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Predicting Adult Stature Without Using Skeletal Age: The Khamis-Roche Method

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ABSTRACT. ***Study objective.*** **To obtain reliable and accurate predictions of adult stature in white American children who are free of disease without using skeletal age.**

Design. **Apply a modification of the Roche-Wainer-Thissen stature prediction model to a sample of white American children.**

Setting. **Longitudinal data (every 6 months) from participants in the Fels Longitudinal Study were used for the development of the stature prediction model.**

Participants. **Residents of Southwest Ohio, 223 white males and 210 white females, at the time of their enrollment into the Fels Longitudinal Study.**

Measurements and results. **The errors of the proposed method, which does not use skeletal age as a predictor variable, are only slightly larger than those for the Roche-Wainer-Thissen method which uses skeletal age as a predictor variable.**

Conclusions. **Adult stature predictions are needed commonly but the current methods are difficult to apply because they require a skeletal age assessed by a modern method. The Khamis-Roche method predicts adult stature in the absence of skeletal age with only a slight deterioration in accuracy and reliability. The applicability of the Khamis-Roche method is limited to white American children without pathologic conditions that alter the potential for growth in stature, but it should be useful for white children who are unusual in stature or in levels of maturity for age.** ***Pediatrics*** **1994;94:504–507;** ***adult stature prediction, skeletal age, children.***

ABBREVIATIONS. RWT, Roche, Wainer, and Thissen method; KR, Khamis-Roche method; MAD, median absolute deviation.

Accurate predictions of adult stature are of considerable interest to pediatricians, children, and their parents.[1] These predictions are important for children growing or maturing at unusual rates and for children with diseases, such as hypothyroidism, that can alter their potentials for growth in stature. The method presented here, like all current methods, is derived from and strictly only applicable to children free of growth-limiting diseases. The method of Bayley and Pinneau,[2] based on chronological and skeletal ages and current stature, is used commonly for the prediction of adult stature, but more accurate methods have been developed.[3-5] Among these newer methods, that of Roche, Wainer, and Thissen (RWT) has been shown to be the most accurate for children who do not have gross pathological conditions that change the potential for growth in stature.[6-7] The statistical methods used in the development of the RWT method were applied in the present study to ensure that the method developed would be applicable to other samples. Cross-validation studies have confirmed the efficiency of these statistical methods.[3]

The original RWT method has been modified resulting in slightly smaller errors of prediction.[8] The modified RWT method, like the original RWT method, is based on linear regressions of adult stature on midparent stature (ie, the average stature of the two parents), and current values of stature, weight, and skeletal age. Three modifications were made in the original RWT method (i) a different procedure was used to smooth the regression coefficients across age, (ii) stature was substituted for recumbent length as a predictor, and (iii) Fels skeletal age[9] was substituted for Greulich-Pyle skeletal age.

Skeletal age is not readily available, even when there is a suitably positioned radiograph, because few are trained to make these assessments with small errors. Consequently, a prediction method has been developed that can be applied in the absence of skeletal age to facilitate predictions of adult stature by clinicians, educators, and those in the field of child development. This new method was expected to be reasonably accurate, because skeletal ages have only small effects on values predicted from the modified RWT method at most ages.[8] The present study has shown that this expectation is true.

The purpose of the present paper is to describe and evaluate the Khamis-Roche (KR) method for the prediction of adult stature in white children who, whil free of pathological conditions, differ from expectea values for stature or maturity at an age. There is a lack of long-term serial data for other ethnic groups that would allow the development of a method to predict adult stature or cross-validation of the KR method.

MATERIALS AND METHODS

The data used in these analyses are from the Fels Longitudinal Study which includes 223 males and 210 females for whom stature was measured at age 18 years. Although males grow in stature until about age 21.2 years,[10] stature at age 18 years was defined as adult stature in accordance with the usual custom. Excluded from the sample were the few black participants (N = 15), one randomly chosen member of each monozygous twin pair (N = 4), and participants with serious pathological conditions, such as trisomy

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21, that would have affected their potentials for growth in stature (N = 14). The Fels Longitudinal Study is of families that were residing in southwestern Ohio at the time of enrollment. The distribution of socioeconomic status of the families matches national distributions except for some under-representation of those with low socioeconomic status. A more complete demographic description of the study sample is given elsewhere.[11] In the Fels Longitudinal Study, data for stature, weight, and skeletal age (using the Fels hand-wrist method)[9] were recorded at 6-month intervals from 3 to 18 years, and the statures of each parent were measured.

In the KR method, there are three predictor variables: current stature, current weight, and midparent stature. The statistical procedures of the modified RWT procedure were applied to these three variables. The regression equation that was derived had the form: predicted adult stature = $\beta_0 + \beta_1$ stature + β_2 weight + β_3 mid-parent stature, where β_1, β_2, and β_3 are the coefficients by which stature, weight, and mid-parent stature, respectively, should be multiplied. A slight deterioration in prediction accuracy, in comparison with the modified RWT method, due to the omission of skeletal age, was anticipated, especially close to age 14 years in males and 11 years in females because skeletal age has its largest effects on the predictions at these ages.[8]

At each chronological age, the median absolute deviation (MAD) was used as the measure of accuracy for the prediction method. The MAD is the median of the absolute values of the differences (disregarding the signs) between the actual 18-year statures and the predicted 18-year statures. When the MAD for the matching age and gender is added to and subtracted from a predicted adult stature, a range of values is obtained within which 50% of actual adult statures lie for the given chronological age and gender. For example, if the predicted adult stature for a given child at 9 years of age is 70 in and the MAD for that age is 1.2 in, then the range from 68.8 to 71.2 in will include the actual adult statures for 50% of children with similar values for the predictor variables. The average of the MAD values for all ages combined is a measure of the accuracy of the prediction procedure for the given range of chronological ages. The 90% error bounds were calculated also; when these are added to and subtracted from a predicted adult stature, they provide the range within which 90% of the actual adult statures will lie for a group of children with similar values for the predictor variables.

RESULTS

The smoothed regression coefficients for the KR method are provided in Tables 1 and 2 for boys and girls, respectively. These tables show the intercepts (β_0) and the values (coefficients) by which values for current stature (in), current weight (lb), and midparent stature (in) should be multiplied. Coefficients corresponding to those in Tables 1 and 2, that are applicable to measurements in centimeters and kilograms, are available from the first author upon request. Values for 3 years are omitted from Tables 1 and 2, because the errors of prediction were large.

Summary statistics for the 50% (MAD) and 90% error bounds are given in Table 3. The average MAD for the KR prediction method from 4 to 18 years is larger than that for the modified RWT method, which includes skeletal age, by about 0.1 in for males and about 0.02 in for females. The 90% error bounds for the KR method exceed those for the modified RWT method by only about 0.3 in for males and 0.2 in for females.

The error statistics are plotted for each chronological age for the modified RWT method (with skeletal age), and for the KR method (without skeletal age), in Figs 1 and 2 for males and females, respectively. The omission of skeletal age caused small increases in the MAD values. The largest increases occurred in boys aged 14.0 to 15.5 years for whom the MAD for KR predictions were 0.24 in to 0.35 in larger than those made by the modified RWT method. At the 90th percentile error bound, which is a level exceeded by only 10% of the differences between the predicted and actual adult statures, the omission of skeletal age had only small effects at ages younger

TABLE 1. Smoothed Values of the Intercepts (β_0) and Regression Coefficients for White Males

Chronological Age	β_0	Stature (in)	Weight (lb)	Midparent Stature (in)
4.0	−10.2567	1.23812	−0.0087235	0.50286
4.5	−10.7190	1.15964	−0.0074454	0.52887
5.0	−11.0213	1.10674	−0.0064778	0.53919
5.5	−11.1556	1.07480	−0.0057760	0.53691
6.0	−11.1138	1.05923	−0.0052947	0.52513
6.5	−11.0221	1.05542	−0.0049892	0.50692
7.0	−10.9984	1.05877	−0.0048144	0.48538
7.5	−11.0214	1.06467	−0.0047256	0.46361
8.0	−11.0696	1.06853	−0.0046778	0.44469
8.5	−11.1220	1.06572	−0.0046261	0.43171
9.0	−11.1571	1.05166	−0.0045254	0.42776
9.5	−11.1405	1.02174	−0.0043311	0.43593
10.0	−11.0380	0.97135	−0.0039981	0.45932
10.5	−10.8286	0.89589	−0.0034814	0.50101
11.0	−10.4917	0.81239	−0.0029050	0.54781
11.5	−10.0065	0.74134	−0.0024167	0.58409
12.0	−9.3522	0.68325	−0.0020076	0.60927
12.5	−8.6055	0.63869	−0.0016681	0.62279
13.0	−7.8632	0.60818	−0.0013895	0.62407
13.5	−7.1348	0.59228	−0.0011624	0.61253
14.0	−6.4299	0.59151	−0.0009776	0.58762
14.5	−5.7578	0.60643	−0.0008261	0.54875
15.0	−5.1282	0.63757	−0.0006988	0.49536
15.5	−4.5092	0.68548	−0.0005863	0.42687
16.0	−3.9292	0.75069	−0.0004795	0.34271
16.5	−3.4873	0.83375	−0.0003695	0.24231
17.0	−3.2830	0.93520	−0.0002470	0.12510
17.5	−3.4156	1.05558	−0.0001027	−0.00950

TABLE 2. Smoothed Values of the Intercepts (β_0) and Regression Coefficients for White Females

Chronological Age	β_0	Stature (in)	Weight (lb)	Midparent Stature (in)
4.0	−8.13250	1.24768	−0.019435	0.44774
4.5	−6.47656	1.22177	−0.018519	0.41381
5.0	−5.13582	1.19932	−0.017530	0.38467
5.5	−4.13791	1.17880	−0.016484	0.36039
6.0	−3.51039	1.15866	−0.015400	0.34105
6.5	−3.14322	1.13737	−0.014294	0.32672
7.0	−2.87645	1.11342	−0.013184	0.31748
7.5	−2.66291	1.08525	−0.012086	0.31340
8.0	−2.45559	1.05135	−0.011019	0.31457
8.5	−2.20728	1.01018	−0.009999	0.32105
9.0	−1.87098	0.96020	−0.009044	0.33291
9.5	−1.06330	0.89989	−0.008171	0.35025
10.0	0.33468	0.82771	−0.007397	0.37312
10.5	1.97366	0.74213	−0.006739	0.40161
11.0	3.50436	0.67173	−0.006136	0.42042
11.5	4.57747	0.64150	−0.005518	0.41686
12.0	4.84365	0.64452	−0.004894	0.39490
12.5	4.27869	0.67386	−0.004272	0.35850
13.0	3.21417	0.72260	−0.003661	0.31163
13.5	1.83456	0.78383	−0.003067	0.25826
14.0	0.32425	0.85062	−0.002500	0.20235
14.5	−1.13224	0.91605	−0.001967	0.14787
15.0	−2.35055	0.97319	−0.001477	0.09880
15.5	−3.10326	1.01514	−0.001037	0.05909
16.0	−3.17885	1.03496	−0.000655	0.03272
16.5	−2.41657	1.02573	−0.000340	0.02364
17.0	−0.65579	0.98054	−0.000100	0.03584
17.5	2.26429	0.89246	0.000057	0.07327

TABLE 3. Average 50% Error Bounds (Mad) and 90% Error Bounds for Predictions With and Without Skeletal Age (SA) from 4.0 to 17.5 Years

	50% Error Bound (in)		90% Error Bound (in)	
	Mean	SD	Mean	SD
White males				
With SA*	0.765	0.205	1.777	0.492
Without SA‡	0.851	0.218	2.101	0.545
White females				
With SA*	0.638	0.264	1.486	0.599
Without SA‡	0.657	0.254	1.675	0.646

* Modified RWT method.[8]
‡ Khamis-Roche method.

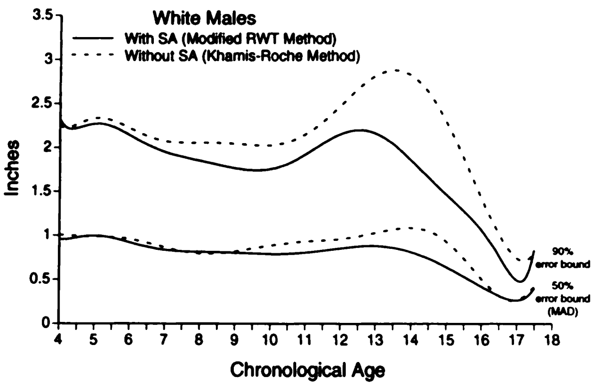

Fig 1. Smoothed values from 4.0 to 17.5 years for the 50th (MAD) and 90th percentile error bounds in males when skeletal age is included in the regressions (modified RWT method[8]) and when it is omitted (Khamis-Roche method). (SA = skeletal age; MAD = median absolute deviation.)

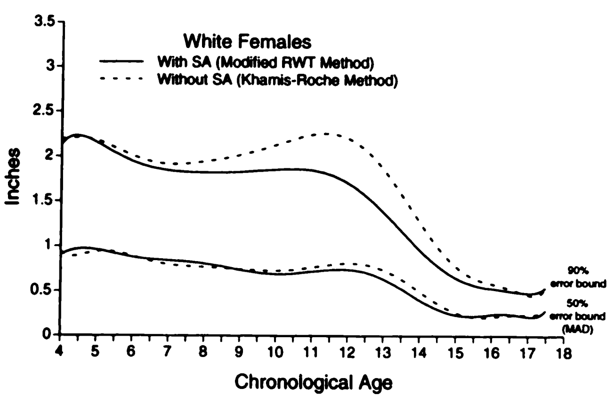

Fig 2. Smoothed values from 4.0 to 17.5 years for the 50th (MAD) and 90th percentile error bounds in white females when skeletal age is included in the regressions (modified RWT method[8]) and when it is omitted (Khamis-Roche method). (SA = skeletal age; MAD = median absolute deviation.)

than 7 years. From 7 to 12 years in males and from 7 to 10 years in females, the 90th percentile error bounds for predictions by the KR method were the larger by about 0.24 in and 0.16 in, respectively. The differences between the two sets of 90th percentile error bounds increased at older ages until the KR error bounds were the larger by 1.0 in at 14 years in males and 0.5 in at 11.5 years in females after which the differences decreased.

DISCUSSION

There are practical advantages to a prediction method that is comparable in accuracy to the RWT method, but uses predictor variables that are readily available and are more precise than skeletal age. This may lead to more widespread use of adult stature predictions in pediatric practice. Use of variables other than current stature, current weight, and mid-parent stature, adjusted for age and sex, or use of only some of these variables, leads to less accurate predictions.[3]

The KR method is applicable from 4.0 to 17.5 years. This age range is considered appropriate, because parents typically do not become interested in their child's stature until seeing him/her standing next to other children—this does not happen until about age 4 years. Additionally, the stature and weight coefficients for males and the weight coefficients for females at ages younger than 4 years tend to deviate substantially from the smoothed curves,[8] indicating that a prediction procedure including these ages may not be as reliable as a procedure starting at age 4 years. This is in general agreement with an earlier assertion.[12]

Wainer, et al[13] avoided the need for skeletal age in the prediction of adult stature by substituting chronological age for skeletal age. The KR method is slightly superior to this approach, with the average MAD approximately 0.1 in smaller in both males and females, and the average 90% error bound smaller by 1.0 in in males and 0.1 in in females. In addition, the KR method is simpler to use since it is based on three regression variables instead of four.

The most accurate current method for the prediction of adult stature, without the use of skeletal age, is to apply the KR regression method that is described here for which the average MAD is about 0.8 in for the age range 4.0 to 17.5 years. The average 90% error bounds are about 2.1 in for males and 1.7 in for females. As stated earlier, these are the errors for predictions of stature at 18 years which is accepted as "adult stature" in this report and elsewhere. Nevertheless, small increases occur in stature after 18 years. The median increases are about 0.3 in for each sex, and they tend to be larger for slowly maturing children.[10,16]

While the stature of one parent is typically available, the stature of the other parent, commonly the father, may not be easy to obtain. We recommend the estimation of the missing adult stature by the parent who is present. Himes and Roche[14] show that such reported statures are useful proxies when determining midparent stature for the prediction of adult stature. Their study was limited to wives' reports of their spouses' statures, but, in clinical pediatric settings, the mother is commonly the only parent accompanying the child. A less appropriate alternative is to substitute a mean published stature for the missing value. The mean for adults aged 25 to 34 years in the second Health and Nutrition Examination Survey is 69.6 in for men and 64.2 in for women.[15]

To illustrate the KR method for predicting adult stature consider a girl aged 7 years with stature 37.6 in, weight 90 lb, and midparent stature 61 in. Referring to Table 2, at the line corresponding to chronological age = 7, we form the equation:

$$\text{Predicted adult stature} = -2.87645 + 37.6 \times 1.11342 + 90 \times (-0.013184) + 61 \times 0.31748 = 57.2 \text{ in}$$

Consequently, this girl's predicted adult stature is 57.2 in. Using the plot in Fig 2 for predictions made without skeletal age, we can further state that the errors will be less than 0.75 in for 50% of such girls and they will be less than 2 in for 90% of such girls. A more complete expression would state that 50% of such girls will have adult statures in the range 56.4 to 57.9 in and 90% of such girls will have adult statures in the range 55.2 to 59.2 in. The interval derived from the 90% error bound can be interpreted by comparing it to reference data. Specifically, for stature at 18 years of age, the 5th, 50th, and 95th percentiles for males are, respectively, 65.6, 69.6, and 74.7 in; for females they are 59.3, 64.1, and 68.5 in.[17] Consequently we can state with 90% confidence that the girl in this example will have an adult stature below the 5th percentile. The most likely value for her adult stature is 57.2 in.

The error bounds of the KR method that are reported here were derived from children whose statures were measured with high accuracy and precision. If the measurement of stature is inaccurate, which is common when stature is measured on scales with a horizontal rod attached to a vertical pillar,[17,18] the error bounds are likely to be increased. It is expected also that the error bounds of the KR method will be larger for children maturing at markedly unusual rates. As stated earlier, this method, like the RWT and Tanner methods,[4–5] should not be applied to children with pathological conditions that alter the potential for growth in stature. The accuracy of each of these methods is known for white children only.

There is a need for methods that are accurate when applied to children with major pathological conditions, but these methods need to be disease- and treatment-specific. There are few suitable data sets from which such methods could be developed. Although the differences in errors between the KR and the RWT method are small, except for the 90% error bounds at about 14 years in males and 12 years in females, the latter is recommended when it is possible to obtain an accurate skeletal age and when the clinical circumstances indicate a need for maximum accuracy of the predictions. Such a need occurs, for example, in monitoring the response to treatment with growth hormone.

In summary, adult stature predictions for the general white population, ages 4 years to 17.5 years, can be accomplished by using the values in Tables 1 and 2. This method, referred to as the KR method, provides the predicted adult stature without a need for the skeletal age of the child, and is comparable in accuracy to the modified RWT method which requires the use of skeletal age. The KR method is recommended as a convenient and reliable method of predicting adult stature in white children who do not have gross pathological conditions.

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