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Tanner's target height formula underestimates final adult height in Korean adolescents and young adults: reassessment of target height based on the Korean National Health and Nutrition Examination Survey 2010–2019

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ABSTRACT

Objective Estimating children's target height (TH) plays an important role in diagnosing, evaluating and treating many paediatric endocrinological diseases. However, in many countries, employing Tanner's formula to predict children's final adult height (FAH) is considered misleading. Therefore, this study aimed to re-evaluate the validity of Tanner's formula for predicting the TH of Korean adolescents and young adults and develop a new formula suitable for Korean children.

Design/setting Data were derived from the Korean National Health and Nutrition Examination Survey 2010–2019.

Patients A total of 2586 participants (1266 men, 1320 women) were included, excluding participants for whom Tanner's formula could not be calculated because of missing parental height data.

Main outcome measures Tanner-based TH was compared with the FAH.

Results The difference between Tanner-based TH and FAH was 4.86±0.178 cm for men and 4.81±0.150 cm for women. Sex-specific univariable and multivariable analyses were conducted to determine variables influencing positive height gap (greater than estimated TH). Both men and women with higher education levels were more likely to exhibit a positive height gap. Those with a history of chronic illness were less likely to exhibit a positive height gap, particularly in women. Using a new formula derived using linear regression analysis, the sum of parental heights explained 27.6% and 30.6% of the variance in sons' and daughters' heights, respectively.

Conclusions Tanner's formula for calculating TH tended to underestimate FAH; hence, our new formula may offer a better alternative for estimating TH and evaluating growth in Korean children and adolescents.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ In paediatric endocrinology, the estimation of children's target height (TH) is crucial for diagnosing, evaluating and treating various diseases; however, the use of Tanner's formula for predicting final adult height is considered misleading in many countries.

WHAT THIS STUDY ADDS

⇒ This study reevaluates the validity of Tanner's formula for predicting the TH of Korean adolescents and young adults using data from the Korean National Health and Nutrition Examination Survey and introduces a new formula specifically tailored to Korean children. This approach addresses the limitations of Tanner's formula and offers a potentially more accurate alternative for estimating TH and assessing growth.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ As the commonly used Tanner's formula tends to underestimate final adult height, indicating the need for a more accurate estimation method, the newly developed formula, grounded in data from the Korean population, could enhance the precision of height predictions for Korean children and adolescents. This may have implications for clinical practice, guiding more accurate diagnoses, evaluations and treatments in paediatric endocrinology for this population.

INTRODUCTION

Predicting children's target height (TH) from parental height has been a longstanding essential calculation in paediatric endocrinology and is used to implement necessary interventions such as growth hormone therapy. In some cases, especially when bone age is significantly lower or higher than chronological age, it indicates possible underlying medical conditions. Numerous environmental and genetic factors, as well as gestational age and birth weight, affect adult height; however, parental height strongly affects the TH of

children. Tanner's TH formula, created by Tanner in 1970, is calculated as follows: (child's height+father's height)/2±6.5 cm.[1]

Despite being widely used over the past 50 years, this method has recently been suggested as misleading and inappropriate for predicting adult height in children.[2 3] Notably, its efficacy across ethnicities is questionable. Moreover, the average height tends to increase in each generation. Over the past century, adult height has increased in both men and women in several countries. Specifically, in Korea, in 1909, the average heights were 161.4 cm for men and 147.5 cm for women; by 2004, these had increased to 173.2 cm and 160.1 cm, respectively (p=0.0002 for both sexes).[4] Therefore, in this study, we aimed to re-evaluate the appropriateness of Tanner's formula for predicting TH in Korean adolescents and young adults and identifying a new formula using Korean National Health and Nutrition Examination Survey (KNHANES) data from the past 10 years.

METHODS

Study participants

Data were obtained from the KNHANES from January 2010 to December 2019. KNHANES is the largest national health and nutrition examination survey in Korea, is conducted by the Korea Disease Control and Prevention Agency (KDCA), and began collecting data on health interviews, health examinations and the nutritional intake of non-institutionalised Korean citizens residing in Korea starting in 1998. Sampling followed a multistage clustered probability design involving health interviews, health examinations and nutrition surveys. All statistics were calculated using the sample weights assigned to the participants. The KDCA has published detailed methods regarding KNHANES data collection and preparation.[5]

Informed consent was obtained from the government at the beginning of the KNHANES survey, and processed data without personal information were made available as public research resources. The KNHANES examination study was approved by the Korean Centers for Disease Control and Prevention Research Ethics Review Committee and renewed annually.[5] Ethical approval for this study was obtained from the Institutional Review Board of Dong-A University Hospital (DAUH' IRB-EXP-22–222).

At the beginning of KNHANES data collection, participants were enrolled in a family group and individuals within the same family received the same 'family number'. Therefore, participant data could be merged according to the same family for analysis.

Among the 80 861 individuals enrolled in the KNHANES from 2010 to 2019, 9291 individuals aged 18–30 years completed their growth. Among these, those with complete height and weight data along with those of their biological parents were included in this study. According to KNHANES guidelines, data from participants and their parents were merged and analysed. The final analysis included 2586 participants (1266 men and 1320 women) (figure 1).

Anthropometric measurements

A professional survey team performed the examinations; height and weight were measured by nurses according to standard methods, with participants wearing light clothing without shoes. Height was measured to the nearest 0.1 cm using a stadiometer (Seca 225; Seca, Germany). Weight was measured to the nearest 0.1 kg using an electronic balance (GL-6000–20; G-Tech, South Korea). Body mass index (BMI) was calculated as weight (kg) divided by height squared (m^2).

Definitions

Obesity and low body weight

According to WHO guidelines for the Asia-Pacific region, obesity for both sexes was defined as BMI≥25 kg/m^2; low

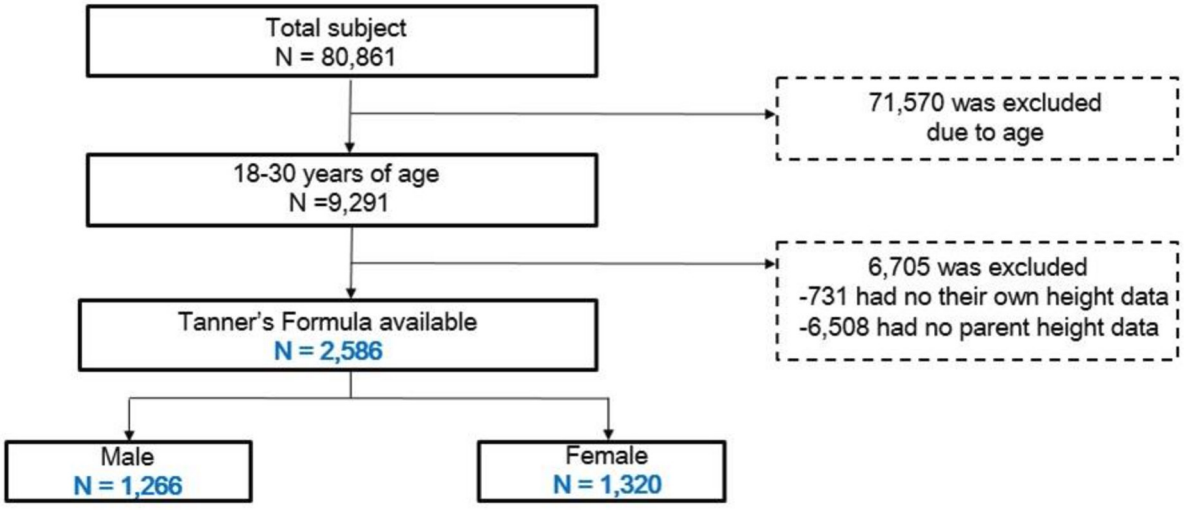

Figure 1 Diagram of participant selection from the Korean National Health and Nutrition Examination Survey from 2010 to 2019.

body weight for both sexes was defined as BMI<18.5 kg/m^2.[6]

Education

Participants were categorised into two groups based on education level at the time of the survey: those who had completed high school or higher (referred to as 'highly educated') and those who had completed middle school or lower.

Income quartile

Income levels were categorised into four quartiles, with the first and fourth quartiles representing the lowest-income and highest-income groups, respectively. The income range for each quartile was determined based on the average monthly household income in South Korea.

Chronic disease

Participants with a history of the following diseases were classified as having chronic disease: hypertension, diabetes, asthma, atopic dermatitis, hepatitis, liver cirrhosis, chronic kidney disease, pulmonary tuberculosis, arthritis, dyslipidaemia, thyroid disease or cancer.

Statistical analyses

KNHANES has specific guidelines for statistical analysis, including cluster sampling and stratification, to ensure data accuracy.[5] To represent the entire Korean population, the sampling weights assigned to the participants were applied to all analyses and generated considering the complex sample design, non-response rate of the target population and post-stratification.

Differences in key anthropometric data and participant characteristics were compared across subgroups using the χ^2 test for categorical variables and independent t-test for continuous variables, as appropriate. Trend analysis was performed for the complex survey design using logistic regression analysis. Univariable and multivariable analyses using logistic regression were performed to identify prognostic factors that were independently related to a positive final height gap. Using these data, based on Tanner's TH formula, a new prediction formula was developed by linear regression. All statistical analyses were performed using IBM SPSS software (V.24.0; IBM, Armonk, New York, USA). Statistical significance was defined as a two-sided p value<0.05.

RESULTS

Demographic and clinical characteristics

Table 1 reports the demographic and clinical characteristics of the study participants. The particularly interesting aspect is that the final height is greater than the TH calculated using Tanner's formula for both sexes, with a difference of 4.9 cm (95% CI: 4.515 to 5.211) in men and 4.8 cm (95% CI: 4.513 to 5.101) in women.

Differences in participant final adult height and their estimated mid-parental height based on Tanner's formula

Participants were divided into those with a positive (final adult height (FAH)≥Tanner-based TH) and negative height gap (FAH<Tanner-based TH). Overall, 84% exhibited a positive height gap, and 16% a negative height gap,

Table 1 Demographic and clinical characteristics of study participants in the Korean National Health and Nutrition Examination Survey (2010–2019)

	Men		Women		
	Mean	SE	Mean	SE	P value
Number	1266		1320		0.001
Age (years)	23.65	0.113	23.28	0.115	0.015
Height (cm)	174.59	0.196	161.60	0.183	<0.001
Height (SDS)	0.04	0.035	0.12	0.037	0.104
BMI (kg/m^2)	23.7	0.134	21.37	0.113	<0.001
Obesity (%)	28.13	1.652	12.73	1.137	<0.001
Low body weight (%)	5.34	0.798	19.05	1.369	<0.001
Education (%)	93.9	0.674	94.1	0.786	0.831
Low household income (%)	4.66	0.740	4.83	0.871	0.866
History of chronic disease (%)	17.94	1.265	17.31	1.207	0.711
Early menarche (≤10 years) (%)			1.12	0.716	
Father's height (cm)	169.12	0.199	169.37	0.196	0.286
Mother's height (cm)	157.35	0.183	157.21	0.174	0.539
Tanner's formula (cm)	169.73	0.151	156.79	0.141	<0.001

BMI, body mass index; SDS, Standard Deviation Score.

Table 2 Logistic regression analysis of association between variables and positive height gap

	Male				Female			
	Univariable analysis		Multivariable analysis		Univariable analysis		Multivariable analysis	
	OR (95% CI)	P value	OR (95% CI)	P value	OR (95% CI)	P value	OR (95% CI)	P value
Obesity (%)	1.22 (0.8 to 1.8)	0.33 3			0.89 (0.5 to 1.5)	0.658		
Low body weight (%)	0.80 (0.4 to 1.6)	0.52 7			1.02 (0.7~1.6)	0.915		
Education (%)	1.79 (1.1 to 3.1)	0.03 2	1.79 (1.1–3.1)	0.032	2.20 (1.2 to 3.9)	0.008	2.49 (1.4 to 4.5)	0.002
Low household income (%)	1.02 (0.5 to 2.2)	0.95 7			1.58 (0.6 to 4.0)	0.340		
History of chronic disease (%)	1.04 (0.7 to 1.6)	0.85 1			0.60 (0.4 to 0.9)	0. 013	0.60 (0.4 to 0.9)	0.012
Difference in father's height and mother's height (≥2 SD)	0.88 (0.4 to 2.0)	0.75 8			1.74 (0.6 to 4.9)	0.291		
Early menarche (≤10 years)					0.58 (0.3 to 1.1)	0.077		

thus most were taller than the Tanner-based estimated TH.

Univariable analysis showed that higher educational attainment was the only significant variable associated with a higher likelihood of a positive height gap in both sexes (men: OR: 1.79, 95% CI: 1.053 to 3.057, p=0.032; women: OR: 2.20, 95% CI: 1.229 to 3.931, p=0.008). In multivariable analysis, the OR was 1.79 (95% CI: 1.053 to 3.057, p=0.032) in men and 2.49 (95% CI: 1.385 to 4.461, p=0.002), in women, further supporting the association between higher education and a positive height gap. In contrast, in the univariable and multivariable analyses, women with a history of chronic illness exhibited a lower OR (0.60, 95% CI: 0.399 to 0.899, p=0.013 and 0.60, 95% CI: 0.397 to 0.891, p=0.012, respectively), indicating that women with chronic disease have a lower likelihood of exhibiting a positive height gap. On the other hand, men with a history of chronic illness exhibited no significant association with a positive height gap (OR: 1.04, 95% CI: 0.689 to 1.570, p=0.851) in the univariable analysis (table 2).

Linear regression line to fit FAH

The independent variables used to construct the new formula model included sex and the sum of parental height; the dependent variable was participant FAH.

Participant FAH was greater than the Tanner-based predicted TH, as depicted by the red regression line above the blue regression line in figure 2. Furthermore, the slope of the new model represented by the red regression line was 0.369 (SE 0.015, p<0.001, 95% CI: 0.338 to 0.399), which is lower than the 0.5 observed using Tanner's formula: this suggests that participant height was less influenced by the sum of parental heights in the new model.

The new TH formula based on linear regression analysis for boys was Y=(47.735+6.520)+0.36 9X=54.255+0.369X and for girls was Y=(47.735–6.520)+0.369X=41.242+0.369X, where X represents the sum of the parental heights.

Multivariable regression analysis results, which included the sum of parental heights and sex (dummy variable), explained 68.1% of the variance in participant height in both sexes. Using Tanner's formula, TH explained 16.7% and 29.7% of the variance in the height of men and women, respectively; however, the sum of parental heights explained 27.6% and 30.6% of the variance, respectively. Furthermore, the mean squared error, which indicates the amount of error in the statistical model, was smaller in our regression model than that using Tanner's formula (23.768 vs 47.869, respectively).

Child's height and new formula difference

Using the new formula, the study reanalysed the study population. When dividing the individuals into two groups based on the difference between the FAH of the participants and their calculated intermediate parental height using the new formula (0 or greater for positive height gap group, and less than 0 for the negative height gap group), the positive height gap group accounted for 48.2% in men and 49.4% in women.

DISCUSSION

The formula proposed by Tanner in 1970 has been widely used by paediatric endocrinologists worldwide to estimate TH in patients for many decades. However, certain factors can potentially affect the accuracy of applying this formula to different demographic groups. Tanner's formula was developed in the 1960s, and over the past

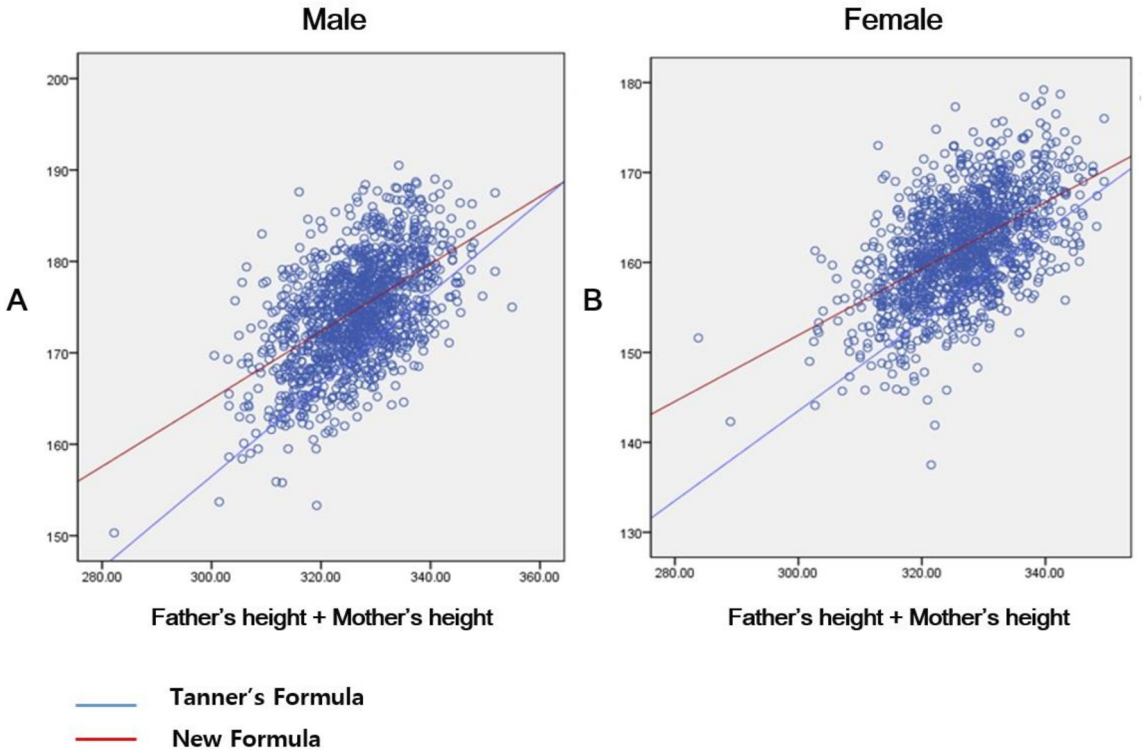

Figure 2 Linear regression line to fit target height (Y=47.735+0.369 *X+6.520 *sex, p<0.001; slope 0.369 (SE 0.02, 95% CI: 0.338 to 0.399, p<0.001); sex 6.52 (SE 0.11, 95% CI: 6.313 to 6.727, p<0.001). (A) The contribution of parents' height to the son (Blue line came from Tanner's formula, and Red line came from New formula) (B) The contribution of parents' height to the daughter (Blue line came from Tanner's formula, and Red line came from New formula) Blue lines locate higher than red line that means actual height of offspring is taller than Tanner's estimated height, and parents' height were less contributed (0.369 vs. 0.5).

century, FAH has increased in most populations of both sexes.[7] These changes are widely observed across generations and countries and are thought to be mainly influenced by nutrition and health improvements.[8–11] Therefore, a high possibility of underestimation is present when Tanner's formula is used. Furthermore, differences between ethnicities may exist when Tanner's formula is used to predict FAH. In addition, if the difference between both parents' heights is too large or small, the accuracy in predicting the FAH of the offspring using Tanner's formula decreases.[12]

Our data also showed that the TH calculated using Tanner's formula underestimated the FAH in both sexes; therefore, the usefulness of this formula should be re-evaluated. However, factors that may influence FAH are quite different from those identified in previous studies. Economic status has influenced FAH directly and indirectly in previous studies.[13–15] However, in this study, economic status was not associated with FAH. Nevertheless, we believe that educational differences reflected some aspects of economic influence on FAH because individuals with high economic status in Korea tend to be highly educated. When Tanner's formula was applied, economic factors, nutritional factors, BMI and obesity were not associated with FAH or a positive height gap.

Many studies have shown that chronic disorders,[16] such as inflammatory bowel disease,[17–19] hepatitis,[20 21] pulmonary tuberculosis,[22 23] systemic lupus erythematosus,[24 25] allergic disease (including atopic dermatitis),[26 27] asthma,[28 29] nephrotic syndrome,[30] chronic kidney disease or hypothyroidism,[31] which require high-dose steroid treatment, affect FAH. We compared these variables in our study but found no association between calculated height differences and FAH. Using data representing the entire Korean population, this study shows a realistic pattern of growth and relationship with various factors, suggesting that these factors may not significantly influence FAH.

To account for sex differences, Tanner's formula was added to a constant value of 13 cm.

There have been varying opinions among studies regarding whether the sex difference is exactly 13 cm or 14 cm. However, on examining previous studies[2 32 33] and our own research within the same era, the sex height difference was approximately 13 cm. According to the 2017 Korean paediatric growth chart, the 50th percentile height for 18-year-old men is 174.5 cm, while that for women is 161.1 cm, resulting in a sex-based height difference of 13.4 cm.[34] Our study also revealed that parents and offspring had a sex-based height difference of 13 cm. In the newly proposed formula, the sex correction remains the same as that in Tanner's formula at 13.013, with only the slope reduced.

In this study, the linear regression slope decreased from 0.5 to 0.369 in Tanner's formula compared with our new formula (figure 2). Though it may not be relevant to compare directly because Tanner's formula is not regression-based, there were many efforts to reduce the gap of 0.5 in clinical settings to reduce the error of predicted potential height of the offspring. This contrasts with findings of the previous Indian study, which had a slope of 0.615 for sons and daughters, as well as studies from Australia[32] and Sweden,[12] showing slopes of 0.78 in sons and 0.75 in daughters, respectively. The reduction in parental height's influence on Korean offspring's height suggests other factors (including environmental factors) exert an important influence on FAH. Unfortunately, our attempt to identify these other factors, including nutritional status, chronic illness and age at menarche, failed to reveal significant associations. Although genetic factors, such as parental height, still play a substantial role in children's height, further research is required to identify other influential factors, as indicated by the new formula.

Our study encompassed data representative of the entire South Korean population and benefited from the participation of skilled experts in the research survey. In addition, this study has the advantage that KNHANES was conducted in an ethnically and culturally homogeneous region, lending credibility to the measured values. However, our study has some limitations. Owing to the cross-sectional nature of the study, it evaluates only participants' immediate status, lacking a comprehensive view of the growth process from birth. Furthermore, medical history data such as chronic illness and age at menarche rely on participant's recall, leading to the possibility for errors. Furthermore, participants enrolled in this study were those who had complete data of both parents' height, and only 27.8% of initial candidates finally underwent analysis. The reason of missing data is various; usually due to participants' preference in the process of consent and participants' time affordability would be the major reason. These processes were purely random, however, the percentage of missing data is quite large, and this also should be considered in predicting this result. Therefore, further research should be proceeded not only explore factors known to impact FAH but also other environmental factors in the sequential growth in the well-controlled cohort. Additionally, there should be an assessment of the impact of endocrine-disrupting chemicals on growth, with a focus on regional differences among participants.

Finally, KNHANES is a nationally representative large-scale survey sample data in Korea with high variation on the dependent variable. Therefore, the low goodness of fit of our model with one or two independent variables is a limitation. In addition, the normality assumption was also violated, and transforming the outcome to normality was unsuccessful. We also analysed quantile regression (data not shown). It was found that the estimation of the regression parameters for sex and sum of the parental heights was significant at level α=0.05 for all quantiles.

In the 0.25th quantile regression model, sex and sum of the parental heights showed significant influences ($p<0.001$). The regression equation based on 0.25th quantile regression model for boys was Y=46.029+0.383X, and for girls was Y=33.091+0.383X. In the 0.50th quantile regression model, sex and sum of the parental heights showed significant influences ($p<0.001$). The regression equation based on 0.50th quantile regression model for boys was Y=50.217+0.381X, and for girls was Y=37.304+0.381X. In the 0.75th quantile regression model, sex and the sum of the parental heights showed significant influences ($p<0.001$). The regression equation based on 0.75th quantile regression model for boys was Y=62.254+0.354X, and for girls was Y=49.274+0.354X.

However, the aim of this study is to model outcomes with a simple formula and compare with Tanner's formula directly. Therefore, results should be interpreted with caution and focus on estimation of linear tendency and compare with Tanner's formula rather than prediction of each data point.

We also could not validate the new formula out of the KNHANES cohort. In the KNHANES cohort the new formula fits better than Tanner's model, but further validation process also need to be used in clinical settings.

CONCLUSION

Tanner's TH formula may not accurately predict and often underestimates adult height in certain ethnic groups. Since the accurate prediction of FAH in individuals with diverse ethnic backgrounds may require population-specific formulas or adjustments, we proposed a new model that considers both era and ethnic characteristics. Furthermore, our new formula suggested a decrease in the contribution of parental height to the child's height. However, additional large-scale studies on factors affecting FAH are required. Our new formula may offer a better alternative for estimating children's TH and evaluating growth compared with the commonly used Tanner's formula.

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Competing interests No potential conflict of interest relevant to this article was reported.

Patient and public involvement Patients and/or the public were involved in the design, or conduct, or reporting, or dissemination plans of this research. Refer to the Methods section for further details.

Patient consent for publication Not applicable.

Ethics approval Ethical approval for this study was obtained from the Institutional Review Board of Dong-A University Hospital (DAUH' IRB-EXP-22-222).

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement Data are available in a public, open access repository. Data are available upon reasonable request. All data relevant to the study are included in the article or uploaded as supplementary information.

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