18] and de Malina *et al.*[8]

The literature reveals that when this variable is observed in the selection process of athletes, it is important to include criteria such as maturation, avoiding hence errors in the sports development process, since the athletes who present taller stature from an early age may be individuals with early maturation and present higher technical control[16,17].

Following this flow of thinking, Cabral *et al.*[19,20] and Cabral reinforce this idea pointing out the great importance of the stature variable in order to reach high sports performance in volleyball, being it hence a special variable within the selection process of athletes for this modality where according to Cabral *et al.*[19], the Brazilian men's youth team presents stature mean of 1.96 meters, while the women's presents mean of 1.81 meters in the same category. Such results have been observed in the last years in all volleyball categories of high performance, presenting stature means similar to the ones observed in the studies with the adult category[19].

However, when a variable like stature is independently analyzed, it can be observed a serious risk of exclusion of athletes with a potential during the initiation process in sports like volleyball, despite knowing that the literature confirms the great importance of this variable to high performance in this modality[8,21].

Therefore, maturation corresponds to a factor of great influence on the different variables normally observed, when selecting young athletes, being many times aassociated with the results in the high levels of sports qualification, where Malina *et al.*[8] mention that children with late maturation tend to be taller than the ones with early maturation, and Borjikian *et al.*[17], when observed that the female athletes with higher performance in volleyball presented late maturation, or even Malina and Bouchard[2], when they related maturation and motor coordination levels of the individual.

The development of methods which allow helping to predict characteristics specific to athletes should possess a strong statistical focus, trying to find physiological attributes which significantly differentiate the individuals within the development process. In this context, Veiga[15] states that concerning maturation we can highlight some equtions used for prediction of relative stature and evaluation of maturational stage, asa the method proposed by Roche, Wainer and Thissen (1975) – RWT, which let us predict stature without the use of bone age; the method proposed by Khamis and Roche (1994) – KR, which suggests formulas different from the ones used by the RWT method of determination of mature stature, with no use of bone age either, and the TW3 method, which uses the bone age values to predict the final adult stature of the subjects, being the last method considered the most reliable of the three. The RWT and KR methods use stature, body mass and mean parental stature as prediction variables[15].

The use of these methods becomes an important step beyond the subjectiveness still present in the process of selection and promotion of talents in sports, allowing the approach of relations between the variables and the observation of the importance of them in the different development stages[22,23]. In the work of sports initiation there is a tendency to select individuals who present early physical development over those with expected or late development, since they present competitive advantages and superiority in morphological standards. Such fact may be considered a mistake in the long run, since the individuals with early maturation will not necessarily continue to present this advantage in adulthood; however, due to competitiveness, the clubs have searched for immediate results and forget about the results perpetuation[14,24].

Although bone age has been considered the gold standard in the literature and presents high reliability, the mathematical models which allow identifying the maturational development, such as RWT, KR and TW3 through the predicted stature, have been considered of great relevance to the sports field due to its simple use and applicability. Nevertheless, studies have demonstrated different results in these methods and also verified that when observing the correlation between them and bone age, all of them significantly correlate; however, the TW3 method is the one which presents the highest correlation (0.98), being this one the only method among the mentioned ones which uses bone age in within the prediction variables[15]. However, in practical terms, bone age cannot be always observed, since it is usually verified through the reliable methods which use hand and wrist X-ray. Thus, the development of a mathematical equation which is able to predict bone age without using X-ray is crucial to the sports science.

The results of the present study allow an analysis from different variables, observing the bone age correlation with these variables, where the ones with better correlation were later highlighted, and from a multiple linear regression with backward model, the parameters for a mathematical equation for prediction of bone age were defined. The equation had bone age as dependent variable and chronological age and stature, tricipital skinfold, arm corrected perimeter and humeral and femoral diameters as independent variables.

As previously mentioned, the model developed from the results found in this study (figure 1) explains 75.4% of the variation of the bone age, without the use of bone X-ray, justifying hence, the crucial need of elaboration of methods with low cost, practical application and easy use. Concerning the maturation variable, it is worth mentioning that despite presenting the best result in the correlation test, it could not make part of the equation, since it uses the bone age itself as a component to express its result.

The literature has strongly stated that ignoring the maturational and of influence of the sports initiation variations factors can become a tendency to select individuals who present early physical development over those with expected or late development, making it easy to make recurrent mistakes in the selection and guidance of young athletes[25-27]. Such statements are complemented by Malina *et al.* (2007)[25], when they mention that the anthropometric and physical variables aassociated with late maturation may constitute great advantages to a future sports talent.

CONCLUSION

The present study reveals the correlation between bone age and the different physical and motor variables, making it evident its importance as an indication of maturation and the need to use different methods as sports selection and guidance criteria. Such measures should be considered when using practical tests of easy application able to minimize the possibilities of error in the formation and development of future athletes in different maturational status. The found results also let us elaborate a mathematical model predictor of bone age which explains 75.4% of the variation of this variable and may be used through methods and components of easy application which do not use X-ray.

All authors have declared there is not any potential conflict of interests concerning this article.

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