Height predictions by Bayley-Pinneau method may misguide pediatric endocrinologists

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Height prediction (HP) methods have been utilized for many years, but the accuracy of these methods has been questioned. The aim of this study was to investigate the accuracy of Bayley-Pinneau (BP) method for height prediction. We calculated the predicted height of children based on the standard height for each major percentile for boys and girls for average, accelerated, and retarded bone age (BA). We compared these results with the projected adult height assuming BA as chronological age (CA).

HP by Bayley-Pinneau method highly overestimates adult height when compared to the projected adult height in children with average BA and more so with accelerated BA. There seems to be a clear underestimation for children with retarded BA. BP method leads to overestimation for accelerated and underestimation for retarded BA and is frequently discordant with the projected height on the growth chart.

Key words: height prediction, Bayley-Pinneau method, projected height.

Height prediction (HP) is a routine procedure in pediatric endocrinology clinics. The clinician makes important decisions about the treatment of many endocrine problems including short stature and precocious puberty and informs the patients and parents about future growth potential based on these predictions. However, many pediatric endocrinologists have experienced surprise or disappointment when final height is achieved. Our predictions may be faulty despite precise height measurements and meticulous bone age (BA) assessment.

The method used most frequently for HP is based on the tables developed by Bayley and Pinneau in 1950 and revised in 1959 based on BA assessment according to the standards of Greulich and Pyle, which involves comparison of the X-ray of the left hand and wrist with the standards in their atlas[1]. Since then, population growth charts have been updated all over the world and normal adult height has considerably increased[2,3]. In addition, timing and progression of normal puberty has also changed[4]. However, the standards of bone maturation have remained the same.

In this study, we aimed to investigate the accuracy of HP based on BA compared to projected height defined as the final height expected to be achieved if the patient continues to grow on the same percentile. We also aimed to provide easy reference tables to look up HPs for Turkish children.

Material and Methods

The height in centimeters for boys and girls at each major percentile from 6 to 18 years of age was obtained from the normal growth chart for Turkish children revised in 2008[2]. For each age and percentile, HPs were calculated for average, retarded, and accelerated BA. These predictions were compared to the final height obtained by projection of the percentile lines on the growth chart, which were also numerically expressed by Neyzi et al. (Table I)[2]. The projection was made according to the BA rather than the chronological age (CA).

Height predictions (HPs) were calculated using the tables developed by Bayley and Pinneau based on the assumption that there is a correlation between skeletal age and the proportion of adult stature achieved at that time. Present height at each age, sex, and percentile was divided by this proportion of assumed adult height to calculate the expected

Table I. Normal height percentiles of Turkish children (From reference number 2).

Normal percentiles for Turkish Children														
Boys							Age							Girls
3	10	25	50	75	90	97		3	10	25	50	75	90	97
107.1	110.0	112.9	116.1	119.3	122.2	125.1	6	106.2	109.0	111.9	115.1	118.4	121.3	124.1
112.1	115.1	118.2	121.5	124.9	128.0	131.0	7	11.6	114.6	117.7	121.1	124.4	127.5	130.5
116.9	120.0	123.3	126.9	130.5	133.7	136.9	8	116.7	119.9	123.1	126.7	130.3	133.5	136.7
121.6	124.9	128.3	132.1	135.9	139.3	142.7	9	121.3	124.7	128.2	132.1	136.0	139.5	142.9
126.4	130.0	133.6	137.6	141.6	145.2	148.7	10	125.8	129.6	133.5	137.9	142.2	146.1	150.0
131.7	135.5	139.4	143.8	148.1	152.0	155.9	11	132.5	136.6	140.8	145.4	150.1	154.2	158.3
137.0	141.3	145.7	150.6	155.4	159.8	164.1	12	141.1	144.9	148.8	153.1	157.4	161.2	165.1
142.8	147.6	152.4	157.7	163.1	167.9	172.6	13	146.6	150.2	153.8	157.8	161.8	165.5	169.0
150.3	155.0	159.7	164.9	170.1	174.8	179.5	14	149.3	152.8	157.8	160.4	164.3	167.9	171.4
156.9	161.2	165.5	170.3	175.1	179.4	183.7	15	150.7	154.2	160.4	161.7	165.7	169.3	172.8
160.9	164.9	168.9	173.4	177.9	181.9	185.9	16	151.3	154.8	161.7	162.4	166.3	169.9	173.4
163.0	166.8	170.7	175.0	179.3	183.2	187.1	17	151.7	155.2	162.4	162.7	166.7	170.3	173.8
164.5	168.2	172.0	176.2	180.4	184.2	187.9	18	152.0	155.6	162.7	163.1	167.1	170.7	174.2

final height. This calculation was repeated for average, retarded, and accelerated BA. The constant proportions were obtained from the tables of Bayley and Pinneau[5]. The projected height according to BA was compared to the predicted height calculated by the method of Bayley and Pinneau.

Results

Assuming average BA, predicted heights for each major percentile at every age compared to the normal adult height for Turkish men and women are listed in Tables II and III. The same data for accelerated and retarded BAs are given in Tables IV-VII.

Examples of comparison of HP by the Bayley-Pinneau method and projected height according to BA are illustrated in Figures 1 and 2.

Discussion

The HPs calculated by the Bayley and Pinneau method given in the Tables are under- or over-estimations compared to the normal final heights in our population. Normal growth is defined as following a given percentile channel with normal growth velocity that is appropriate for the target height expected given the height of the parents. The current method of HP does not meet this definition and may potentially misguide the clinician in deciding whether or not to treat patients with short stature and/or precocious puberty.

Bayley and Pinneau stated that these predictions are subject to large errors especially in younger ages. Indeed, the standard deviation of percent of mature height achieved by the children of the Berkeley Growth Study may be as high as 3.96 for boys at 14 and 3.27 for girls at 12 years of CA[5]. In our study, the predicted height of a 13-year-old boy with average BA at the 97^{th} percentile is 197 cm, whereas the final height for adult males at the 97th percentile in our population is only 187.9 cm. Likewise, the predicted height of a 12-year-old girl with average BA at the 97^{th} percentile is 179.1 cm, whereas the final height for adult women at the 97^{th} percentile in our population is only 174.2 cm. The discrepancy is even higher when BA is accelerated. On the other hand, underestimation seems to be a greater problem for children with retarded BA growing at lower percentiles (Figs. 1, 2).

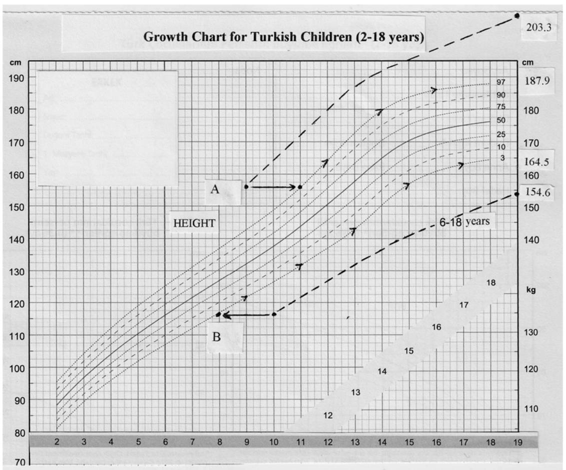

Fig. 1. The comparison of predicted and projected height of two boys with accelerated and retarded BA. The interrupted lines represent predicted height. (A) This 9-year-old boy has a height of 155.9 cm and accelerated BA of 11. His predicted height is is 203.3 cm. However, when his present height is plotted against his BA (perceived as CA) he is at the 97th percentile and the projected height of a normal adult at 97th percentile is 187.9 cm. (B). This is a 10-year-old boy with a height of 116.9 cm and a retarded BA of 8 years. His present height is appropriate for 3rd percentile of children at 8 years of age. In other words, when his height is plotted against his BA (perceived as CA), he is at the 3rd percentile. His predicted height is only 154.6 cm while the normal adult stature for men at 3rd percentile is 164.5 cm.

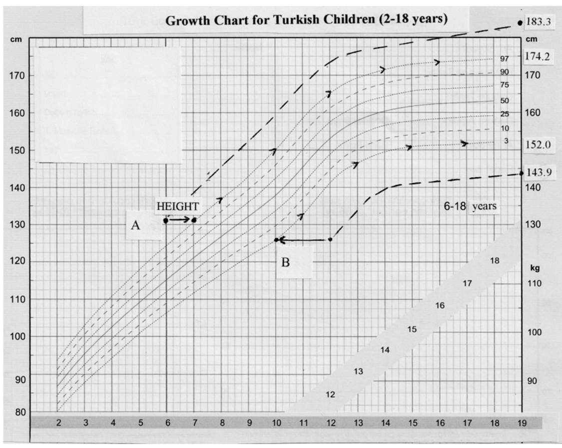

Fig. 2. The comparison of predicted and projected height of two girls with accelerated and retarded BA. The interrupted lines represent predicted height. (A) This is a 6-year-old girl with a height of 130.5 cm and advanced BA of 7 years. Her height is appropriate for 97th percentile of children at 7 years of age. Her predicted height is 183.3 cm while a normal adult woman at the 97th percentile is 174.2 cm tall. (B) This is a 12-year-old girl with a height of 125.8 cm and a retarded BA of 10 years. Her height is appropriate for 3rd percentile of children at 10 years of age. Her predicted height is only 143.9 cm while the normal adult stature for women at 3rd percentile is 152.0 cm.

Table II. Predicted height compared to the normal adult height for Turkish men assuming average BA.

	Predicted height for boys with average bone age Percentile						
CA=BA	3	10	25	50	75	90	97
7	161.3	165.6	170.1	174.8	179.7	184.2	188.5
8	161.7	166.0	170.5	175.5	180.5	184.9	189.3
9	161.7	166.1	170.6	175.7	180.7	185.2	189.8
10	161.2	165.8	170.4	175.5	180.6	185.2	189.7
11	163.8	168.5	173.4	178.9	184.2	189.0	193.9
12	164.3	169.4	174.7	180.6	186.3	191.6	196.8
13	163.0	168.5	174.0	184.2	186.2	191.7	197.0
14	162.1	167.2	172.3	186.3	183.5	188.6	193.6
15	162.0	166.5	171.0	186.2	180.9	185.3	189.8
16	163.8	167.9	172.0	183.5	181.2	185.2	189.3
17	164.5	168.3	172.3	180.9	180.9	184.9	188.8
18	165.2	168.9	172.7	181.1	181.1	184.9	188.7
Normal adult ht	164.5	168.2	172.0	180.4	180.4	184.3	187.9

CA: chronological age, RA: bone age

Table III. Predicted height compared to the normal adult height for Turkish women assuming average BA.

	Predicted height for girls with average bone age Percentile						
CA=BA	3	10	25	50	75	90	97
6	147.5	151.4	155.4	159.9	164.4	168.5	172.4
7	147.4	151.4	155.5	160.0	164.3	168.4	172.4
8	147.7	151.8	155.8	160.4	164.9	169.0	173.0
9	146.7	150.8	155.0	159.7	164.4	168.7	172.8
10	145.9	150.3	154.9	160.0	165.0	169.5	174.0
11	146.2	150.8	155.4	160.5	165.7	170.2	174.7
12	153.0	157.2	161.4	166.1	170.7	174.8	179.1
13	153.0	156.8	160.5	164.7	168.9	172.8	176.4
14	152.3	155.9	159.6	163.7	167.7	171.3	174.9
15	152.2	155.8	159.4	163.3	167.4	171.0	174.5
16	151.9	155.4	159.0	163.1	167.0	170.6	174.1
17	151.9	155.4	159.0	162.9	166.9	170.5	174.0
18	152.0	155.6	159.1	163.1	167.1	170.7	174.2
Normal adult ht	152.0	155.6	159.1	163.1	167.1	170.7	174.2

CA: chronological age, RA: bone age

One may argue that the 3rd and 97th percentiles are outliers in the population, and that a child with advanced BA may be above the 97th percentile for CA, while a child with retarded BA may be below the 3rd percentile for CA. In these cases, the projected height of the patients would have to be made on parallel lines above and below the normal distribution for the population. However, it seems more rational to assume that growth will proceed according to the level of maturation or BA in this case, which is also the principal

Table IV. Predicted height compared to the normal adult height for Turkish men assuming accelerated BA.

	Predicted height for boys with accelerated bone age Percentile						
BA	3	10	25	50	75	90	97
7	167.3	171.8	176.4	181.3	186.4	191.0	196.5
8	168.0	172.4	177.2	182.3	187.5	192.1	196.7
9	168.9	173.5	178.2	183.5	188.8	193.5	198.2
10	169.2	174.0	178.9	184.2	189.6	194.4	199.1
11	171.7	176.7	181.7	187.5	193.1	198.2	203.3
12	169.3	174.7	180.1	186.2	192.1	197.5	202.8
13	168.0	173.6	179.3	185.5	191.9	197.5	203.1
14	166.1	171.3	176.5	182.2	188.0	193.4	198.3
15	163.8	168.3	172.8	177.8	182.8	187.3	191.8
16	164.2	168.3	172.3	176.9	181.5	185.6	189.7
17	164.6	168.5	172.4	176.8	181.1	185.1	189.0
Normal adult ht	164.5	168.2	172.0	176.2	180.4	184.2	187.9

BA: bone age

Table V. Predicted height compared to the normal adult height for Turkish women assuming accelerated BA.

	Predicted height for girls with accelerated bone age Percentile						
BA	3	10	25	50	75	90	97
7	156.7	161.0	165.3	170.1	174.7	179.1	183.3
8	155.6	159.9	164.1	168.9	173.7	178.0	182.3
9	153.5	157.8	162.3	167.2	172.2	176.6	180.9
10	151.9	156.5	161.2	166.5	171.7	176.4	181.2
11	150.1	154.7	159.5	164.7	170.0	174.6	179.3
12	156.6	160.8	165.1	169.9	174.7	178.9	183.2
13	155.1	158.9	162.8	167.0	171.2	175.1	178.8
14	153.6	157.2	160.9	165.0	169.0	172.7	176.3
15	152.8	156.4	160.0	164.0	168.1	171.7	175.3
16	152.4	155.9	159.5	163.5	167.5	171.1	174.6
17	152.0	155.5	159.1	163.0	167.0	170.6	174.1
Normal adult ht	152.0	155.5	159.1	163.0	167.0	170.6	174.1

BA: bone age

assumption of Bayley and Pinneau[1]. Therefore, the projected height must be made according to the BA rather than the CA. This argument is illustrated in Figures 1 and 2.

In addition, evaluation of the HP made for children growing at the 50th percentile with average BA clearly demonstrates that HP does not match the projected height on the 50th percentile. For example, a 12-year-old boy at the 50th percentile has a HP of 180.6 cm, while the normal average adult height for Turkish men is 176.2 cm.

Similarly, a 12-year-old girl at the 50th percentile has a HP of 166.1 cm, while the normal average adult height for Turkish women is 163.1 cm. The question is why should a child with normal growth and BA deviate from normal?

Table VI. Predicted height compared to the normal adult height for Turkish men assuming retarded BA.

Predicted height for boys with retarded bone age Percentile							
BA	3	10	25	50	75	90	97
6	157.5	161.8	166.0	170.7	175.4	179.7	184.0
7	156.1	160.3	164.6	169.2	174.0	178.3	182.5
8	154.6	158.7	163.1	167.9	172.6	176.9	181.1
9	154.7	158.9	163.2	168.1	172.9	177.2	181.6
10	155.7	160.1	164.5	169.5	174.4	178.8	183.1
11	160.0	164.6	169.4	174.7	180.0	184.7	189.4
12	162.1	167.2	172.4	178.2	183.9	189.1	194.2
13	162.3	167.7	173.2	179.2	185.3	190.8	196.1
14-18 not available							
Normal adult ht	164.5	168.2	172.0	176.2	180.4	184.2	187.9

BA: bone age

Table VII. Predicted height compared to the normal adult height for Turkish women assuming retarded BA.

Predicted height for girls with retarded bone age Percentile							
BA	3	10	25	50	75	90	97
6	144.9	148.7	152.7	157.0	161.5	165.5	169.3
7	144.9	148.8	152.9	157.3	161.6	165.6	169.5
8	145.1	149.1	153.1	157.6	162.1	166.0	170.0
9	150.9	148.3	152.4	157.1	161.7	165.9	169.9
10	143.9	148.3	152.7	157.8	162.7	167.2	171.6
11	144.3	148.8	153.4	158.4	163.5	168.0	172.4
12	151.4	155.5	159.7	164.3	168.9	173.0	177.1
13	152.1	155.8	159.5	163.7	167.8	171.7	175.5
14	151.9	155.4	159.1	163.2	167.1	170.8	174.4
15	151.6	155.1	158.8	162.7	166.7	170.3	173.8
16	151.6	155.1	158.7	162.7	166.6	170.2	173.7
17	151.7	155.2	158.8	162.7	166.7	170.3	173.8
Normal adult ht	152.0	155.6	159.1	163.1	167.1	170.7	174.2

BA: bone age

Bayley and Pinneau summarize the sources of error in making HPs as follows: a) X- rays may be inaccurately read, b) the prediction tables have been derived from the standards for hands and have not been tested for readings made from other areas of the skeleton, and c) there may be some inaccuracy in measurements of height. More important, the variations in children's developmental processes may change the growth pattern due to illnesses, accidents, changes in diet, and the hormonal milieu[1]. The deviation in skeletal age may be due to an endocrine problem, the prognosis of which will obviously determine the final height. For instance, retarded BA may be due to hypothyroidism or growth hormone deficiency, while precocious puberty leads to accelerated BA. In these pathological conditions, the progression of BA largely depends on the efficacy of treatment, which is not always foreseeable in an individual child. A child with central precocious puberty may be treated by gonadotropin-releasing hormone analogs to halt puberty and BA advancement, thereby increasing the time for continuation of growth. However, this medication may also suppress growth hormone and insulin-like growth factor-1 (IGF-1), leading to a decrease in growth velocity[6]. This effect may be partially overcome by additional growth hormone treatment[7]. All these interventions and the dynamic nature of the disease process may cause significant deviation from the predicted height.

Several researchers have investigated the accuracy of HP by various methods[8-12]. Bar et al.[8] reported that the HP made at the time of the initial examination and the height age correlated with adult height, concluding that the initial HP can be useful in identifying girls with idiopathic central precocious puberty at risk for short stature. In contrast, Kirkland et al.[9] observed that HPs were more accurate at CAs approaching mature heights. Specifically, HP made from 0-2 years before adult stature was obtained was 1.6 cm in error. The magnitude of error increased to 6.6±1.5 cm when HP was made 2-4 years before adult stature was obtained and to 8.8±2.0 cm when HP was made 4-8 years before final height was reached. Bueno Lozano et al.[10] reported that the patients who were diagnosed and treated early for congenital primary hypothyroidism reached an adult height in the normal range, which is probably related to the total recovery of their retarded BA. In this pathological condition, the Bayley-Pinneau and Tanner-Whitehouse Mark were the most reliable methods of HP. The same authors compared three methods of HP in another study, and found that all three methods overestimated final height, although the Bayley-Pinneau method was the most reliable in children with short stature[11]. Joss et al.[12] compared the accuracy of five different methods of HP in constitutionally tall stature. They observed that up to BA of 12 years, the final height was massively overestimated by the Bayley-Pinneau method, but this method gave relatively accurate estimations thereafter. The conclusion of that study was that there is no best or most accurate method for predicting adult height in tall children.

Bayley and Pinneau[1] discuss that children who are accelerated in physical maturity tend to grow with exceptional vigor. However, this assumption seems to have disregarded the loss of time that may allow continuation of growth with the same vigor for sufficient duration to reach the predicted height, because the predicted height in the accelerated group is considerably higher than the final height for a given percentile had the child continued to follow the same pattern. This false logic becomes more obvious during puberty as illustrated in Tables II and III, leading to exaggerated HP at pubertal ages because of assuming continuation of growth with the same vigor. The children with accelerated BA usually suffer precocious puberty, which continuously accelerates BA and stops growth with epiphyseal fusion at a time earlier than expected for CA. The HPs given in the Tables for accelerated BA give the impression that advanced BA is an advantage for achieving taller final height. However, just the opposite is true in reality. The more delayed the BA, the greater the length of time before epiphyseal fusion prevents further growth[13]. Likewise, the adult height of patients with precocious puberty may be less than genetically expected due to accelerated BA[14]. Therefore, a different method for estimating future growth potential is needed. If advanced BA is a disadvantage, the BA of the patient may be perceived as CA, because we may assume that the body is behaving according to the level of maturity rather than the time in the calendar. This assumption is in accordance with the assumption of Bayley and Pinneau1. If the height of the patient is plotted on the growth chart according to BA rather than CA, the projected height on that percentile may be more realistic in estimating expected adult height as seen in the examples above (Figs. 1, 2). This may still be an overestimation, because the underlying cause of BA acceleration usually continues and further limits the duration of growth.

In case of retarded BA, plotting the present height according to BA will place the child at a higher percentile and then the projected height will be better, preventing the underestimation of the Bayley-Pinneau method (Figs. 1, 2). However, this method also needs to be validated by prospective studies in large cohorts.

Although the examples above represent extreme ends of the growth chart, they are chosen to emphasize the deviation between the predicted height and final height of a child if he or she had continued to grow on the present percentile. The assumption of the BP method that advanced BA is an advantage and delayed BA is a disadvantage for final height is not realistic. In fact, advanced BA negatively affects final height because of premature closure of the epiphyses as expected in precocious puberty. In contrast, delayed BA provides more time for linear growth as in constitutional growth delay.

It seems that a precise method that takes into account all the present and future dynamic factors and variations in this process is not possible, but clinicians and patients need an estimation for future expectation. It must be kept in mind and explained to the parents as such that this estimation takes into account only the present data and is not a horoscope-type future reading.

In conclusion, this paper provides reference tables for HPs in Turkish children for major percentiles calculated according to average, accelerated, and retarded BA. However, the Bayley-Pinneau method is not accurate and leads to overestimation for average and accelerated and to underestimation for retarded BA, and is frequently discordant with the projected height on the growth chart. Alternatively, the current height plotted according to BA rather than CA and projection of this percentile to adulthood may provide a more realistic HP. This hypothesis needs to be tested in large cohorts prospectively.

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