The RWT Method for the Prediction of Adult Stature

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ABSTRACT. The Roche-Wainer-Thissen (RWT) method estimates the adult stature of an individual from data recorded at a single childhood examination. The data required are recumbent length, nude weight, midparent stature, and hand-wrist skeletal age. If necessary, a measurement of the child's stature can be transformed to be approximately equivalent to recumbent length with little loss of accuracy. When applied to data from three longitudinal growth studies, the prediction errors with the RWT method were smaller than those with the method of Bayley and Pinneau. *Pediatrics*, 56:1,026-1,033, 1975, PREDICTION, STATURE, GROWTH.

This paper summarizes a recent study that has been reported in full elsewhere.[1] It describes the Roche-Wainer-Thissen (RWT) method which is the most accurate current system for predicting the adult statures of individual children. The considerable recent interest in this subject[2,3] reflects the need for predictions of adult stature now that many children are treated with hormones, anabolic steroids, or other agents that can alter the rates of skeletal elongation or skeletal maturation.

It is well known that the stature and skeletal age of a child, used in combination, can provide reasonable estimates of adult stature.[4,5] These two measures are the basis for the widely used method of Bayley and Pinneau.[6] Unfortunately, these authors tested their method on a very small sample and its accuracy when applied to other children is unknown except for studies of small samples of tall girls.[7-9] These studies indicate that the Bayley-Pinneau tables are useful but they tend to overpredict for girls with skeletal ages of 14 years or more and to underpredict in those who are retarded skeletally. Others have had less satisfactory experiences. For example, Zachmann *et al.*[3] reported that in their experience Bayley and Pinneau predictions are inaccurate.

An ideal prediction method would be based on variables that can be obtained from each sex over long age ranges and that can be observed at a single examination. The possible variables include the statures of the parents, childhood stature (or recumbent length), tibial length, and skeletal maturity. None of these is a sufficiently accurate predictor when used alone.[10-13] Some other possible predictors are of little use because they can be observed only during later age ranges when little potential remains for growth in stature. These include age at menarche, stature at menarche, ratings of secondary sex characteristics, and the age when the rate of pubescent growth is maximal (peak height velocity). The rate of growth of the child is not a good predictor unless serial data are available from birth to at least 10.5 years and these are used in combination with midparent stature (the average of the statures of each parent).[13] This method is not generally applicable to clinical situations.

Several systems based on multiple predictors have been reported. The Bayley-Pinneau method[6] uses the present stature and the skeletal age (Greulich-Pyle) of the child. Later, Bayley[14] showed that the addition of midparent stature in-

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creased the accuracy of predictions during infancy. Walker[2] reported a method based on the present stature of the child, the growth rate during the previous 9 to 18 months, and a judgment as to whether the child had passed the stage of peak height velocity. Of course, in children maturing at average rates, the latter can be determined well only if serial data are available extending to at least 16 years in boys and 14 years in girls. After these ages little growth remains to be predicted. When Walker[2] tested his method using reported growth data,[15] the prediction errors were relatively large.

The method developed during the present investigation uses recumbent length, weight, midparent stature, and skeletal age as predictors. It predicts *stature* at 18 years. After this age, the total median increments are 8 mm in boys and 6 mm in girls.[16] If desired, these values can be added to the estimated adult statures.

MATERIAL AND METHODS

The development of a method for adult stature prediction requires data of a particular nature. Variables likely to be useful in prediction must be recorded during childhood and the adult statures of the same children must be known. The RWT method was developed using long-term serial data recorded every six months from white Southwestern Ohio children studied at the Fels Research Institute. About 100 sets of data were available for each sex at each age.

At each six-month visit, recumbent length was measured by two observers working independently; the larger measurement was recorded unless the paired data differed by 5 mm or more in which case the measurements were repeated. Weight was measured nude. Bone-specific skeletal ages were assessed by trained observers using standard atlases for the hand-wrist, foot-ankle, and knee.[17-19] Some of these bone-specific skeletal ages were combined with 11 different area skeletal ages for the hand-wrist. Selection between the many bone-specific skeletal ages as predictors was based on radiographic positioning, levels of irradiation, accuracy of assessment, and, most importantly, the findings of statistical analyses. Commonly, parts of the skeleton differ in their maturity levels[20,21] but there is little information as to which part of the skeleton should be rated when a skeletal age is needed for the prediction of adult stature.

DEVELOPMENT OF THE RWT METHOD

In the children studied, 78 possible predictors had been recorded serially—most of these were bone-specific skeletal ages. In addition, recumbent length and weight were measured serially and the adult statures of both parents were recorded.

The choice between the many bone-specific skeletal ages, and their combinations, was based primarily on the interrelationships between these variables at different ages. These interrelationships were analyzed using principal component[22] and cluster analyses.[23] As a result, 18 variables were selected for further testing during which all possible combinations between these variables were considered.[24] Finally, a set of four predictors was chosen that was applicable to both sexes throughout the age ranges considered. These predictors are recumbent length, weight, midparent stature, and skeletal age (median of Greulich-Pyle bone-specific skeletal ages for the hand-wrist). Recumbent length was preferred to stature because it can be obtained at all ages.

Regression techniques were used to estimate weights for each of these four predictor variables. Continuous functions of age were derived from these weights for each predictor variable; consequently predictions can be made at any age. The method for deriving these functions involved the utilization of some of the serial properties of the data; this has been shown to yield robust estimates of predictor weights.[25] Three-month tables of these weights are provided separately for boys from 1 to 16 years and for girls from 1 to 14 years (Tables I and II). More precise estimates for other ages within these age ranges can be obtained from data in the monograph[1] or by using the polynomial functions that generated these tables or a computer program that incorporates them.[26]

Using data from the Fels sample, many other possible predictors were tested to determine whether their inclusion in a prediction method would reduce the errors. It was shown that none of the following reduced the errors significantly: birth order, birthweight, occurrence of illnesses in parents during growth, illness in child, growth pattern of child, prediction errors in siblings, Tanner-Whitehouse skeletal age,[27] and differences between bones or groups of bones in skeletal age. The errors were not associated with the present recumbent length of the child or parental stature. All the children and parents were "normal" but the group included some who were more than 3 SD from the mean in recumbent length or stature.

USE OF THE PREDICTION TABLES

The recumbent length of the child (cm) should be measured but if only stature is available, 1.25 cm can be added to this with only slight loss of

TABLE I

MONTHLY WEIGHTS FOR THE PREDICTION OF ADULT STATURE IN BOYS*

Age (yr)	Age (mo)	β_{RL}	β_W	β_{MPS}	β_{SA}	β_o
1	0	0.966	0.199	0.606	−0.673	1.632
1	3	1.032	0.086	0.580	−0.417	−1.841
1	6	1.086	−0.016	0.559	−0.205	−4.892
1	9	1.130	−0.106	0.540	−0.033	−7.528
2	0	1.163	−0.186	0.523	0.104	−9.764
2	3	1.189	−0.256	0.509	0.211	−11.618
2	6	1.207	−0.316	0.496	0.291	−13.114
2	9	1.219	−0.369	0.485	0.349	−14.278
3	0	1.227	−0.413	0.475	0.388	−15.139
3	3	1.230	−0.450	0.466	0.410	−15.729
3	6	1.229	−0.481	0.458	0.419	−16.081
3	9	1.226	−0.505	0.451	0.417	−16.228
4	0	1.221	−0.523	0.444	0.405	−16.201
4	3	1.214	−0.537	0.437	0.387	−16.034
4	6	1.206	−0.546	0.431	0.363	−15.758
4	9	1.197	−0.550	0.424	0.335	−15.400
5	0	1.188	−0.551	0.418	0.303	−14.990
5	3	1.179	−0.548	0.412	0.269	−14.551
5	6	1.169	−0.543	0.406	0.234	−14.106
5	9	1.160	−0.535	0.400	0.198	−13.672
6	0	1.152	−0.524	0.394	0.161	−13.267
6	3	1.143	−0.512	0.389	0.123	−12.901
6	6	1.135	−0.499	0.383	0.085	−12.583
6	9	1.127	−0.484	0.378	0.046	−12.318
7	0	1.120	−0.468	0.373	0.006	−12.107
7	3	1.113	−0.451	0.369	−0.034	−11.948
7	6	1.106	−0.434	0.365	−0.077	−11.834
7	9	1.100	−0.417	0.361	−0.121	−11.756
8	0	1.093	−0.400	0.358	−0.167	−11.701
8	3	1.086	−0.382	0.356	−0.217	−11.652
8	6	1.079	−0.365	0.354	−0.270	−11.592
8	9	1.071	−0.349	0.353	−0.327	−11.498
9	0	1.063	−0.333	0.353	−0.389	−11.349
9	3	1.054	−0.317	0.353	−0.455	−11.118
9	6	1.044	−0.303	0.355	−0.527	−10.779
9	9	1.033	−0.289	0.357	−0.605	−10.306

TABLE I (CONTINUED)

MONTHLY WEIGHTS FOR THE PREDICTION OF ADULT STATURE IN BOYS*

Age (yr)	Age (mo)	β_{RL}	β_W	β_{MPS}	β_{SA}	β_o
10	0	1.021	−0.276	0.360	−0.690	−9.671
10	3	1.008	−0.263	0.363	−0.781	−8.848
10	6	0.993	−0.252	0.368	−0.878	−7.812
10	9	0.977	−0.241	0.373	−0.983	−6.540
11	0	0.960	−0.231	0.378	−1.094	−5.010
11	3	0.942	−0.222	0.384	−1.211	−3.206
11	6	0.923	−0.213	0.390	−1.335	−1.113
11	9	0.902	−0.206	0.397	−1.464	1.273
12	0	0.881	−0.198	0.403	−1.597	3.958
12	3	0.859	−0.191	0.409	−1.735	6.931
12	6	0.837	−0.184	0.414	−1.875	10.181
12	9	0.815	−0.177	0.418	−2.015	13.684
13	0	0.794	−0.170	0.421	−2.156	17.405
13	3	0.773	−0.163	0.422	−2.294	21.297
13	6	0.755	−0.155	0.422	−2.427	25.304
13	9	0.738	−0.146	0.418	−2.553	29.349
14	0	0.724	−0.136	0.412	−2.668	33.345
14	3	0.714	−0.125	0.401	−2.771	37.183
14	6	0.709	−0.112	0.387	−2.856	40.738
14	9	0.709	−0.098	0.367	−2.922	43.869
15	0	0.717	−0.081	0.342	−2.962	46.403
15	3	0.732	−0.062	0.310	−2.973	48.154
15	6	0.756	−0.040	0.271	−2.949	48.898
15	9	0.792	−0.015	0.223	−2.885	48.402
16	0	0.839	−0.014	0.167	−2.776	46.391

*The abbreviations are as follows: β_{RL} = regression weights for recumbent stature; β_W = weight; β_{MPS} = midparent stature; β_{SA} = skeletal age; and β_o = the intercept of the regression equation.

accuracy in the predictions. Nude weight (kg) should be recorded but a clothed weight can be adjusted to be approximately equivalent to nude weight. Values in the literature for the weight of "light indoor clothing" vary markedly. The necessary correction should be established by the pediatrician within his own practice. The stature of each parent should be measured. If unavoidable, a stated stature for a parent can be used and if the stature of a parent is not available, the sex-appropriate value for the population can be employed but the prediction will be less accurate. In the United States these values are 174.5 cm (father) and 162.0 cm (mother). The skeletal age of the left hand-wrist is assessed, bone by bone, using the Greulich-Pyle atlas.[17] If more than one half of these bones are adult in maturity, the RWT method should not be applied. Prior to 13 years in boys and 8 years in girls, however, chronological age can be substituted for skeletal age with little loss of accuracy. If this is done, the chronological age that is substituted for skeletal age must be multiplied by the skeletal age weight when the prediction tables are being applied.

The use of Tables I and II can be explained by an example. To predict the adult stature of a boy aged 6 years 3 months with a recumbent length of 108.7 cm, a nude weight of 17.4 kg, a midparent stature of 169.0 cm, and a skeletal age of 5.4 years, the following calculations would be made:

Variable	Value	Weight	Products: Positive	Products: Negative
Recumbent length	108.7	1.143	124.244	–
Weight	17.4	−0.512	–	−8.909
Midparent stature	169.0	0.389	65.741	–
Skeletal age	5.4	−0.123	0.664	–
Constant	–	–	–	−12.901
		Subtotals	190.649	−21.810
		Prediction = 168.839 cm		

This prediction should be rounded to one decimal place and its limits of accuracy given. The values necessary to calculate approximate 90% error limits are shown in Figure 1. These values should be added to the predicted value, and subtracted from it, to provide the upper and lower limits between which the actual adult statures will lie for 90% of children. For the example given, 4.7 cm should be added and subtracted. It is important for the clinician to be aware that the above prediction of 168.8 cm (after rounding off) should be qualified. In 90% of such boys, the adult stature will lie between 164.1 and 173.5 cm. In 10% of such boys, the adult stature will be outside this 9.4-cm range.

COMPARABILITY STUDIES

A comparison has been made between RWT and Bayley-Pinneau predictions[6] for children observed in the longitudinal growth studies at Yellow Springs (the Fels Research Institute), Denver (the Child Research Council), and Boston (the Harvard School of Public Health). Comparisons are possible only after seven years in boys and six years in girls because the Bayley-Pinneau method is not applicable to younger children.

The RWT method is more accurate than the Bayley-Pinneau method when both are applied to the Fels children (Fig. 2). This is not surprising because the RWT method was developed using data from these children. Increases in the median absolute errors of prediction (disregarding the signs of the differences) were smaller during pubescence with the RWT method than with the Bayley-Pinneau method. The median errors were more regular across age with the RWT than with the Bayley-Pinneau method. Correspondingly, the errors of serial predictions for individual children were more regular with the RWT method. In the Fels children, the Bayley-Pinneau method

TABLE II

MONTHLY WEIGHTS FOR THE PREDICTION OF ADULT STATURE IN GIRLS*

Age (yr)	Age (mo)	β_{RL}	β_W	β_{MPS}	β_{SA}	β_o
1	0	1.087	−0.271	0.386	0.434	21.729
1	3	1.112	−0.369	0.367	0.094	20.684
1	6	1.134	−0.455	0.349	−0.172	19.957
1	9	1.153	−0.530	0.332	−0.374	19.463
2	0	1.170	−0.594	0.316	−0.523	19.131
2	3	1.183	−0.648	0.301	−0.625	18.905
2	6	1.195	−0.693	0.287	−0.690	18.740
2	9	1.204	−0.729	0.274	−0.725	18.604
3	0	1.210	−0.757	0.262	−0.736	18.474
3	3	1.215	−0.777	0.251	−0.729	18.337
3	6	1.217	−0.791	0.241	−0.711	18.187
3	9	1.217	−0.798	0.232	−0.684	18.024
4	0	1.215	−0.800	0.224	−0.655	17.855
4	3	1.212	−0.797	0.217	−0.626	17.691
4	6	1.206	−0.789	0.210	−0.600	17.548
4	9	1.199	−0.777	0.205	−0.582	17.444
5	0	1.190	−0.761	0.200	−0.571	17.398
5	3	1.180	−0.742	0.197	−0.572	17.431
5	6	1.168	−0.721	0.193	−0.584	17.567
5	9	1.155	−0.697	0.191	−0.609	17.826
6	0	1.140	−0.671	0.190	−0.647	18.229
6	3	1.124	−0.644	0.189	−0.700	18.796
6	6	1.107	−0.616	0.188	−0.766	19.544
6	9	1.089	−0.587	0.189	−0.845	20.489
7	0	1.069	−0.557	0.189	−0.938	21.642
7	3	1.049	−0.527	0.191	−1.043	23.011
7	6	1.028	−0.498	0.192	−1.158	24.602
7	9	1.006	−0.468	0.194	−1.284	26.416
8	0	0.983	−0.439	0.196	−1.418	28.448
8	3	0.960	−0.411	0.199	−1.558	30.690
8	6	0.937	−0.384	0.202	−1.704	33.129
8	9	0.914	−0.359	0.204	−1.853	35.747
9	0	0.891	−0.334	0.207	−2.003	38.520
9	3	0.868	−0.311	0.210	−2.154	41.421
9	6	0.845	−0.289	0.212	−2.301	44.415
9	9	0.824	−0.269	0.214	−2.444	47.464
10	0	0.803	−0.250	0.216	−2.581	50.525
10	3	0.783	−0.233	0.217	−2.710	53.548
10	6	0.766	−0.217	0.217	−2.829	56.481
10	9	0.749	−0.203	0.217	−2.936	59.267
11	0	0.736	−0.190	0.216	−3.029	61.841
11	3	0.724	−0.179	0.214	−3.108	84.136
11	6	0.716	−0.169	0.211	−3.171	66.093
11	9	0.711	−0.159	0.206	−3.217	67.627
12	0	0.710	−0.151	0.201	−3.245	68.670
12	3	0.713	−0.143	0.193	−3.254	69.140
12	6	0.720	−0.136	0.184	−3.244	68.966
12	9	0.733	−0.129	0.173	−3.214	68.061
13	0	0.752	−0.121	0.160	−3.166	66.339
13	3	0.777	−0.113	0.144	−3.100	63.728
13	6	0.810	−0.105	0.127	−3.015	60.150
13	9	0.850	−0.085	0.106	−2.915	55.522
14	0	0.898	−0.083	0.083	−2.800	49.781

*Abbreviations are the same as those in Table I.

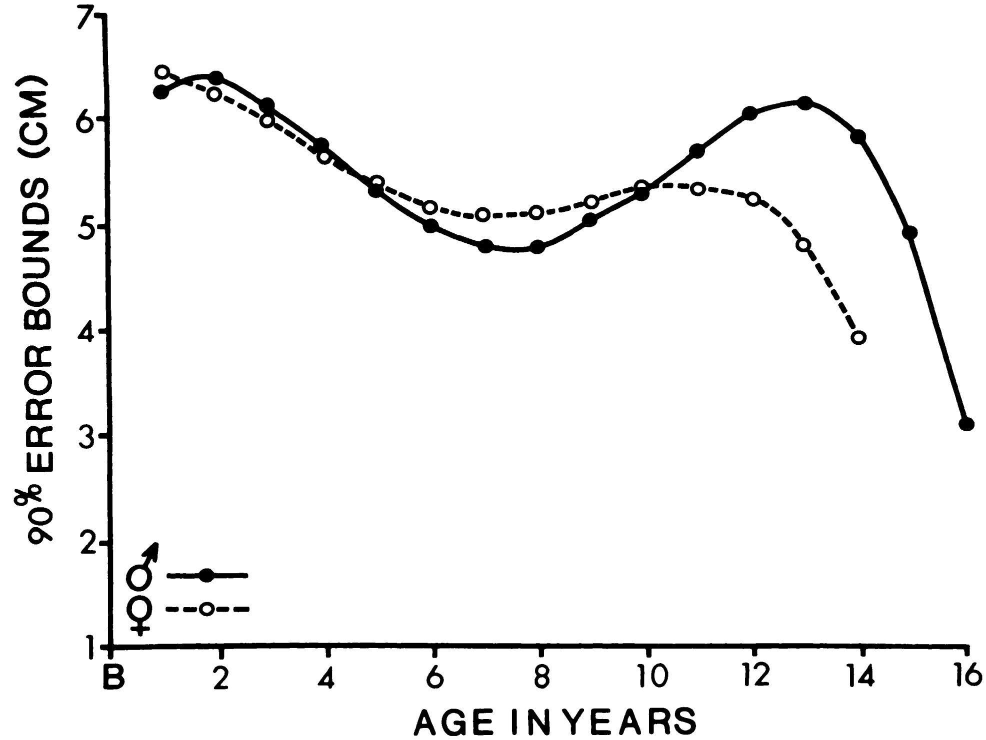

FIG. 1. Ninety percent error bounds (cm) for predictions using the RWT method.

systematically underpredicted for the girls at all ages and for the boys at 7, 15, and 16 years.

Towards the end of the age range during which predictions were made, the Bayley-Pinneau method was considerably less accurate in the Fels children than in the Berkeley children from whom it was derived. This difference is due largely to variations between the Fels and Berkeley samples of older children. The Bayley-Pinneau tables were derived from the *whole* sample

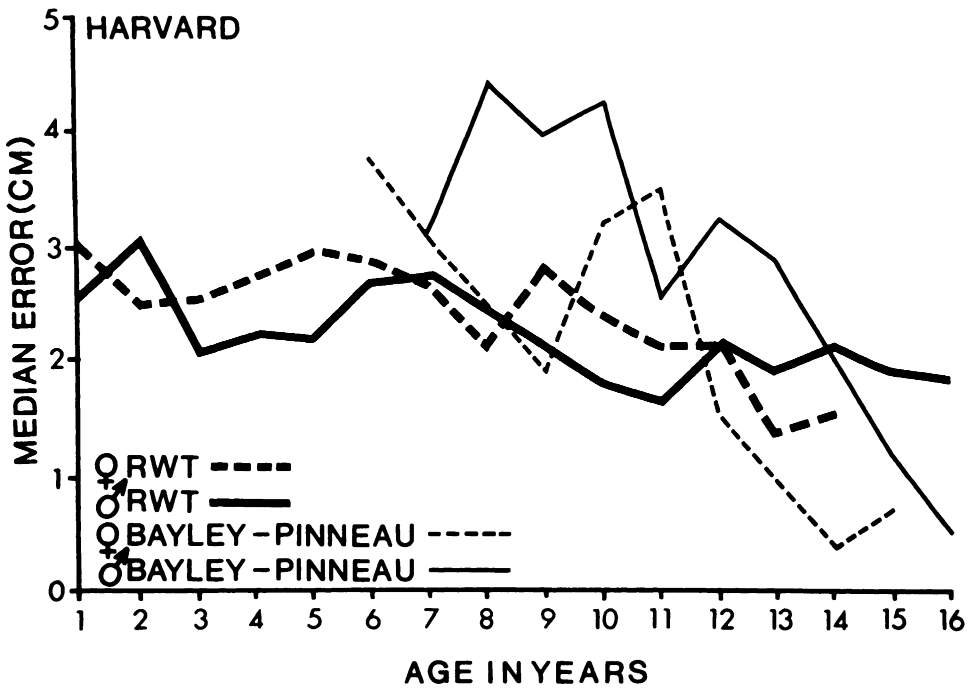

FIG. 2. Median absolute errors of prediction in children of the Fels sample.

of older children, *e.g.*, girls up to 18 years. The RWT method was developed from and should be applied only to children in whom at least one half the hand-wrist bones are not adult in maturity. Clinicians are unlikely to require predictions in more mature children who would have very little growth potential.

The median absolute prediction errors in the Denver and Harvard children, when the RWT method was applied, were similar to those for Fels children. The RWT errors were markedly less than the corresponding Bayley-Pinneau errors for the Denver girls and the Harvard boys. The RWT errors were only slightly smaller for the Denver boys and Harvard girls (Figs. 3 and 4). As in the Fels children, the RWT errors were more regular across age than the Bayley-Pinneau errors. At later ages, the Bayley-Pinneau predictions appeared more accurate than the RWT ones but this is artifactual. Because the skeletal ages for the Denver and Harvard children were not assessed bone by bone, older children in whom more than one half the hand-wrist bones were mature could not be excluded. Necessarily, therefore, both methods were used for *all* the older children and consequently, the RWT method was applied to many for whom it was not designed. At almost all ages the Bayley-Pinneau method underpredicted in the girls; both methods tended to overpredict slightly in the boys.

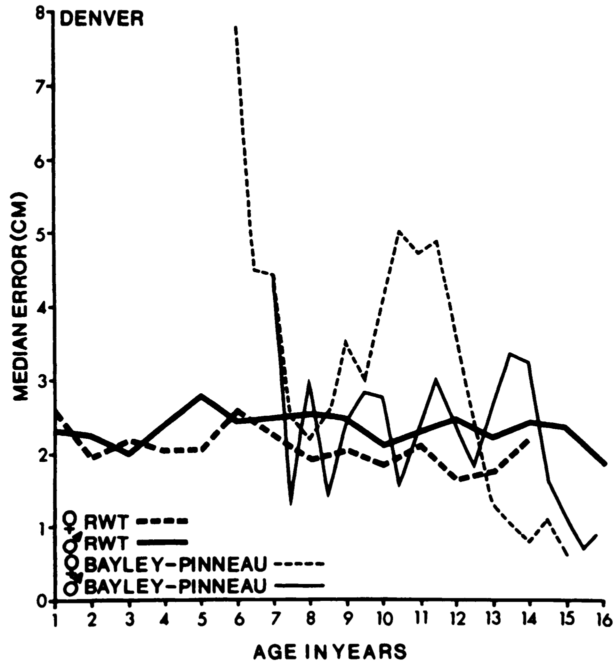

Fig. 3. Median absolute errors of prediction in children of the Denver sample.

CONCLUSION

Using data from three longitudinal growth studies, it has been shown that the errors of prediction are generally smaller and more consistent across age with the RWT method than with the

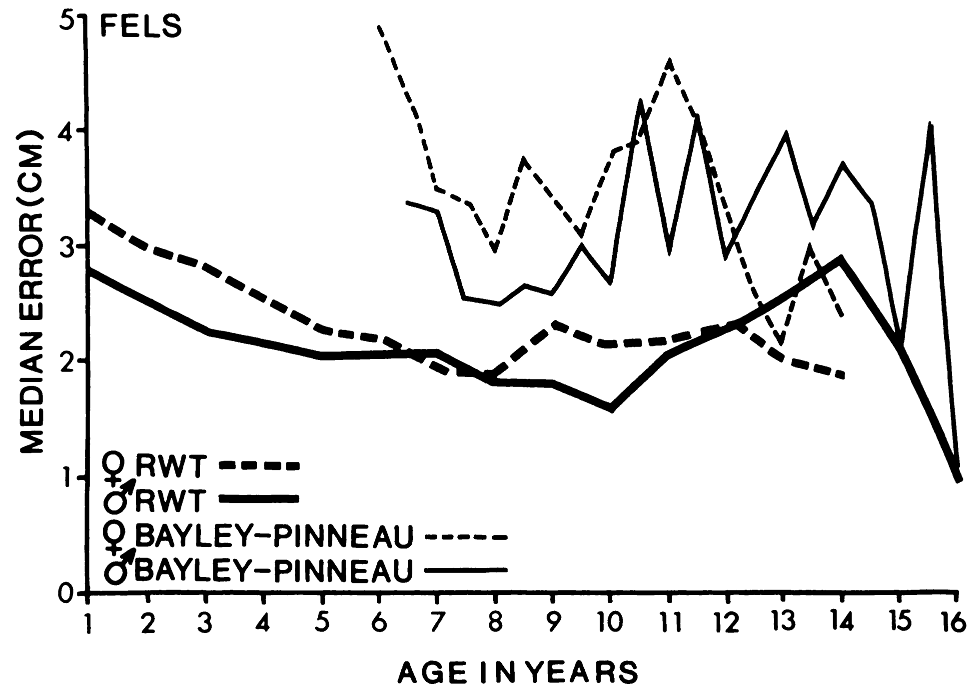

Fig. 4. Median absolute errors of prediction in children of the Harvard sample.

method of Bayley and Pinneau.[6] Furthermore, the RWT method is age-specific with predictor weights varying as continuous functions of age. Thus, it is more appropriate to the clinical situation where children are examined at random ages. Only in longitudinal growth studies are all examinations made close to birthdays or half birthdays.

Errors will occur when any prediction method is applied to individuals. These errors are due to imperfections in the prediction equations, which do not provide all the information necessary for exact predictions. Furthermore, errors will result from inaccurate recording of the predicting variables (*e.g.*, skeletal age) and changes in the children (*e.g.*, illness), after predictions are made, that can differentially alter the rates of elongation and maturation of the skeleton.[28,29]

The present aim was to develop a prediction method that would be applicable when a child and his parents enter a physician's office for the first time. Variables that require multiple visits were excluded. A more accurate prediction method could perhaps be developed using serial data for the same predicting variables but such a method would require multiple observations of the child over a period of several years. Furthermore, in the future, it may be possible to make more accurate predictions using data derived from studies of genes, hormones, or enzymes. It seems clear, however, that the RWT prediction method is about as accurate as possible for a method that utilizes *any* of the commonly recorded variables.

It must be stressed that the RWT method should not be applied to children in whom more than one half the bones of the hand-wrist are adult. It should be noted also that the RWT prediction method was derived from, and validated against, "normal" white American children. Its accuracy when applied to children with pathological conditions or differing in racial or environmental factors is unknown because of the lack of extensive suitable data.

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YOUTH: TRANSITION TO ADULTHOOD

The Coleman Report on inequality of education in the mid 1960's was one of the most influential reports of that decade. Now, in the mid-1970's, a second Coleman report,[1] this time on youth, has appeared, together with a thoughtful appraisal of this report by over a dozen critics.[2] Taken together they stake out the formidable problems faced by youth today, and of course these problems are those of our whole society. Coleman II and the critiques should receive as wide distribution and discussion as Coleman I. As Havighurst says in his review, "... the 10 year period 1974-1984 will be one of major constructive attention by American society to its young people and their problem of growing to maturity in a society which at present does not have adequate institutions to support and facilitate transition from youth to adulthood." The report recommends that society develop new environments for youth "designed to develop not only cognitive learning but other aspects of learning as well."

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