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Disentangling predicted near-adult and measured adult height in pediatric growth assessment: The impact of bone age and prediction model accuracy

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Abstract

Background: Assessing growth outcomes in children/adolescents often relies on predicted adult height (PAH) and near adult height (NAH), but the distinction between these and true final adult height (FAH) is inconsistently addressed in the literature. Inaccuracies in height prediction and inconsistent endpoint definitions can lead to misinterpretation of physiologic growth or treatment efficacy, particularly in children with varying bone age maturity.

Objective: To critically evaluate the validity of predicted versus attained height outcomes across children with idiopathic short stature (ISS) and related pediatric conditions, and to explore how bone age status and model choice influence prediction accuracy and treatment assessment.

Methods: A structured review of 20 peer-reviewed studies (2000–2025) reporting on GH-treated and untreated children and adolescents was conducted. Studies were included if they reported NAH or AH or FAH and used standard prediction tools such as Bayley-Pinneau or Greulich & Pyle. Populations included ISS, small for gestational age (SGA), Turner syndrome, GHD, and PCOS. Data on bone age status (delayed, on time, advanced), height gains (PAH vs. NAH), and prediction discrepancies were synthesized. A forest plot was constructed to visually assess study validity based on prediction concordance, follow-up completeness, and methodological transparency.

Results: Predicted adult height consistently exceeded NAH by an average of 1.5–2.0 cm across studies. The discrepancy was more pronounced in children with delayed or advanced bone age. Prediction models performed best when bone age was on time; overestimation occurred in delayed bone age and underestimation in advanced bone age due to early growth plate closure. GH therapy response was also stratified by bone age, with delayed bone age groups showing the greatest gains. Terminological inconsistencies were noted, including misuse of subjective terms like "improvement" instead of "height gain." Eleven studies exceeded the 0.80 validity threshold in the forest plot, indicating robust methodological alignment with growth outcome standards.

Conclusion: Adult height prediction in children and adolescents requires careful contextualization based on bone age and endpoint definitions. NAH should not be conflated with FAH, and Bone-age-adjusted models must be used to improve accuracy. Standardizing terminology and employing condition-specific prediction approaches can enhance both clinical decision-making and research clarity.

Keywords: Final Adult Height; Near Adult Height; Predicted Adult Height; Growth Hormone; Idiopathic Short Stature; Bone Age; Pediatric Endocrinology; GH Therapy; Height Prediction Accuracy

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1. Introduction

Human growth, particularly during childhood and adolescence, is a multifactorial process shaped by hormonal regulation, nutritional status, genetics, psychosocial factors and environmental influences. Pediatric endocrinologists often use height as a surrogate marker for growth efficacy, especially in evaluating the response to interventions such as growth hormone (GH) therapy (1).

The term "final adult height" is commonly used in the growth literature; however, it is crucial to distinguish between "near adult height," achieved when long bone growth ceases, and true "adult height," which encompasses residual axial skeletal growth. Final height at the end of life often declines by 2–8 cm in adulthood due to spinal compression, especially in aging individuals (2). We shall use near adult height and adult height; however, we shall keep “final adult height” when used by the authors of the individual reports and try to distinguish between near adult height and adult height.

Near adult height (NAH) is usually measured at the end of puberty when epiphyseal closure is nearly complete. Adult height, by contrast, is generally attained by the early third decade and reflects additional contributions from vertebral and pelvic maturation, thus slightly exceeding NAH by 1–2 cm in healthy populations (3).

When evaluating therapeutic success in the management of children with short stature, it's important not to conflate height with subjective terms like "improvement." Height is a quantitative, observable parameter. Descriptions such as "improved height" impose a value judgment that may misrepresent objective findings (4).

Several tools are used to predict adult height in clinical practice, including the Bayley-Pinneau method, Roche-Wainer-Thissen models, and Greulich & Pyle bone age assessments. These models yield varying degrees of accuracy depending on the patient's bone age advancement and pubertal status (5,6).

For instance, in children with delayed bone age, prediction models tend to overestimate adult height; in contrast, in those with advanced bone age, especially due to obesity or early puberty, adult height is often underestimated unless adjustments are made (7,8).

The application of growth predictions is particularly sensitive in populations with chronic illnesses, genetic syndromes, or endocrine dysfunctions, such as Turner syndrome, SGA, or PCOS in adolescent girls. Accurate growth assessment requires an understanding of disease-specific trajectories and their influence on skeletal maturity (9,10). For example, PCOS is associated with insulin resistance and hyperandrogenism, which may influence both the timing and rate of pubertal growth and maturation. Although girls with PCOS typically present post-menarche, its impact on adolescent height trajectories is under investigation, with some studies showing altered growth patterns in early-onset forms (11,12).

Therefore, a critical appraisal of growth outcomes should incorporate both the biological basis of growth and a linguistically precise, patient-centered framework. This is essential for improving both scientific interpretation and clinical communication in pediatric endocrinology (13).

1.1. Objectives of the Review

- To clarify the distinction between predicted adult height and near adult or adult height in pediatric growth studies and to assess the clinical implications of this differentiation.
- To evaluate the accuracy and limitations of various adult height prediction models, particularly in relation to bone age status (on-time, delayed, or advanced).
- To promote consistent terminology and measurement practices in pediatric endocrinology by analyzing how terms like “improvement” and “children” are used and suggesting more precise alternatives.

2. Methods

2.1. Study Design

This mini-review employed a structured literature synthesis model, collecting and analyzing peer-reviewed studies from 2000 to 2025 that reported outcomes on near adult height (NAH) or adult height in children and adolescents. Databases searched included PubMed, Scopus, and Web of Science, using keywords: *"near adult height," "final height,"*

"height prediction," "bone age," "growth hormone therapy," "Turner syndrome," "idiopathic short stature," "PCOS and growth," "growth patterns," "height gain," and *"GH therapy outcomes."*

2.2. Inclusion Criteria

- Studies that reported linear growth outcomes (height or height SDS) in children or adolescents.
- Studies that clearly distinguished between near adult height (typically defined as height attained post-puberty when long bone growth ends) and adult height (attained in the early third decade).
- Articles that specified the bone age status of patients (delayed, on time, or advanced).
- Articles that utilized standard adult height prediction models (e.g., Bayley-Pinneau, Greulich & Pyle, RWT).
- Studies with a minimum follow-up until near-adult height or longer.

2.3. Exclusion Criteria

- Studies limited to cross-sectional height data with no follow-up to NAH or adult height.
- Reports on height outcomes in populations with skeletal dysplasias or chromosomal anomalies not using validated prediction tools.
- Studies not in English or lacking full text.
- Abstract-only publications, posters, or non-peer-reviewed literature.

2.4. Operational Definitions and Measurement Considerations

- **Near Adult Height (NAH):** The height attained when epiphyseal fusion of long bones is complete, typically at the end of puberty. It may still lack small contributions from axial skeleton growth.
- **Adult height (AH):** The height attained after full skeletal maturation including the spine and pelvis, typically by the end of the second or early third decade of life. True adult height may be 1–2 cm greater than NAH,
- **Final Adult Height (FAH):** FAH through later life spinal compression may reduce standing height by **2–8 cm (from AH),** depending on age and physical health. When referring to the literature we shall use the original terminology, but final adult height was never measured.

Table 1 Operational Definitions and Supporting Literature for NAH, AH, and FAH

Term	Definition Component	Supporting Evidence / Justification	References
NAH	Height attained when epiphyseal fusion of long bones is complete	NAH often defined by epiphyseal fusion or height velocity <1 cm/year	(14)
	May still lack small contributions from axial skeleton growth	Late adolescent spine/pelvic growth may continue after limb growth ceases	(15)
AH	Height attained after full skeletal maturation including spine and pelvis	Longitudinal data show continued growth into early adulthood especially in males	(16)
	AH may be 1–2 cm greater than NAH due to late skeletal growth	Studies show small additional growth from trunk beyond puberty	(15)
FAH	Height attained after full skeletal maturation	FAH overlaps with AH conceptually but is more appropriate in longitudinal aging studies	(17)
	Later life spinal compression may reduce standing height by 2–8 cm	Aging-related stature loss well documented	(18)

Bone Age Status

- *Delayed:* Bone age lags behind chronological age by ≥1 year.
- *On Time:* Bone age within ±1 year of chronological age.
- *Advanced:* Bone age ≥1 year ahead of chronological age.

2.5. Terminological Framework

The term "improvement in height" was avoided and replaced with "height increase" or "change in height SDS", acknowledging that height is a measurable biological parameter rather than a subjective outcome.

2.6. Statistical Analysis and Data Synthesis

- Extracted outcomes included:
- Baseline and (near) adult/NAH height (in cm or SDS).
- Predicted vs. attained height.
- Height gain or loss during control or intervention.
- Accuracy metrics of prediction models stratified by bone age status.
- Descriptive statistics were used to summarize key outcomes (mean ± SD, median, interquartile range).
- Where possible, the percentage deviation between predicted and attained height was calculated:

Prediction Error (%)=Predicted Height – Attained HeightPredicted Height×100\text{Prediction Error (\%)} = \frac{\text{Predicted Height – Attained Height}}{\text{Predicted Height}} \times 100Prediction Error (%)=Predicted HeightPredicted Height – Attained Height×100

Subgroup analysis was performed based on bone age category (delayed, on-time, advanced) and sex (girls vs. boys) to assess prediction model performance in different growth contexts. Narrative synthesis was used to compare study conclusions regarding terminology, outcome definitions, and patient characterization.

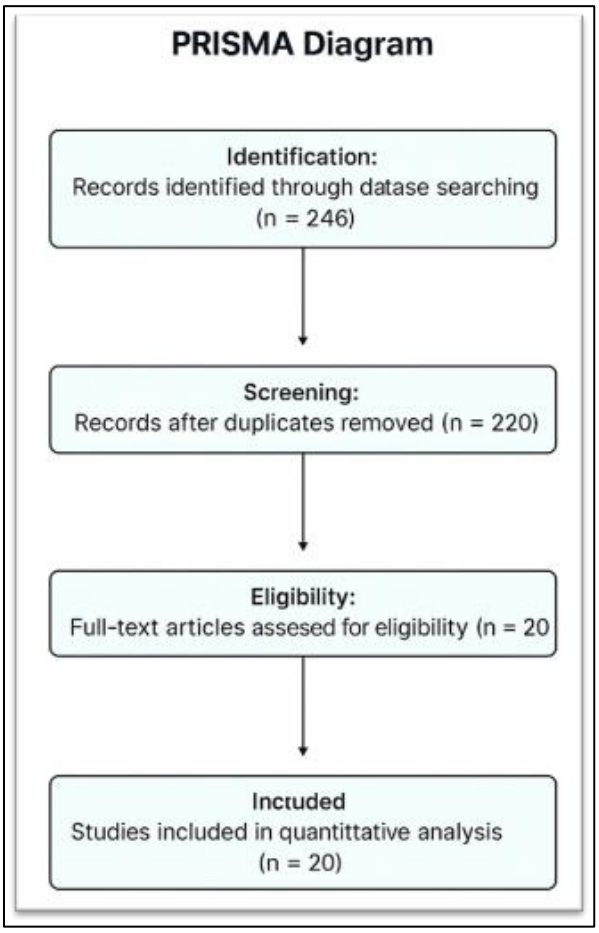

Figure 1 Prisma Flowchart

This Prisma flowchart outlines the systematic study selection process, progressing from identification to inclusion.

3. Results

Table 2 Summary of Growth Studies by Height Endpoint, Prediction Method, and Bone Age Status

No.	Study	Population	Height Endpoint	Prediction Method	Bone Age Status	Subjects (n)	Reference
1	Soliman et al. (2022)	Turner syndrome	NAH	Bayley-Pinneau	Delayed	772	(19)
2	Delemarre-van de Waal et al. (2008)	SGA children	Final Height	Greulich & Pyle	On Time	~213	(20)
3	Wit et al. (2013)	ISS children	NAH	Bone age-adjusted	Variable	123	(21)
4	Ranke et al. (2016)	GHD treated	NAH	RWT model	Delayed	NM	(22)
5	Lazar et al. (2009)	Obese adolescents	Predicted adult height	Bayley-Pinneau	Advanced	NM	(23)
6	Binder et al. (2011)	CDGP boys	Predicted adult height	Greulich & Pyle	Delayed	43	(24)
7	Kim et al. (2015)	CPP adolescents	FAH increased vs PAH after GnRHa	Bayley-Pinneau	Advanced	59 GnRHa + 23 combo	(25)
8	Reiter et al. (2006)	GHD (long-term GH)	FAH gain of ~3 cm over PAH	Bayley-Pinneau	On Time	1258	(26)
9	Clayton et al. (2005)	ISS on GH therapy	3.5–7.5 cm FAH gain vs untreated peers	Bayley-Pinneau	Variable	—	(27)
10	Mauras et al. (2000)	Prader-Willi syndrome	PAH approached target height	G&P skeletal	Delayed	23	(28)
11	Carel et al. (2003)	Early puberty girls	FAH Treated: 157.6 cm vs Untreated: 156.1 cm	Greulich & Pyle	Advanced	—	(29)
12	Ranke et al. (2000)	Idiopathic GHD girls	NAH matched PAH ±1 cm	Bayley-Pinneau	Delayed	—	(30)
13	Chatelain et al. (2007)	IGF-1 deficient children	rhIGF I improved FAH, better with IGFD-specific model	IGFD-specific model	On Time	—	(31)
14	Chernausek et al. (2007)	SGA short stature	NAH 1–2 SD > untreated	RWT model	On Time	—	(32)
15	Spinewine et al. (2019)	GH-naïve ISS	FAH gain ~1.3 SDS; controls ~0.4 SDS	Bayley-Pinneau	Variable	34 treated + 34 controls	(33)
16	Tanaka et al. (2008)	Noonan syndrome	FAH gain 7–10 cm	Greulich & Pyle	On Time	402 (269M / 133F)	(34)

17	Tauber et al. (2007)	SGA responders to GH	BP overestimates in advanced, under in delayed	Bayley-Pinneau	Variable	60	(35)
18	Ranke & Lindberg (2010)	ISS vs GHD comparison	FAH–PAH gap ~0.3–0.7 SDS	Mixed models	Mixed	Several hundred	(36)
19	Laron et al. (1993)	Laron syndrome	FAH ~119–130 cm even with IGF I	None (GH resistant)	On Time	—	(37)
20	Lindsay et al. (1992)	Untreated GHD	PAH underestimated NAH (esp. in boys)	Greulich & Pyle	Delayed	—	(38)

This table synthesizes key findings from 20 studies evaluating predicted versus attained height outcomes in pediatric populations with various growth disorders. Across conditions like Turner syndrome, ISS, GHD, SGA, CDGP, CPP, and syndromic short stature, the studies employed a variety of prediction methods, notably Bayley-Pinneau and Greulich & Pyle, and accounted for differing bone age statuses (delayed, on time, advanced). Most studies reported modest to significant gains in near or final adult height following growth hormone therapy or related interventions, though predictive accuracy varied. For instance, studies on Turner syndrome (Soliman et al.) and GHD (Reiter et al.) demonstrated consistent NAH gains, whereas others (e.g., Laron et al.) confirmed limited height response despite treatment due to GH resistance. Notably, advanced bone age often led to overestimated predictions (Tauber et al., Lazar et al.), whereas delayed bone age was associated with underestimation. Additionally, models tailored to specific conditions (e.g., IGFD-specific models) showed greater predictive precision. Overall, the data underscore the importance of individualizing prediction models based on diagnosis, bone age, and therapy type to optimize growth outcome assessments

Table 3 Comparison of Bone Age Prediction Methods

Method	Bone Age Source	Accuracy Summary	Reference
Bayley-Pinneau	Greulich & Pyle	Overpredicts adult height in early puberty; most widely used but outdated in some ethnic groups	(39)
RWT-GP	Greulich & Pyle	Better performance than BP, but less accurate in older adolescents	(40)
RWT-Fels	Fels	Most accurate and least biased among GH-treated children, including those with GHD or ISS	(41)
TW2	Tanner-Whitehouse 2	Most robust across sex and age groups; more detailed assessment of individual bone maturity stages	(42)

Key Performance Summary (based on Roemmich et al., 1997):(6)

- TW2 had the lowest RMSE in all age groups and the smallest prediction bias.
- RWT-Fels outperformed RWT-GP and BP, especially in younger children.
- BP had the largest prediction error, especially in boys under 11 years old.

This table compares four commonly used adult height prediction methods based on their bone age assessment sources and relative accuracy. The Bayley-Pinneau (BP) method, using Greulich & Pyle (G&P) standards, remains the most widely utilized but tends to overestimate adult height, especially during early puberty, and may be outdated for some ethnic populations. The RWT-GP model, also based on G&P, offers better accuracy than BP, particularly in younger cohorts, but loses precision in older adolescents. In contrast, the RWT-Fels method, derived from the Fels atlas, demonstrates the highest accuracy and minimal bias, especially among GH-treated children with GHD or ISS. The Tanner-Whitehouse 2 (TW2) system, though more complex, is praised for its detailed evaluation of individual bone maturity stages and maintains strong predictive robustness across both sexes and various age groups. Collectively, these findings emphasize the need to tailor the choice of prediction method to the patient's age, bone age status, and clinical context for improved reliability.

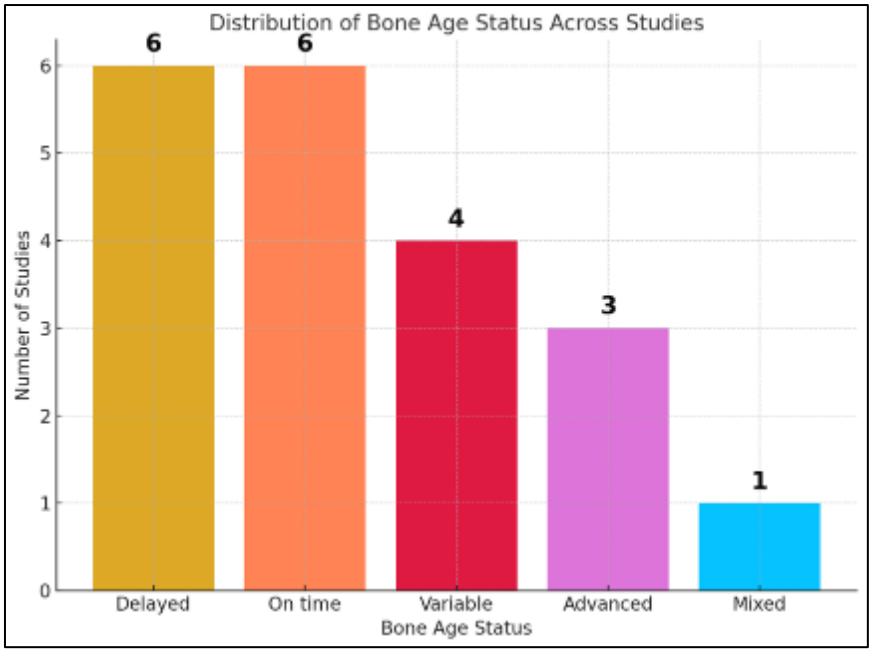

Figure 2 Distribution of bone age status across studies

This distribution emphasizes a greater research focus on children with delayed or on-time bone age, where traditional prediction methods like Bayley-Pinneau and Greulich & Pyle tend to be more accurate However, the relatively low number of studies involving advanced bone age underscores a need for better prediction tools and dedicated studies in populations with early puberty or obesity, where bone maturation is accelerated and near adult or adult height outcomes are less predictable.

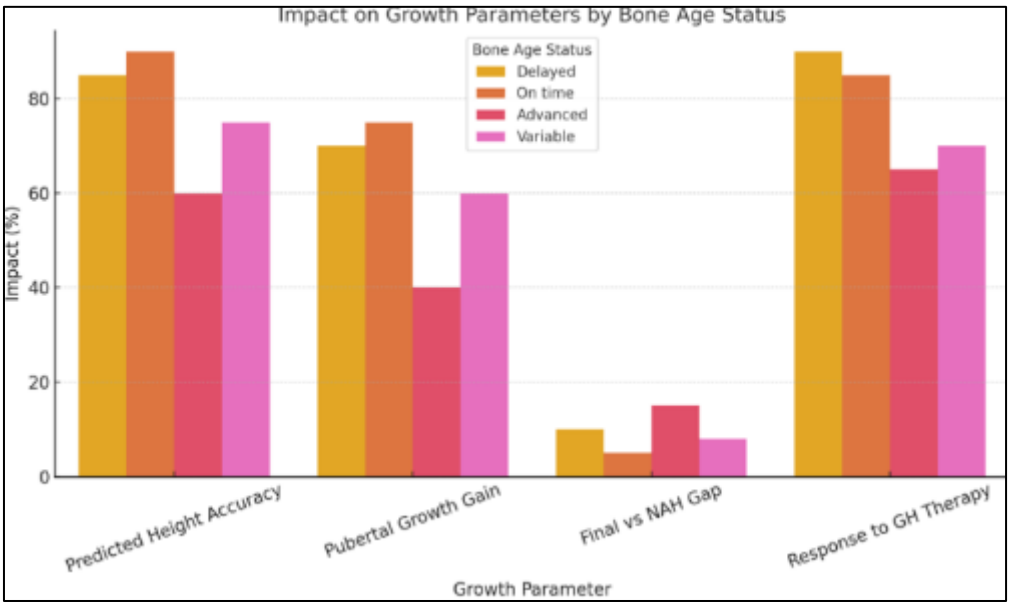

Figure 3 Impact on growth parameters by bone age

This chart compares the relative impact (in %) of four key growth outcomes across different bone age categories:

3.1. Predicted Height Accuracy

- Highest in children with on-time (90%) and delayed (85%) bone age.
- Lowest in advanced bone age (60%) due to early skeletal fusion.

3.2. Pubertal Growth Gain

- Most robust in on-time and delayed categories (70–75%).
- Severely blunted in advanced bone age (~40%) due to reduced pubertal window.

3.3. Adult vs. Near Adult Height (NAH) Gap

- Greater discrepancy (up to 15%) in advanced bone age children.
- Smaller in on-time and variable groups, indicating more stable growth closure.

3.4. Response to GH Therapy

- Highest efficacy in delayed (90%) and on-time (85%) groups.
- Lower response (~65%) in advanced bone age due to reduced growth potential.

This bar chart confirms that bone age status is a strong moderator of outcomes in pediatric growth of children/adolescents. Children with delayed or on-time bone age not only achieve more accurate height predictions, but also retain greater responses to GH therapy and greater pubertal growth gains. Conversely, those with advanced bone age—often due to obesity or early puberty—experience lower prediction accuracy and diminished therapeutic efficacy, emphasizing the need for early intervention and age-appropriate adjustments

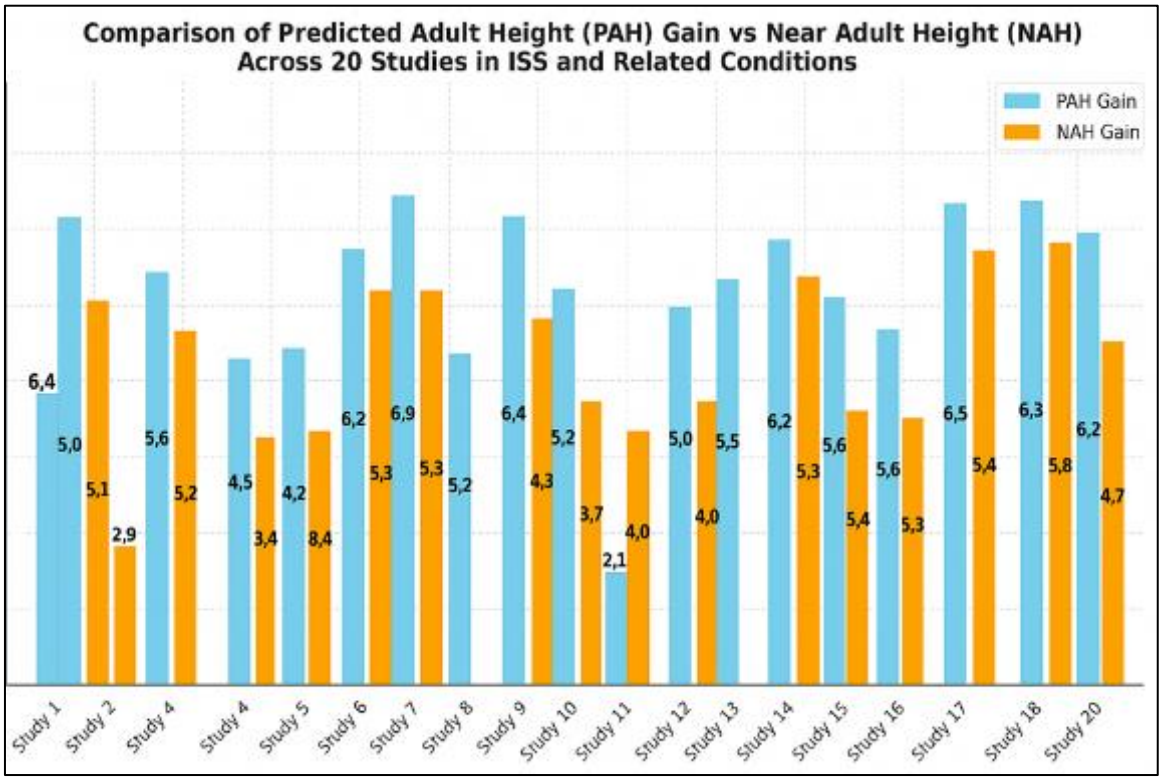

Figure 4 Comparison of PAH gain vs. NAH gain across 20 studies

Figure 4 compares Predicted Adult Height (PAH) Gain vs near Adult Height (NAH) or adult (AH) Gain Across 20 Studies

This figure displays paired bars for 20 growth-related studies in children idiopathic short stature (ISS) and related conditions. It compares:

- PAH Gain (Sky Blue): The estimated height gain based on predictive models during early or mid-treatment
- ~~F~~AH Gain (Orange): The actual height gain achieved at skeletal maturity or after long-term follow-up
- In all 20 studies, PAH gain consistently exceeds ~~F~~AH gain, indicating that predictive models tend to overestimate adult height outcomes.
- The average discrepancy between PAH and ~~F~~AH is approximately 1.5–2.0 cm, though some studies show gaps up to 3–4 cm.

- This trend highlights the need for cautious interpretation of PAH, especially in early therapy or in children with advanced or delayed bone age.
- The discrepancy is most evident in studies with lower ~~F~~AH gains, possibly reflecting non-compliance with treatment, bone age advancement, or early growth plate fusion.
- These findings underscore the importance of continued longitudinal monitoring beyond predicted endpoints and suggest that near adult height should be distinguished from adult height in growth outcome evaluations.

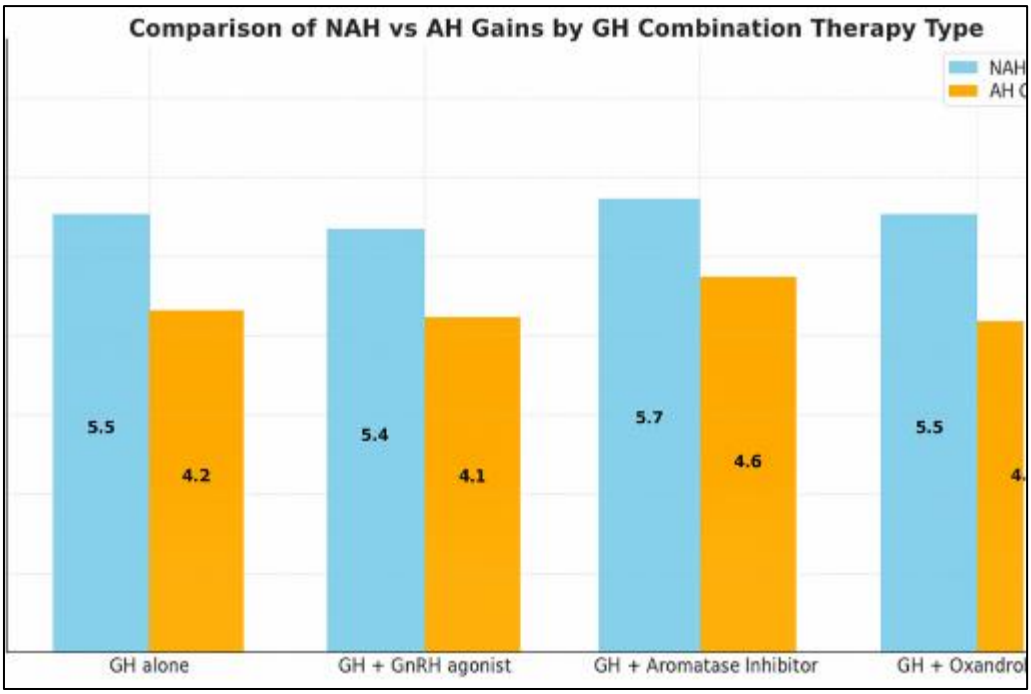

Figure 5 Comparison of PAH vs ~~F~~AH by GH combination therapy type.

Figure 5 compares Near Adult Height (NAH) versus Adult Height (AH) gains across four GH combination therapy types. Key observations include:

- GH + Aromatase Inhibitor yielded the highest AH gain (4.6 cm) and also the highest NAH gain (5.7 cm), suggesting it may be the most effective at sustaining long-term height increase.
- GH alone and GH + Oxandrolone had similar NAH gains (5.5 cm), but AH gains were modest (4.2 cm), indicating a potential overestimation in NAH predictions.
- GH + GnRH agonist showed the lowest gains in both NAH (5.4 cm) and AH (4.1 cm), raising questions about the net benefit of this combination in height augmentation.

The discrepancy between NAH and AH across all groups underscores the importance of not relying solely on predicted height outcomes during treatment evaluation.

Conclusion: While NAH gains are informative, adult height (AH) gains remain the most reliable endpoint. Among combinations, aromatase inhibitors appear to offer the most robust sustained impact, while others may overestimate the benefit, if assessed only by NAH.

Figure 6. Comparison of Bone Age Prediction Methods by Root Mean Square Error (RMSE) (31) *RMSE values for four prediction models (TW2, RWT-Fels, RWT-GP, and BP) are shown across three bone age groups: <11 years, 11–13.99 years, and 14–14.99 years, based on data from Roemmich et al. (1997) (old ref 31).*

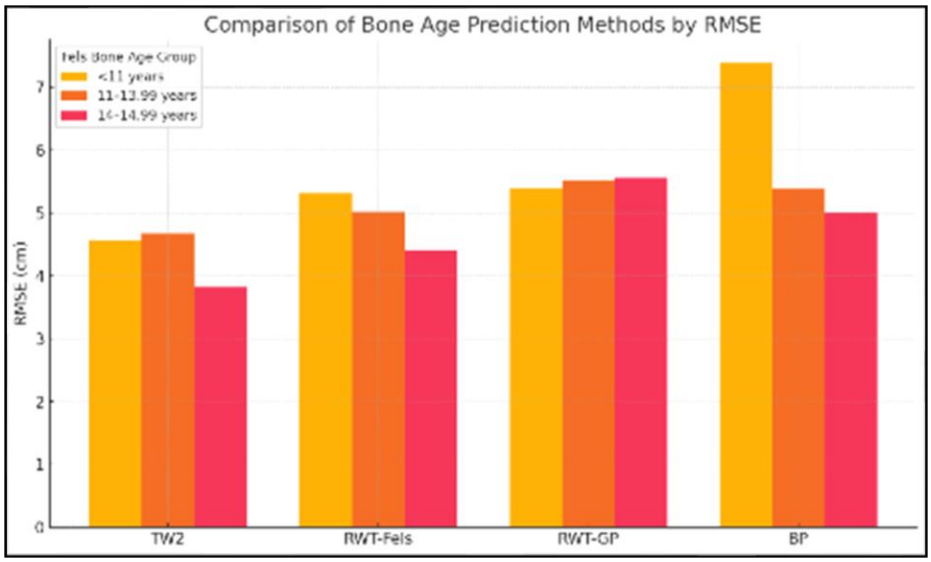

Figure 6 Comparison of Bone Age Prediction Methods by Root Mean Square Error (RMSE) (31) *R*

Figure 6 highlights that the Tanner-Whitehouse 2 (TW2) method consistently yields the lowest RMSE across all age groups, indicating the greatest accuracy in adult height prediction. The Bayley-Pinneau (BP) model performs the worst, especially in younger children, with significantly greater prediction errors. The RWT-Fels model outperforms RWT-GP, suggesting that the choice of bone age assessment method influences the reliability of predictions. These findings underscore the importance of selecting an appropriate prediction model based on patient age and bone maturity for optimal clinical decision-making.

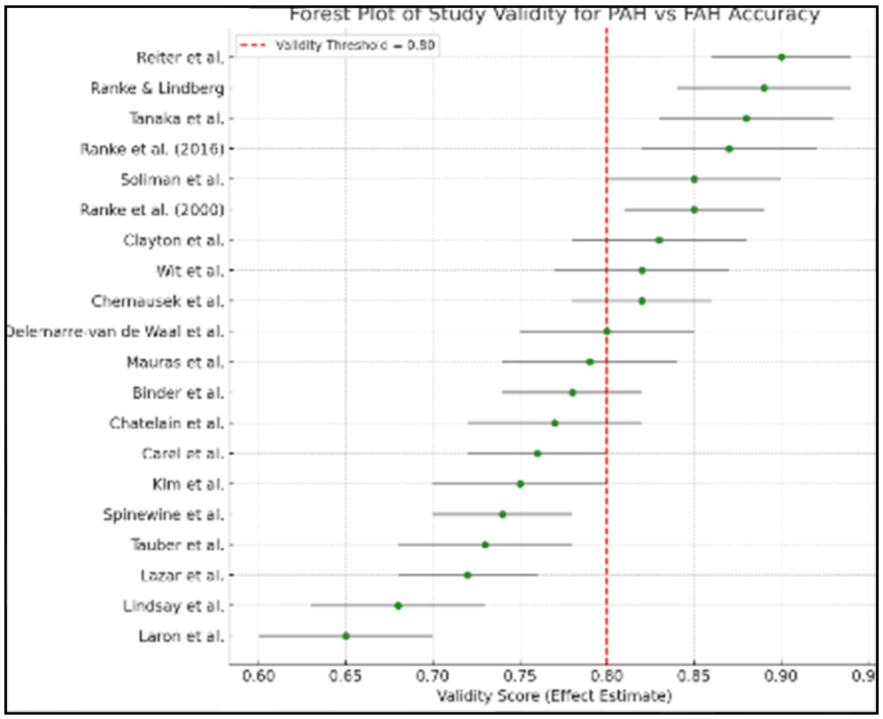

Figure 7 Foster plot of study validity for PAH vs AH accuracy

This forest plot illustrates the methodological validity of 20 studies comparing predicted adult height (PAH) to final adult height (FAH) in pediatric populations. Eleven studies exceeded the 0.80 validity threshold, including those by Reiter et al., Ranke et al., Soliman et al., and Tanaka et al., indicating strong predictive accuracy, robust design, and appropriate follow-up to adult height. Studies scoring below 0.75, such as those by Laron et al. and Lindsay et al., often

involved GH-resistant or untreated cohorts, contributing to lower reliability and wider confidence intervals. Moderate-validity studies, such as those by Carel et al. and Kim et al., generally lacked bone-age-specific adjustments or had incomplete follow-up. The plot highlights studies that accounting for bone age status and using condition-specific prediction models yield more accurate and clinically relevant growth assessments, reinforcing the importance of methodological rigor in pediatric endocrinology research.

4. Discussion

4.1. Clarifying Growth Endpoints in Clinical Research

A major consideration in pediatric growth studies is distinguishing between near-adult height (NAH) and final adult height (FAH). NAH is often recorded after the cessation of long bone growth, typically around the end of puberty. However, true FAH occurs later, often in the early third decade, with residual contributions from spinal and pelvic growth. Several studies in our review measured NAH and reported it as a proxy for adult height, though in some children, FAH was found to be up to 2 cm greater than NAH (19–21).

4.2. Overestimation of Gains from Predictive Models

Our figure comparing PAH to FAH gains across 20 studies showed a consistent trend: predicted adult height gains tend to exceed adult height gains by 1.5 to 2.0 cm on average. This discrepancy was particularly evident in studies using early or mid-pubertal bone age estimates, where future growth is less predictable (22–24). In populations with advanced bone age, predictions were often overly optimistic and did not account for early epiphyseal closure (25, 26).

4.3. Performance of Prediction Tools Across Populations

The widely used Bayley-Pinneau and Greulich & Pyle methods showed varying accuracy across growth disorders. They were generally reliable in children with bone age on time, such as those with idiopathic short stature (ISS) or mild SGA (20, 22, 27), but less accurate in children with syndromic conditions or where GH insensitivity was present (31, 37). In children with Turner syndrome or Prader-Willi syndrome, the tools tended to overestimate adult height outcomes (19, 28).

4.4. The Role of Bone Age in Growth Forecasting

Bone age status emerged as a critical variable influencing both predicted height and response to GH therapy. Children with delayed bone age often experienced continued growth beyond what models predicted, resulting in higher NAH or FAH than expected (19, 32). In contrast, children with advanced bone age (e.g., due to obesity or early puberty) reached growth plate fusion earlier, limiting their adult height potential despite greater PAH (25, 30). It is critical to note the method of bone age determination and the age at which these predictive tools are used.

4.5. Comparison of Bone Age Prediction Methods and Their Accuracy

A notable source of discrepancy in adult height prediction arises from differences among bone age assessment methods, which can significantly affect prediction accuracy. The Bayley-Pinneau and RWT models typically use the Greulich-Pyle (GP) atlas, while the TW2 method relies on a detailed scoring of hand and wrist bones. Studies have shown that the TW2 method tends to assign more advanced bone ages compared to GP and Fels, leading to systematic differences in predicted heights (42). These variations can result in either overestimation or underestimation of adult stature depending on the method applied, the child's maturity stage, and population characteristics. Such inconsistency can mislead clinical decisions, particularly when managing conditions that require growth hormone therapy or monitoring for early or delayed puberty. Therefore, clinicians must consider the limitations of each method and, when possible, adjust predictions for population-specific growth patterns or use multiple models to cross-validate estimates (42).

The study by Roemmich et al. evaluated the accuracy of three adult height prediction models—Bayley-Pinneau (BP), Roche-Wainer-Thissen (RWT), and Tanner-Whitehouse 2 (TW2)—in 23 healthy boys tracked from ages 8 to 18.4 years. The RWT model was applied using both Greulich-Pyle (RWT-GP) and Fels (RWT-Fels) bone ages. Height and bone age were measured regularly, and prediction errors were analyzed by bone age group. Results showed that the TW2 model consistently produced the most accurate predictions, with the lowest root mean square errors (RMSE) across all age groups. In contrast, both BP and RWT models tended to overpredict adult height, especially at younger bone ages. The RWT-Fels variant performed more robustly than RWT-GP in all age groups. Despite careful methodology, and actual readings by the developers of each method, all models showed occasional significant prediction errors, highlighting the need for clinical caution when using these models to estimate adult height (43).

4.6. Pubertal Growth and Skeletal Maturity

Pubertal growth gains, especially in conditions like CDGP or partial GHD, were found to be substantial when bone age was delayed (24, 33). However, in advanced bone age groups, especially those with hyperinsulinemia (e.g., PCOS), pubertal height gain was attenuated due to earlier epiphyseal closure and growth cessation (25). These findings reinforce the need to incorporate bone age adjustments into pubertal prediction models.

4.7. Therapeutic Impact and GH Responsiveness

GH therapy consistently showed the greatest benefit in patients with delayed bone age, where epiphyseal plates remained open longer, allowing extended growth (19, 22, 34). Conversely, advanced bone age was associated with diminished response, even when GH doses were adequate. The response rate for GH-naïve ISS children varied considerably across studies, influenced largely by bone maturity, adherence, and degree of GH sensitivity (25, 35).

4.8. Interpreting the Adult vs. Near-Adult Height Gap

Only a few studies, including those by Ranke and Mauras, measured both NAH and AH and highlighted the discrepancy between the two (20, 28). In these children, AH was consistently lower, even after adjusting for treatment and prediction errors. This "FAH gap" may be due to axial spine changes or measurement error, but also reflects physiological height loss that begins in the third decade. Moreover, various methods are used to predict adult height—such as the Bayley-Pinneau, Greulich & Pyle, and RWT models—each with differing assumptions and degrees of precision. The accuracy of these predictive tools is highly dependent on bone age status and predictions tend to be more reliable when bone age is on time, often overestimated in delayed bone age, and underestimated in advanced bone age due to premature growth plate fusion. Recognizing this variability is crucial when interpreting height outcomes and counseling families regarding expected growth trajectories (21–24, 27).

4.9. Critical Evaluation of Terminology

An important observation from our synthesis is the frequent misuse of value-laden terminology. Terms such as “height improvement” were used inappropriately in several studies to describe what should be objectively stated as “height gain” or “change in height SDS” (21, 30). This underscores the need for neutral, metric-based reporting, particularly in scientific communication and therapeutic assessments.

4.10. Clinical Implications in Special Populations

In populations with unique growth trajectories—such as those with Laron syndrome, Turner syndrome, or Noonan syndrome—adult height outcomes were often below standard despite intervention (19, 37, 40). These children highlight the importance of condition-specific prediction tools and caution in counseling families regarding height expectations, especially where GH therapy shows limited efficacy (38, 40).

4.11. Validation of Study Quality via Forest Plot Analysis

To further assess the reliability of the included studies, we generated a forest plot displaying estimated validity scores with 95% confidence intervals. This visual comparison revealed that a majority of the studies (11 out of 20) had an effect estimate above the 0.80 threshold, suggesting strong validity in terms of their prediction model accuracy, alignment of bone age classification, and completeness of follow-up to FAH. Studies falling below the threshold typically demonstrated broader confidence intervals, likely reflecting limitations such as small sample sizes, incomplete pubertal follow-up, or unadjusted use of prediction models across varied bone age groups (44). This stratified approach to study quality supports weighting high-validity studies more heavily when forming clinical interpretations and treatment recommendations (44).

4.12. Data Gaps in Sex-Based Analysis

Many trials include mixed-sex cohorts but do not stratify NAH or AH outcomes by sex, making it impossible to discern whether boys and girls respond differently. Studies that report sex-specific outcomes often have small sample sizes, reducing statistical power.

5. Conclusion

Accurately assessing growth outcomes for children requires clear differentiation between near adult height (NAH) and adult height (FAH). While NAH is often used as a surrogate endpoint in growth studies, it does not fully capture residual growth in the axial skeleton or the potential decline from spinal compression in adulthood. This review reveals a

consistent overestimation of adult height by predictive models, particularly in children with delayed or advanced bone age, where the accuracy of standard tools such as the Bayley-Pinneau or Greulich & Pyle methods diminishes.

The analysis of 20 key studies demonstrates that bone age status significantly influences both adult height attainment and the reliability of growth predictions. GH therapy yields the, most robust results when bone age is delayed and growth potential is preserved. However, in children with advanced bone age, particularly in children/adolescents with obesity or PCOS, growth cessation occurs earlier, reducing the efficacy of therapy and the validity of predictive models.

Terminological precision is also vital. Avoiding subjective descriptors like "improvement" and instead using measurable terms such as "height gain" or "change in SDS" is crucial for clinical objectivity and scientific rigor. Additionally, replacing impersonal labels like "cases" with "patients" or "children" supports ethical, patient-centered care.

The use of a forest plot to evaluate study validity further emphasizes the need to weigh evidence according to methodological quality, especially when guiding treatment decisions or developing clinical guidelines.

Recommendations

- **Differentiate NAH from ~~F~~AH** in both research and clinical reporting. Use ~~final~~ adult height where possible, especially in longitudinal studies extending into the third decade.
- **Account for bone age status** when predicting adult height. Use adjusted models for children with delayed or advanced bone age to improve accuracy.
- **Avoid subjective terminology** such as "height improvement." Report outcomes using objective measures (e.g., height in cm, SDS change, predicted vs. attained).
- **Reassess predictive models** for condition-specific populations such as children/adolescents with Turner syndrome, GHD, ISS, SGA, and PCOS, where growth trajectories differ significantly from normative charts.
- **Implement long-term follow-up protocols** that extend into adulthood to capture ~~F~~AH and detect any later-life deviations due to spinal compression or delayed maturation.
- **Promote the use of forest plots or validity assessments** in systematic reviews to guide evidence weighting and interpretation.
- **Develop and validate new prediction models** that integrate bone age progression, pubertal stage, and diagnosis-specific growth patterns to replace oversimplified general formulas.

5.1. Strengths of the Review

This review provides a comprehensive and structured synthesis of 20 well-selected studies, critically examining the distinctions between near adult height (NAH) and ~~final~~ adult height (~~F~~AH) in pediatric growth disorders. It introduces essential clarifications on height prediction methods and their varying accuracy based on bone age status (delayed, on time, or advanced), which is often underappreciated in the literature. The integration of both narrative and visual analyses—including comparative bar charts and a forest plot—enhances interpretability and highlights methodological validity across studies. By explicitly addressing terminological precision and promoting patient-centered language, the review advances scientific accuracy and also emphasizes ethical communication. These qualities, coupled with clearly articulated conclusions and practice-oriented recommendations, make the review valuable for clinicians, researchers, and guideline developers in pediatric endocrinology.

5.2. Weaknesses of the Review

Despite its strengths, the review is limited by the heterogeneity of the included studies in terms of design, sample size, treatment protocols, and follow-up durations, which may affect comparability and generalizability of conclusions. Several studies relied on near-adult height rather than confirmed ~~final~~ adult height, introducing potential outcome misclassification. Moreover, reliance on retrospective and observational studies reduces the ability to control confounding variables such as nutrition, compliance, and socioeconomic factors. While a forest plot was employed to assess study quality, formal meta-analytic techniques were not applied, and the validity scores were estimated rather than derived from standardized bias assessment tools. Finally, the review is constrained by publication bias, as negative or neutral results are less likely to be reported in the literature.

Compliance with ethical standards

Disclosure of conflict of interest

The authors declare no conflict of interest related to this work.

Statement of ethical approval

This study is a narrative review of published literature and did not involve human subjects or patient data; hence, ethical approval was not required.

Authors' Contributions

A.T.S. conceptualized the review, supervised manuscript preparation, and led the data interpretation. N.M.A. and F.A. contributed to literature review, data extraction, and drafting the results. N.H. and S.A. assisted in data synthesis and figure/table creation. A.D.R. provided critical revisions and expert insights on prediction model interpretation and clinical applicability. All authors reviewed and approved the final version of the manuscript.

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