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original article

Discriminant analysis of pubertal maturation in young males based on anthropometric characteristics

Análise discriminante da maturação puberal de jovens do sexo masculino, a partir das características antropométricas

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Abstract – The relationship between anthropometric variables and maturation stages is important for a more detailed monitoring of pubertal development and may provide a suitable tool for clinical diagnosis. The aim of this study was to analyze the predictive contribution of anthropometric variables to pubertal maturation using multivariate discriminant analysis. A total of 190 boys aged 8 to 18 years, from public and private schools in Natal, Brazil, participated in the study. Thirty-two anthropometric variables were measured and pubertal maturation was evaluated objectively by observing pubic hair development. Measures of central tendency and dispersion, inferential analysis of variance, and multivariate discriminant analysis were used for statistical analysis. Pubertal advancement was accompanied by significant changes in anthropometric variables ($p<0.05$). Discriminant analysis identified eight variables with a high predictive capacity of pubertal maturation: age, sitting height, biacromial breadth, acromiale-radiale, trochanterion-tibiale laterale and tibiale laterale bone lengths, and abdominal and forearm girths. The anthropometric variables showed a high correlation with the classification of pubertal maturation, demonstrating a high predictive level among them. These findings indicate the possibility of developing a predictive equation for pubertal stages.

Key words: Anthropometry; Discriminant analysis; Puberty; Sexual maturity.

Resumo – *A relação entre a antropometria e os momentos maturacionais é de grande importância para o acompanhamento mais detalhado do desenvolvimento puberal, pois pode ser considerado como um meio externo adequado para o diagnóstico clínico. O objetivo do presente estudo foi analisar a contribuição preditiva das variáveis antropométricas sobre a maturação puberal, a partir do método multivariado de análise discriminante. Foram avaliados 190 sujeitos do sexo masculino, entre oito e 18 anos, alunos de escolas públicas e privadas de Natal, Brasil. Trinta e duas variáveis antropométricas foram mensuradas e a avaliação da maturação puberal foi realizada a partir do método objetivo da pilosidade púbica. A estatística foi representada pelos valores de tendência central e seus derivados, e de forma inferencial, pela Análise de Variância e análise discriminante multivariada. O avanço dos estágios puberais foi acompanhado de modificações significativas das variáveis antropométricas ($p< 0,05$). A análise discriminante identificou oito variáveis com alta capacidade preditiva da maturação puberal, sendo elas a idade, ATC, diâmetro bi-acromial, comprimentos ósseos acrômio-radial, trocânter-tibial e tibial, e perimetrias de abdômen e antebraço. Estas variáveis foram responsáveis por estimar os estágios puberais com índice preditivo de 77,4% de chance de acerto, confirmando a alta relação entre estes parâmetros. As variáveis antropométricas apresentaram uma alta relação com a classificação da maturação puberal, demonstrando um alto nível preditivo entre elas, e confirmando a viabilidade da criação de uma equação preditiva dos estágios puberais.*

Palavras-chave: *Antropometria; Análise discriminante; Puberdade; Maturidade sexual.*

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INTRODUCTION

Considered one of the most complex phases of human development, puberty is understood as the process of transformation from the child's body into an adult body capable of reproduction. This process is directly related to events of mental, somatic and sexual maturation[1,2]. During this phase, the activation of the production of adrenal androgens is the result of maturation of the adrenal cortex, a process known as "adrenarche". This event manifests as clinical signs such as the appearance of armpit odor, an increase in skin oiliness, and growth of axillary and/or pubic hair ("pubarche")[3,4].

In addition to pubic hair, the clinical evaluation of male genital and female breast development is the standard method to monitor pubertal development, since it identifies the progression of secondary sexual characteristics[2,5-7]. The method proposed by Marshall and Tanner[8] is the most commonly used for this purpose, which describes the main changes in external sexual characteristics that occur during the period before (stage 1) and after puberty (stage 5).

In boys, these stages are marked by an increase in the production of sex hormones. These hormones are responsible for morphological modifications and, consequently, for the process of physical growth and differentiation of body composition and anthropometric measures[9,10]. The relationship between maturation stages and anthropometry is important for a more detailed monitoring of pubertal development, since external characteristics are more visible for clinical diagnosis[5,9,11]. In this respect, anthropometric assessment is a potentially adequate and suitable tool for the evaluation of pubertal stages, since it avoids more delicate situations such as embarrassment and/or lack of privacy during the observation of secondary sexual characteristics[11,12].

However, the analysis of this relationship should not only take into account a perspective of causality, but also the inter-relations between variables, by evaluating the capacity of one or more dependent variables to predict an independent variable. Therefore, in this study multivariate discriminant analysis of pubertal maturation was performed based on anthropometric variables, identifying the inter-relation between variables and their predictive capacity.

METHODOLOGICAL PROCEDURES

Sample

A cross-sectional study was conducted on 190 boys aged 8 to 18 years, who were randomly selected at four public and four private schools in Natal, Brazil. The sample size was defined based on a previous pilot study conducted at the Pediatrics Hospital of the Federal University of Rio Grande do Norte (Hospital de Pediatria da Universidade Federal do Rio Grande do Norte – HOSPED-UFRN) using a 95% confidence interval and stand-

ard deviation, and standard error of the estimate of the data. A minimum sample size of 181 subjects was defined.

Only subjects whose parents or legal guardian signed the free informed consent form were submitted to the evaluations. The initial sample consisted of 198 boys. However, on the basis of criteria previously established by the researchers, eight subjects were excluded because of the presence of some genetic syndrome, cognitive deficit, treatment with growth hormone, gonadotrophin-releasing hormone agonists and sex steroids, or a diagnosis of chronic diseases that would compromise the interpretation of the results.

The study was approved by the Research Ethics Committee of UFRN (Protocol No. 618/11).

Anthropometric assessment

The following 30 anthropometric variables were measured according to the recommendations of the International Society for the Advancement of Kinanthropometry (ISAK)[13]: body mass, stature, sitting height, five breadths (biacromial, biiliocristal, transverse chest, biepicondylar humerus, and biepicondylar femur), five bone lengths (acromiale-radiale, radiale-stylion, midstylion-dactylion, trochanterion-tibiale laterale, and tibiale laterale), 10 girths (head, neck, arm relaxed, arm flexed and tensed, forearm, wrist, chest, waist, hip, and calf), and seven skinfolds (triceps, subscapular, biceps, abdominal, supraspinale, iliac crest, and medial calf). In addition, abdominal girth was evaluated as described by Martins and Lopes[14], and leg length was calculated as the difference between sitting height and stature.

Body mass was measured with a Welmy (model W110H) electronic scale (capacity of 300 kg) to the nearest 50 g. Stature was measured with a height ruler (scale of 1.00 to 2.00 m) to the nearest 0.1 cm. A Sanny anthropometric measuring tape (2 m long) was used to measure girths and sitting height to the nearest 0.1 cm. Breadths and bone lengths were measured to the nearest 0.1 cm with a Sanny segmometer (2 m long) and a Cescorf metal pachymeter, respectively. A Harpenden caliper (John Bull British Indicators Ltd), with a scale of 0.2-mm units and interpolation of 0.1 mm, was used for skinfold measurements.

Technical error of measurement

A study including 26 subjects was conducted in parallel to calculate the inter- and intraobserver technical error of measurement (TEM). Frontal thigh skinfold and thigh girth presented an error of 7.59% and 4.50%, respectively, and were excluded from the study since these results are higher than the cut-off values reported in the literature (5% for skinfolds and 1% for the other anthropometric variables).

Evaluation of pubertal maturation

Two pediatric endocrinologists from HOSPED-UFRN evaluated pubertal stage based on the Tanner stages for pubic hair (P1-P5)[15]. The coefficient of interobserver agreement was considered to be good (kappa 0.79; CI 0.74 – 0.84)[16].

Statistical analysis

First, analysis of the distribution of the data by the Shapiro-Wilk and Levene tests showed that all skinfold variables presented a nonparametric distribution. These variables were corrected by base 10 logarithmic transformation. Next, descriptive analysis was performed using measures of central tendency and dispersion. One-way analysis of variance (ANOVA), with the Scheffé post hoc test, was used for inferential analysis.

Multivariate discriminant analysis was performed by simultaneous estimation in order to generate a function that would identify the interrelation between pubertal stages and anthropometric variables. Discriminant analysis is the most adequate statistical method for this purpose as recommended by Hair et al.[17] and reported in recent studies[11,12]. In addition, the assumptions of discriminant analysis of normality, multicollinearity (tolerance > 0.1 and variance inflation factor < 10) and homogeneity of the covariance matrix ($p > 0.05$), were determined as shown in Table 1.

The Statistica 6.0 program and SPSS 19.0 package (SPSS Inc., Chicago, IL, USA) were used for data analysis, adopting a level of significance of $p < 0.05$.

Table 1. Collinearity tests and homogeneity of the covariance matrix.

	Collinearity test		Box's M test
	Tolerance	VIF	
Age	0.266	3.753	0.078
Sitting height	0.140	7.123	
Tibiale length	0.204	4.905	
Acromiale-radiale length	0.171	5.863	
Trochanterion-tibiale laterale length	0.250	4.006	
Acromial breadth	0.175	5.717	
Forearm girth	0.162	6.174	
Abdominal girth	0.295	3.395	

VIF: variance inflation factor.

RESULTS

Table 2 shows the measures of central tendency of the anthropometric variables according to pubertal stage. Except for skinfolds, changes were observed in all variables with advancement of pubertal development, particularly in chronological age, body mass and stature. Subscapular skinfold thickness was the only variable showing a significant difference, which was observed between stages P1 and P5. This finding indicates that, in boys, subcutaneous adiposity does not undergo marked modifications during puberty despite all the physiological processes that occur during this period. Comparison of the different stages showed that the main differences occurred in relation to P1, demonstrating the changes that occur during puberty, and between P4 and P5. The latter finding may be explained by the occurrence of peak growth velocity.

Table 2. Mean and standard deviation of the anthropometric variables according to pubertal stage of pubic hair development.

(n = 190)	P1 (n = 68)	P2 (n = 22)	P3 (n = 18)	P4 (n = 40)	P5 (n = 42)
Body size					
Age (years)	10.08 ± 1.37	12.42 ± 0.79†	12.99 ± 1.24†	14.18 ± 1.11†‡	15.62 ± 1.30†‡
Body mass (kg)	35.87 ± 10.21	43.15 ± 13.28†	54.21 ± 13.73†‡	55.61 ± 9.86†	70.50 ± 16.54†‡
Stature (m)	1.38 ± 0.09	1.49 ± 0.08†	1.58 ± 0.09†‡	1.64 ± 0.08†‡	1.71 ± 0.07†‡
Sitting height (m)	0.71 ± 0.04	0.75 ± 0.05†	0.80 ± 0.05†‡	0.84 ± 0.04†‡	0.88 ± 0.04†‡
Leg length (m)	0.68 ± 0.06	0.74 ± 0.05†	0.78 ± 0.06†	0.81 ± 0.06†	0.83 ± 0.05†
Bone breadth (cm)					
Biacromial	30.78 ± 2.12	33.02 ± 3.44	35.42 ± 2.46†	36.53 ± 2.47†	39.43 ± 3.13†‡
Transverse chest	22.83 ± 2.78	24.75 ± 3.03	27.00 ± 3.01†	27.45 ± 2.20†	29.55 ± 3.19†‡
Biiliocristal	22.81 ± 3.22	24.34 ± 2.60	26.74 ± 4.33†	26.98 ± 2.38†	28.91 ± 3.72†‡
Biepicondylar humerus	5.71 ± 0.49	6.09 ± 0.64	6.70 ± 0.56†‡	6.76 ± 0.38†	7.08 ± 0.48†‡
Biepicondylar femur	8.67 ± 0.79	8.94 ± 0.73	9.71 ± 0.62†	9.75 ± 0.65†	9.97 ± 0.66†
Bone length (cm)					
Acromiale-radiale	25.73 ± 2.12	27.98 ± 1.67†	29.91 ± 2.57†	31.15 ± 1.91†	32.42 ± 2.06†‡
Radiale-stylion	21.82 ± 1.81	23.44 ± 2.50	25.34 ± 2.45†	26.09 ± 1.96†	27.58 ± 1.96†‡
Midstylion-dactylion	15.56 ± 1.13	16.87 ± 1.37†	17.78 ± 1.40†	18.53 ± 1.03†‡	19.08 ± 1.11†
Trochanterion-tibiale laterale	34.61 ± 4.11	38.30 ± 3.68	42.18 ± 3.84†	42.76 ± 4.08†‡	44.33 ± 4.31†
Tibiale laterale	38.52 ± 3.76	42.89 ± 2.99†	44.28 ± 4.87†	46.95 ± 2.87†	47.10 ± 3.86†
Girth (cm)					
Head	53.32 ± 1.74	53.98 ± 1.58	54.33 ± 0.92	55.06 ± 1.47†	56.29 ± 1.70†‡
Neck	28.60 ± 2.03	29.48 ± 2.26	31.38 ± 2.74†	32.71 ± 2.43†	35.60 ± 2.68†‡
Arm flexed	22.00 ± 3.24	23.63 ± 3.92	26.02 ± 3.51†	26.93 ± 3.27†	30.36 ± 3.69†‡
Arm relaxed	20.97 ± 3.60	22.67 ± 4.65	24.98 ± 3.76†	25.27 ± 3.21†	28.50 ± 4.10†‡
Forearm	20.01 ± 2.26	20.97 ± 2.42	22.65 ± 1.89†	23.77 ± 1.89†	25.80 ± 2.26†‡
Wrist	13.84 ± 1.13	14.44 ± 1.20	15.26 ± 1.54†	15.99 ± 0.93†	16.54 ± 1.07†
Chest	68.36 ± 9.42	73.72 ± 9.90	77.74 ± 15.58†	81.28 ± 7.75†	89.16 ± 12.50†‡
Waist	63.26 ± 9.43	68.69 ± 12.05	72.02 ± 9.59†	72.92 ± 7.95†	79.52 ± 12.07†‡
Abdominal	67.11 ± 11.09	73.01 ± 13.94	76.14 ± 10.57†	76.22 ± 9.24†	84.42 ± 13.40†‡
Hip	73.73 ± 9.53	80.02 ± 10.43	86.16 ± 8.29†	87.64 ± 7.62†	96.16 ± 10.42†‡
Calf	28.26 ± 3.51	29.95 ± 3.90	32.58 ± 2.94†	33.36 ± 2.77	36.59 ± 3.69†‡
Skinfold (mm)*					
Triceps	13.0 (8.7 – 16.4)	13.9 (6.8 – 20.2)	14.8 (9.0 – 19.0)	9.8 (7.6 – 14.7)	12.2 (8.4 – 18.7)
Subscapular	7.7 (6.0 – 11.9)	9.6 (7.0 – 21.4)	10.5 (6.8 – 17.2)	8.8 (7.4 – 14.5)	11.6 (8.3 – 21.7)†
Biceps	8.0 (5.6 – 11.8)	7.3 (4.2 – 10.9)	8.5 (5.5 – 10.4)	6.2 (4.3 – 10.7)	6.8 (4.5 – 9.4)
Iliac crest	12.07 (8.0 – 23.1)	17.0 (6.8 – 34.7)	21.0 (9.1 – 29.8)	13.1 (9.5 – 23.1)	15.2 (11.5 – 27.7)
Supraspinal	8.0 (5.4 – 15.5)	8.3 (4.7 – 26.2)	13.4 (6.1 – 20.8)	8.7 (6.5 – 15.7)	10.7 (7.0 – 19.9)
Abdominal	12.27 (7.8 – 23.6)	14.9 (6.5 – 23.8)	14.4 (11.0 – 20.6)	13.8 (9.6 – 26.7)	17.2 (12.1 – 32.9)
Medial calf	13.4 (9.2 – 18.2)	11.1 (8.3 -21.8)	12.7 (9.1 – 18.9)	13.1 (8.2 – 18.1)	12.5 (9.8 – 17.0)

† Significant difference ($p < 0.05$) compared to P1. ‡ Significant difference ($p < 0.05$) compared to the previous pubertal stage. * These variables presented a nonparametric distribution and are reported as the median and interquartile range.

The 33 variables used in this study (32 anthropometric variables plus age) were submitted to multivariate discriminant analysis. Of these, only eight variables were selected as the best predictors of pubertal stage: age, sitting height, biacromial breadth, acromiale-radiale, trochanterion-tibiale laterale and tibiale laterale bone lengths, and abdominal and forearm girths. This analysis permitted the creation of four discriminant functions that represent the discriminatory power of the eight variables selected to predict pubertal maturation.

The validity of the four discriminant functions was tested based on eigenvalues, canonical correlations and Wilk's lambda values. In general, the first function explained most of the variance (94.8%) in the prediction of pubertal stages. On the other hand, the fourth function showed a poor prediction rate, as indicated by a very low eigenvalue and a *p* value higher than 0.05. This finding shows that this function has a low capacity of observing differences between groups and its use becomes unnecessary further analysis.

Table 3. Contribution load of each variable to the discriminant functions.

	Function			
	1	2	3	4
Sitting height	0.727*	-0.061	-0.026	0.248
Age	0.714*	0.408	0.169	-0.203
Biacromial breadth	0.632*	-0.062	0.137	0.291
Acromiale-radiale length	0.565*	0.245	-0.272	0.379
Forearm girth	0.462*	0.075	0.144	-0.233
Tibiale length	0.469	0.441	-0.503*	0.181
Abdominal girth	0.235	0.251	0.493*	0.051
Trochanterion-tibiale length	0.441	0.364	-0.198	0.565*

* Highest absolute correlation between each variable and any discriminant function.

The contribution of each anthropometric variable to the formation of the four discriminant functions is shown in Table 3. Age and sitting height were the most important variables to explain the difference between subjects classified as P1 to P5, followed by biacromial breadth, acromiale-radiale bone length and forearm girth. Tibiale and trochanterion-tibiale lengths and abdominal girth were more important for the formation of discriminant functions 3 and 4, confirming their relationship with advanced maturation stages, but more discretely.

Table 4. Mean values of the discriminant functions (centroids) according to pubertal stage.

Pubic hair	Function			
	1	2	3	4
Stage 1	-2.780	-0.299	0.001	-0.037
Stage 2	-1.094	1.075	0.280	-0.142
Stage 3	0.346	0.165	0.130	0.577
Stage 4	1.711	0.142	-0.542	-0.030
Stage 5	3.308	-0.299	0.319	-0.087

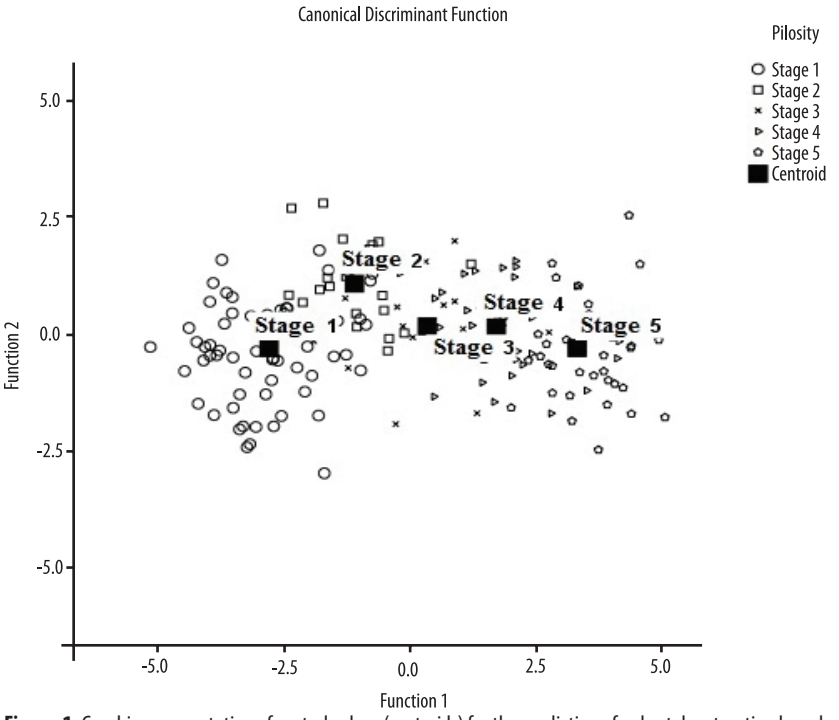

Figure 1. Graphic representation of central values (centroids) for the prediction of pubertal maturation based on anthropometric variables.

Table 4 shows the centroids of the discriminant functions, which are defined as the mean value of discriminant Z scores obtained for each group, i.e., each centroid corresponds to the cut-offs necessary to separate the five groups analyzed. These values permit visual analysis of the distance between pubertal stages, as illustrated in Figure 1.

Analysis of the rate of successful prediction of pubertal maturation based on the anthropometric variables showed good results. This analysis, called classification matrix, is considered to be analog to the R^2 of multiple linear regression and permits to determine the predictive significance of discriminant functions. In the present study, 77.4% of the groups were classified correctly, demonstrating satisfactory prediction of maturation stages when based on the eight anthropometric variables selected by discriminant analysis. The minimum percent value found was 64.8% for P3, whereas the maximum value was 85.1% for P1.

DISCUSSION

Analysis of the relationship between the advancement of puberty and changes in the anthropometric profile of boys is an important noninvasive diagnostic tool of maturation stage in these subjects, especially because it reduces the invasion of the patient's privacy.

In this respect, Table 2 demonstrates the influence of pubic hair development on the anthropometric variables studied, in agreement with the literature[6,15,18]. The hormone-regulated metabolic processes that occur during puberty are responsible for morphological changes in boys. These

changes are more clearly visualized by a growth in stature and by an increase in body mass[18-20].

No significant difference in skinfolds was observed between pubertal stages, except for subscapular skinfold thickness between P4 and P5. In addition, these variables showed a nonparametric distribution. This finding demonstrates the need to control for the nutritional status of the subjects which may interfere with the progression of each stage. This was a limitation of the present study.

However, the absence of significant differences in the distribution of body adiposity is a common feature during puberty, since the increase in body mass is more related to a gain in muscle mass and consequent stabilization of fat mass[18,19].

Multivariate discriminant analysis of the variables studied identified eight variables with a high predictive power for pubertal stages, with the observation of a high inter-relation index. Using the same method in young Venezuelan swimmers, Pérez et al.[12] obtained a high predictive index based on eight anthropometric variables, indicating that this is a habitual number for discriminant analysis in subjects of this age group.

On the basis of the canonical correlations, we observed that function 1 explained 86% of the variance of discriminant analysis, a value considered to be high[17], thus identifying this function as the most important. This perspective is confirmed by Wilks' lambda test, a test used to calculate the significance of discriminant functions, with this being found only in the first three functions of this study, and identifying the low estimation of the fourth function for continuation of the analysis.

As can be seen in Table 3, age, sitting height, biacromial breadth, acromiale-radiale bone length and forearm girth presented the highest contribution loads for the formation of function 1. In young swimming athletes, Pérez et al.[12] identified stature, body mass, calf and relaxed arm girth, and stylion-dactylion and trochanterion-tibiale bone lengths. Although samples with different characteristics were studied, the variables selected in the two studies and their relationships were similar.

The centroid values showed the level of dispersion between pubertal stages. Function 1 more efficiently predicts the separation of pubertal stages into three different groups based on the grouping P1+P2, only on stage P3, and on the grouping P4+P5. Despite the cross-sectional design, these results are likely to be related to the period of deceleration in anthropometric changes during the early stages of pubertal development, followed by acceleration in stage 4 which is determined mainly by the occurrence of peak growth velocity in boys[18].

Similarly, the centroid values of function 2 permit the separation of pubertal stages into three distinct groups (P1, P2-P3-P4, P5), in agreement with Tanner[15] who proposed three phases of pubic hair development, i.e., prepuberty (stage I), puberty (stages II, III and IV) and post-puberty (stage V).

These results demonstrate the strong relationship between the eight anthropometric variables selected for the prediction model and the processes

related to each maturation stage, concretely confirming the suitability of this method. This interpretation can be better understood by inspection of Figure 1, which clearly illustrates the degree of separation between the five stages.

The predictive index of pubic hair stages was 77.4% based on only seven anthropometric variables. This value is considered to be high and is within the limits established in the literature. This index is thus adequate for the determination of the inter-relation between the variables analyzed and the predictive value that one has over the other[17,21].

However, a more detailed analysis indicated caution with respect to stage 3, since this stage showed a moderate correlation with the anthropometric variables and may be underestimated in predictive analyses. In addition, we observed a percent error of 23.9%, which exposed the main limitation of the study, i.e., the biases found in anthropometric assessment which, in addition to requiring training, are strongly influenced by the skills of the observers as well as by inter- and intraobserver errors. Despite the control of these errors in the present study, we identified this to be an essential problem for future studies.

CONCLUSIONS

Discriminant analysis revealed a strong relationship between the anthropometric variables and pubertal stages, demonstrating the suitability of this observation method as a noninvasive tool for the diagnosis of pubertal maturation in boys. However, the bias in anthropometric assessment should be taken into account. On this basis, we identified eight variables with a high predictive capacity of pubertal stages, thus confirming the possibility of developing predictive equations using these variables.

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