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ANNOTATION

Proposed new target height equations for use in Australian growth clinics

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Abstract: Equations for target height estimation designed for easy use in the Australian growth clinics are presented that are based on the standard deviation score method of Hermanussen and Cole. These equations are superior to the commonly used corrected midparental height method as they account for assortative mating and regression to the mean. Simulations using different mating types were performed to compare different methods of target height estimation. While the equations relate directly to growth charts used in Australia, it is noted that neither account for the secular increase in height observed from generation to generation.

Key words: assortative mating; genetic potential height; regression to the mean; secular trend; target height.

Introduction

It is common to estimate genetic potential height or target height to help in the ongoing assessment of a child's growth and development. It is also useful to estimate the target height of a child being treated for a growth disorder in order to estimate treatment efficacy. To do this, it is still common to use the corrected midparental height (CMH) method introduced by Tanner in 1970.[1] The CMH, or Tanner, method calculates the target height or height estimate ($\hat{H}$), by adding 6.5 cm to the mean of the parental heights for a boy or subtracting 6.5 cm from this mean for a girl. The CMH method is very simple to use but introduces an underestimation bias of 4–6 cm for children with short parents,[2,3] which leads to an overestimation of the effectiveness of therapy for short stature. The problem was addressed in 1998 by Luo *et al.*,[4] who simply defined a linear function between the height estimate and midparental height using a large population sample. This method, known as the final parental height (FPH) model, is essentially empirical and needs to be recalculated for each population it is used on.[3] In 2003, Hermanussen and Cole[2] specifically looked at the factors contributing to biases in target height calculations and published a new method that directly took into account assortative mating and parent–offspring correlations. Assortative mating is the situation in which individuals of similar rather than dissimilar phenotypes, height in this case, tend to partner to produce progeny. With regard to the parent–offspring height correlation, once corrected for sex, it might be expected that there would be a correlation close to one between parent and offspring heights but, as discussed later, this is not the case and must be accounted for.

Key Points

1. Target height estimates are widely used in assessing growth potential in children and are also important in evaluating the efficacy of treatment of growth disorders.
2. The target height equations presented here are simple to use in the clinic situation and account for biases due to assortative mating and regression to the mean, which have caused previous methods to be inaccurate.
3. The equations presented relate directly to the growth charts used in Australia, but neither take into account the secular increase in height.

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The Standard Deviation Score (SDS) Method of Hermanussen and Cole

The target height estimation method of Hermanussen and Cole[2] is based on calculating midparent height as an SDS and correcting this by a factor corresponding to the influence of assortative mating and parent–offspring correlations. Previously, Cole[5] had shown that calculating target height in terms of midparental height SDS was superior to Tanner's CMH method[1] as the former accounted for the fact that the distribution of male heights is wider (larger standard deviation) by about 10% than the female distribution of heights.

A distribution of SDSs must, by definition, have a standard deviation of 1.0, but assortative mating leads to a slight increase in this value. To correct for assortative mating, Hermanussen and Cole[2] multiplied the midparental height SDS by $\sqrt{2/(1+r_{Mother,Father})}$, where $r_{Mother,Father}$ is the correlation between the heights of parents in the population. The value of this correlation was assumed to be 0.27 based on Luo and coworkers (1998).[4] Short parents tend to have children who, on average,

Table 1 SDS values for centiles commonly used in Australian growth charts

Centile	1	3	5	10	25	50	75	90	95	97	99
Standard deviation score	–2.33	–1.88	–1.64	–1.28	–0.67	0.00	0.67	1.28	1.64	1.88	2.33

are not as short, and similarly with tall parents, their children are not quite so tall. This is the phenomenon of regression to the mean, first described by Francis Galton in 1886,[6] and results from the correlation between midparental height SDS and the final height of progeny SDS, $r_{Midparent,Progeny}$, being less than perfect. To adjust for this, the midparental height SDS is simply multiplied by $r_{Midparent,Progeny}$, which was given a value of 0.57, again based on Luo *et al.*, 1998[2,4].

Thus, Hermanussen and Cole's target height formula is

$$\hat{H}_{SDS} = \left(\frac{H_{SDS-Father} + H_{SDS-Mother}}{2}\right) \times r_{Midparent,Progeny} \times \sqrt{\frac{2}{1 + r_{Mother,Father}}} \quad (1)$$

Where $\hat{H}_{SDS}$ is the target height in SDS and which reduces to

$$\hat{H}_{SDS} = 0.72\left(\frac{H_{SDS-Father} + H_{SDS-Mother}}{2}\right) \quad (2)$$

A Modification to Hermanussen and Cole's Equation

While there are obvious advantages to using SDSs, Hermanussen and Cole's equation is not readily applicable to the clinic situation as clinicians and parents require the target height in terms of centimetres. The conversion from SDS to centimetres requires a knowledge of the mean and variance of heights in the population as well as a little statistical understanding. As a result, the SDS method, while superior, has not caught on. Here, we present target height equations based on those of Hermanussen and Cole[2] but more suited to the clinic situation.

$$\hat{H}_{Female} = 163.3 + 2.33\left(\left(\frac{H_{Father} - 176.9}{7.1}\right) + \left(\frac{H_{Mother} - 163.3}{6.5}\right)\right) \quad (3)$$

$$\hat{H}_{Male} = 176.9 + 2.57\left(\left(\frac{H_{Father} - 176.9}{7.1}\right) + \left(\frac{H_{Mother} - 163.3}{6.5}\right)\right) \quad (4)$$

These equations can be used to calculate the target height in centimetres of female, $\hat{H}_{Female}$, or male, $\hat{H}_{Male}$ offspring of parents with heights in centimetres of H_{Mother} and H_{Father}. The 95% confidence interval (1.64 standard deviations) for the female target height estimate is ± 10.6 cm, and for the male target height estimate it is ± 11.7 cm.

These formulae are based on the fact that $H_{SDS} = \frac{H - \mu}{\sigma}$, where H is an individual's height, μ is the mean height of the population and σ is the standard deviation of height in the population. Thus, $H = \sigma H_{SDS} + \mu$, in which H_{SDS} can be substituted for by Hermanussen and Cole's equation. As μ and σ are different for males and females, two target height equations are required. We have used means ($\mu_{Female} = 163.3$ cm, $\mu_{Male} = 176.9$ cm) and standard deviations ($\sigma_{Female} = 6.5$, $\sigma_{Male} = 7.1$) from the Centers for Disease Control (CDC), United States, datasets (http://www.cdc.gov/nchs/about/major/nhanes/growthcharts/charts.htm) as these form the basis of growth charts currently used in Australia.

Using Hermanussen and Cole's Equation in its Original Form

As noted earlier, it is often useful to use Hermanussen and Cole's equation in its original form to produce a target height SDS. The main advantage is that the target height SDS can be directly related to the height SDS of the child at a particular age. For example, if the child is tracking a growth curve at an SDS of –1.8 and the target height SDS is –1.5, then the clinician would be less concerned than if the child had tall parents and a target height SDS of 2.0. There is a minor problem, however, in that growth curves are labelled in terms of centiles rather than SDS. Centiles are related to SDSs in that they represent the area under a normal curve to the left of the SDS value. As such, SDSs can be converted to centiles using standard normal tables or, for example, the NORMSINV command in Excel (Microsoft Corporation). Table 1 lists SDS values for centiles commonly used in Australian growth curves.

Secular Trend

It is well known that there has been a gradual increase in mean height, referred to as a secular trend, in most populations over the last century.[7] The value of this secular trend, measured in cm/decade, varies between populations. In Australia, it has been estimated to be 0.4–2.1 cm/decade for males and 0.01–1.6 cm/decade for females.[8] While Hermanussen and Cole's equation does not specifically account for secular trend, they claim that if parental height SDSs are obtained from means and variances that date back one generation, it will automatically be incorporated into the target height estimate for their progeny.[2] The CDC data were collected over five separate surveys between 1963 and 1994.[9] Based on figures from the Australian Bureau of Statistics National Health Survey 2004–2005 and other contemporary reports, including one introducing new reference curves for growth, the mean height of young Australian males is approximately 180 cm and females is approximately 166 cm.[10–13] As the CDC means used were 176.9 cm and 163.3 cm, respectively, it is assumed that secular trend will be accounted for according to Hermanussen and Cole's assertion.[2]

Comparison of Methods

Target height estimations using the SDS method described here were compared with the CMH, or Tanner, method by simulating

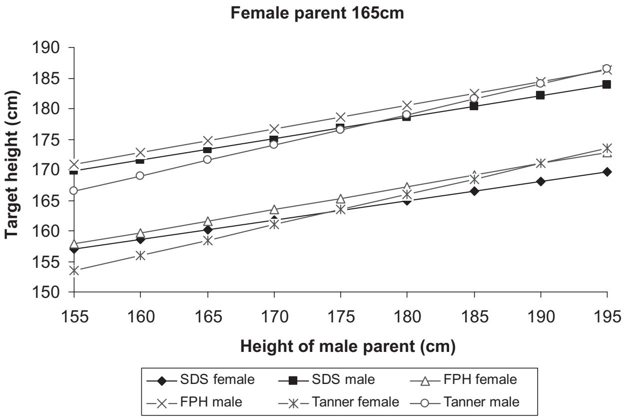

Fig. 1 Target height estimates for various male parent heights in which the female parent height is always 165 cm.

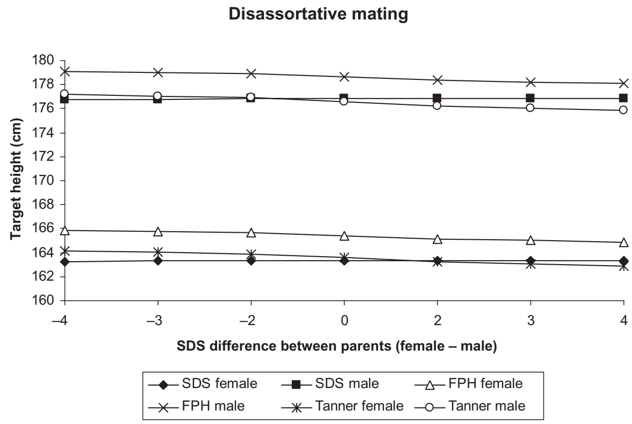

Fig. 3 Target height estimates following disassortative mating (midparent height standard deviation score (SDS) = 0).

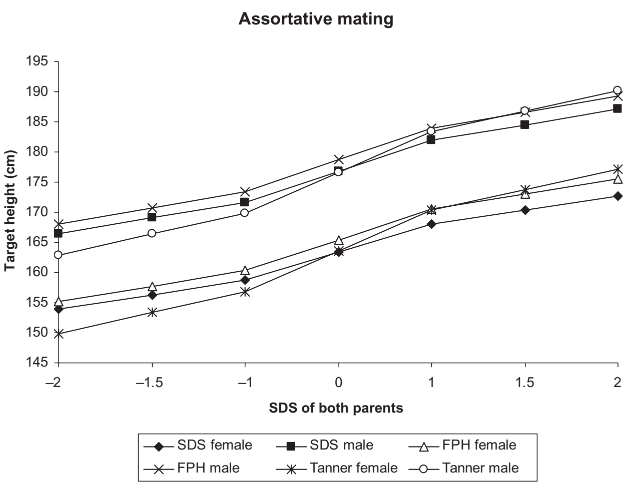

Fig. 2 Target height estimates following assortative mating.

three different mating situations. In the first case, the female parent's height was held at 165 cm while the male parent's height varied from 155 cm to 195 cm (Fig. 1). The second and third cases simulated assortative (Fig. 2) and disassortative (Fig. 3) mating types. In addition, the FPH method, using Luo *et al.*'s equations,[4] was examined as the mean heights of their Swedish population (male = 179.4 cm, female = 166.5 cm) were similar to those of the Australian population. Specifically, the equations used were $\hat{H}_{Female} = 37.85 + 0.75\overline{H}_{Parents}$ and $\hat{H}_{Male} = 45.99 + 0.78\overline{H}_{Parents}$, where $\overline{H}_{Parents}$ is the mean of the parental heights.

From Figure 1, it can be seen, as expected, that the SDS method predicts less extreme heights for children with tall or short fathers than does the Tanner method. The SDS method predicts progeny to be shorter than predictions made using the FPH method, and this difference increases with increasing male parent height.

In Figure 2, it is evident that both the SDS and FPH methods successfully correct for regression to the mean, which leads to the Tanner method predicting taller progeny from tall parents and shorter progeny from short parents than the other two methods.

In disassortative mating (Fig. 3), the SDSs of parents combine to give a midparent SDS of 0, and the target height using the SDS method will always be the mean height. In this case, the Tanner method approximates the SDS method while the FPH method consistently estimates target heights to be 1 cm–2 cm higher.

Discussion

In constructing the equations described here, it was assumed that the parent–parent and the midparent SDS–progeny SDS correlations for height were 0.27 and 0.57, respectively, based on Luo *et al.*'s Swedish population.[4] Both of these values are likely to vary between populations, and to improve the accuracy of these equations for use in Australia, it would be recommended that estimates specific for the Australian population be made. The correlation for assortative mating is well known and is commonly reported to be about 0.3.[4,14,15] The midparent height to adult height of progeny is a less well-documented statistic, and it is difficult to assess its variability between populations, hence the likely error in using the value of 0.57 on the Australian population.

From Figures 1–3, it is evident that the FPH method consistently estimated target height to be 1 cm–2 cm greater than when using the SDS method. As the FPH method is empirical, it automatically accounts for assortative mating between parents and for any secular trend in height between generations. The mean heights used to produce the FPH method were similar to current generation Australian mean heights, whereas the SDS method used means from the CDC growth data, which were equivalent to means from the previous generation. It was claimed by Hermanussen and Cole[2] that secular trend would be accounted for if SDSs were calculated using means and variances that date back one generation. Thus, it would have been expected that the two methods should have produced

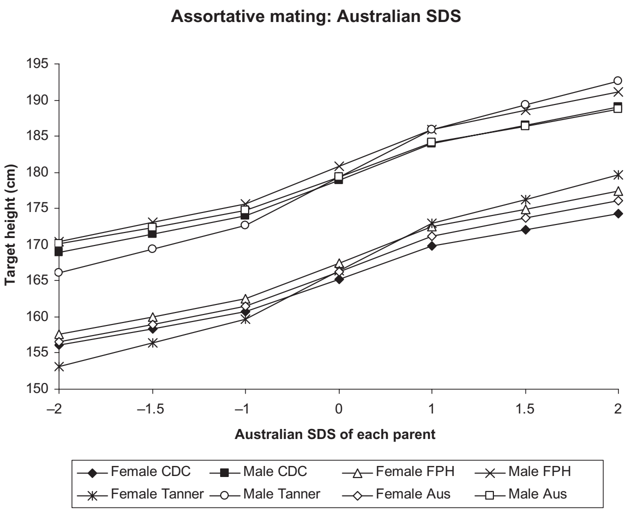

Fig. 4 Target height estimates from assortative matings where parental heights were based on Australian standard deviation scores (SDS). 'Centers for Disease Control (CDC)' refers to the SDS method using means and standard deviations from the CDC datasets.

essentially similar results. However, this is not the case and an incomplete consideration of a secular trend is the most likely explanation. Consider a midparent score is calculated as 172 cm, which is exactly the population mean as measured in 2000. Thus, in terms of the year 2000, the midparent SDS would be 0. However, the SDS is calculated in terms of 1975 means and standard deviations when the mean was smaller and so the SDS is calculated as 0.1. The secular trend is thus accounted for. Now, this midparent height SDS is also the target height SDS for a child who reaches adult height in 2025. But when the SDS of 0.1 is converted to centimetres, based on the 1975 mean and standard deviation for midparent height, it is found that this is equal to 172 cm. This is the same as that in the 2000 generation and thus does not account for secular trend. Similarly, when this SDS is converted to centimetres for male or female adult heights using means and variances from 1975, it will also underestimate adult heights by the secular trend for one generation.

If Australian means and standard deviations were used to calculate target heights by the SDS method, it would be expected that these would approach those of the FPH method. Indeed, this is generally seen to be the case. Figures 4 and 5 compare target heights derived from different methods when parental heights were based on Australian SDS values.

It can be seen from Figures 4 and 5 that using Australian means and standard deviations rather than those from the CDC increases the target height estimate. However, this is very marginal for males, and for both males and females the difference between CDC and Australian-based estimates varies with parental heights such that, for example, for tall parents the target height predictions for a male child are approximately the same. This can be attributed to the larger standard deviation for male heights from the CDC data (7.14 cm) than from the Australian data (6.47 cm).

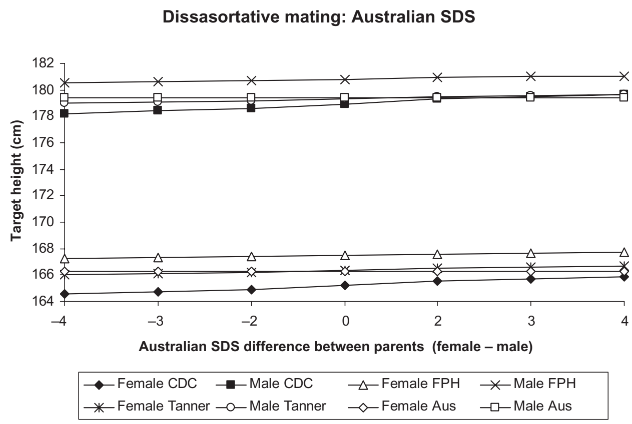

Fig. 5 Target height estimates from disassortative matings (midparent height standard deviation score (SDS) = 0) based on Australian SDSs.

Conclusions

The target height equations presented here, based on Hermanussen and Cole's SDS method[2] and the CDC means and standard deviations, are a significant improvement on the widely used Tanner method while still being simple to understand and perform. The improvement is primarily due to the account being made of assortative mating and regression to the mean, which led to less extreme target height predictions for children of very tall or very short parents. However, these equations, which are based on the same data (CDC) as those used to construct the growth charts used in Australia, do not use correlations calculated from an Australian population sample or take full account of the secular trend in height observed in the Australian population. Almost all of the secular increase in adult height is due to an increase in leg length in early childhood.[7] As a result, the observed height of a child will track up to 2 cm above and parallel to their correct centile. Thus, in most cases, the target height will be a slight underestimate of the actual adult height attained. This will lead to an equivalent overestimate of the effectiveness of any treatment for short stature. Bearing all this in mind, these equations present the most accurate target height estimates until a large-scale survey of Australian heights is undertaken and accurate mean, standard deviation and correlation values are obtained.

Acknowledgement

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