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ORIGINAL ARTICLES

Effect of Adjusting for Tanner Stage Age on Prevalence of Short and Tall Stature of Youths in the United States

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Objective To evaluate the extent to which pubertal timing alters the classification of extremes of attained stature across race-ethnicity groups of youths in the US.

Study design We performed analyses of height and Tanner staging data of 3206 cross-sectional national sample of youths ages 8-18 years (53% male, n = 1606), 72% of whom were non-Hispanic white, 9% Mexican American, and 19% non-Hispanic black . Specialized growth models were used to derive Tanner-stage-age-adjusted z scores (TSA_{HAZ}). The prevalence of shortness (<–1SD) and tallness (≥+1SD) status was quantified using TSA_{HAZ}.

Results Highly variable patterns of prevalence of shortness and tallness via chronologic age height z score (CA_{HAZ}) were observed in results stratified by race-ethnicity and sex. Tallness CA_{HAZ} prevalence was high among non-Hispanic white and non-Hispanic black male youths relative to Mexican American (40.0%-43.3% vs 20.5%) with a similar pattern in female youths. In both sexes, this pattern was eliminated with TSA_{HAZ}, with Mexican American youth becoming statistically not different from their non-Hispanic white and non-Hispanic black peers.

Conclusions Differences in timing of puberty between race-ethnicity groups affects estimated prevalence of shortness and tallness of attained height that remains uncaptured with CA_{HAZ}. Adjustment for pubertal development might help isolate crucial determinants of attained stature and other aspects of body composition that may be most responsive to intervention programs in populations. The curves developed by adjusting for pubertal status may help the clinician avoid misclassification of children with early and late pubertal development. *(J Pediatr 2018;■■:■■-■■).*

Pubertal staging has been shown to distort anthropometric indicators of existing growth reference curves that often are based on chronologic age in healthy children and adolescents from US, Europe, China, and elsewhere.[1-5] One example is that children with early pubertal development tend to be tall for chronologic age and have a higher body mass index (BMI) for chronologic age, which can lead to them being misclassified as overweight/obese.[3-8] Further, children with delayed puberty can be misclassified as having low bone mineral density (BMD) because of their relative short stature compared with their peers of the same chronologic age if pubertal status is not considered.

Although the concept of adjustment of size for maturation (pubertal stage) beyond age is used by specialists evaluating children with growth disorders in some circumstances, including the use of bone age and height-age, specific tools for applying such adjustments are not available for specialists, pediatricians, or field researchers. Parsing out maturation vs chronologic effects is important given that timely interventions during this pubertal window of opportunity[9] have adult health implications.[10] Better understanding of the impact of differences in pubertal timing on growth outcomes in different populations may better guide interventions aimed at improving growth outcomes in individual children or a population subgroup.

We applied statistical modeling of height-for-maturational age that accounts for pubertal staging beyond chronologic age in US children/youths ages 8-18 years. Our research objectives were to examine growth pattern differences in Tanner stage age-adjusted height z scores (TSA_{HAZ}) vs chronologic age height z scores (CA_{HAZ}) for US children transitioning through puberty ages at 8-18 years and Tanner stages II-V; to quantify maturation-chronologic age differences when estimating prevalence of common indicators of attained stature in US youths; and to provide an example of how Tanner stage adjusted curves can be used as a practical tool that could be used by clinicians to avoid misclassification of children with early or late puberty. We hypothesized that accounting for differences in timing of puberty between race-ethnicity groups by TSA_{HAZ} can affect the estimated prevalence of shortness and tallness of attained stature.

BMD	Bone mineral density
BMI	Body mass index
CA_{HAZ}	Chronologic age height z scores
CDC	Centers for Disease Control and Prevention
HAZ	Height-for-Age z scores
NHANES III	National Health and Nutrition Examinations Survey cycle 1988-1994
TSA_{HAZ}	Tanner stage-age adjusted height z scores

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Methods

We performed secondary data analyses of anthropometric and Tanner staging data of US children ages 8-18 years from National Health and Nutrition Examinations Survey cycle 1988-1994 (NHANES III),[11] which is a complex cross-sectional survey design (multistage sampling) of US noninstitutionalized civilians. The anthropometric variables used in this study (weight, height) were measured by trained technicians following standardized protocols.[12] The key inclusion criterion was the availability of nonmissing data on maturational staging, age, and height.

Pubertal Staging

Pubertal/sexual maturity was assessed following Marshall-Tanner[13,14] criteria. Trained physicians, who received standardized training,[11] assigned maturation staging for each child based on secondary sexual characteristics (breast [girls] and genitalia stage [boys] by inspection compared with standardized photos). Physician inter-rater reliability of the Tanner stage assessments was found to be high and acceptable.[15-17] Statistical analyses were restricted to children at or greater than Tanner stage II, for whom pubertal onset is confirmed to have begun.

Height for-Tanner Stage-Age Statistical Modeling

We separated out the contribution of pubertal maturation staging from chronologic age on short/tall classification by using TSA_{HAZ} for further analyses. An extended function of semiparametric *Lambda, Mu, Sigma* (LMS) method in GAMLSS[18,19] technique of growth modeling was used to generate specialized age-conditioned growth equations within each stage and ensured that each child's age, Tanner staging, and race-ethnicity were incorporated in the estimation of their maturation adjusted height-for-age z-scores (HAZ). With each fitted function, TSA_{HAZ}, analogous to the US Centers for Disease Control and Prevention (CDC) 2000 CA_{HAZ},[20] were calculated. Average growth patterns were characterized with smoothed age splines through each set of z scores.

Anthropometric Indicators

Short and tall stature were defined by HAZ <–1 SD (≤15th percentile, shortness) or ≥+ 1 SD (≥85th percentile, tallness), respectively. Four height indicators were derived to represent categories before (short-CA_{HAZ} and tall-CA_{HAZ}) and after (short-TSA_{HAZ} and tall-TSA_{HAZ}) adjustment for pubertal status.

All analyses were conducted in R (R Foundation for Statistical Computing, Vienna, Austria) and SAS (SAS Institute, Cary, North Carolina). Following the NHANES III demographic designations the 3 race-ethnicities included in this work are non-Hispanic white, non-Hispanic black, and Mexican American.[11] Descriptive statistics are presented as means and percentages with SEs. To accommodate 3 race-ethnicity groups, hypotheses testing and multiple comparisons of anthropometric indicators (short/tall) were conducted at alpha of .0167 (ie, alpha/3; .05/3). CIs were set a priori at 98.33% CI and were derived from bootstrap replications of 5000 resamples.

We used prevalence ratios (95% CI) to quantify differences for race-ethnicity in likelihood of classifying shortness and tallness based on the CDC-2000 CA_{HAZ}. For all other analyses, statistical significance was set at $P < .05$ with adjustment for complex survey design effects and weighting, where appropriate.

Results

Mean age of the participants was 14.3 years for both sexes (Table I) with a range of 8-18 years. There were no pooled mean race-ethnicity differences for weight, height, and BMI. In terms of population maturation tempo, only 3%-8% of all participants were considered early "bloomers" based on their age being less than the US published national timing estimates by Sun et al, for their sex/race-ethnic population median age-at-entry into Tanner stage II. The cohort was generally in good health with ≤ 2.2 % self-reporting "poor" health.[21]

As shown in Figure 1, prevalence of shortness (<- 1 SD) and tallness (≥+ 1 SD) varied greatly across Tanner stages for both sexes. Mexican American youths, were more likely to be classified as short over the entire pubertal period (14%-18.2% in male youths, and 10%-28.9% in female youths). From early to mid-puberty, tallness (%) was highest in non-Hispanic black male and female youths (44%-56%), followed by non-Hispanic white (34%-52%) and then 25%-48% among Mexican American youths. In late puberty (Tanner stage IV-V), tallness was lowest in Mexican American (4.6%–6.9%) as opposed to ~26% for their non-Hispanic white and non-Hispanic black peers. Figure 1, B describes population prevalence difference derived from adjustment for pubertal status expressed as CA_{HAZ} minus TSA_{HAZ}. Tallness misclassifications were high and ranged from 24-26 percentage points in non-Hispanic white and non-Hispanic black male youths, and non-Hispanic black female youths, and one-half as much (13 percentage points) in non-Hispanic white female youths. Mexican American youths had lowest (1.4-2.0 percentage points) tallness misclassification. For shortness, misclassifications were generally low and were all under 8% across race-ethnicity/sex, albeit lowest in Mexican American male youths.

Figure 2 (available at www.jpeds.com) shows 2 sample Tanner stage height-for-age curves for Mexican American male youths superimposed on the CDC 2000 Height-for-Age charts. Examples of children with early and delayed pubertal development with their height plotted on these curves demonstrates how the use of these models can avoid misclassification of children as short or tall. Generation of such curves for other ethnicities and anthropometric variables may have similar or additional clinical applications.

Figure 3 (available at www.jpeds.com) describes age-spline smoothed curves contrasting and comparing average patterns using HAZ scores based on chronological age only (CA_{HAZ}), and that adjusted for Tanner stage age (TSA_{HAZ}). Again, distinct differences in linear growth curvatures were observed from age 8-18 years across sex and race-ethnicity.

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