A family seeks evaluation and treatment of short stature in their 11.5-year-old son. He previously was in the 3rd percentile for height, but his growth rate has slowed during the past 2 years, and his height is now just below the 1st percentile (Fig. 1). His mother is 5 ft 0 in. (152 cm), and his father is 5 ft 6 in. (167 cm). The child's size at birth was normal. His medical history and a review of systems are unremarkable. His physical examination is normal and shows prepubertal development. The complete blood count, erythrocyte sedimentation rate, thyrotropin, tissue transglutaminase antibody, and insulin-like growth factor I (IGF-I) levels and growth hormone levels after provocative testing are normal. His skeletal maturation (bone age) is approximately 9 years, and his predicted adult height is 5 ft 5 in. (165 cm) plus or minus 1.3 in. (3.3 cm). How should his condition be managed?

**THE CLINICAL PROBLEM**

Short stature in childhood is a very common reason for referral to pediatric endocrinologists. Although evaluation for growth-inhibiting disorders is often indicated, most children with short stature are essentially healthy. Testing for growth hormone secretion often does not clearly distinguish isolated growth hormone deficiency from idiopathic short stature. Treatment with recombinant human growth hormone can increase the adult height of children with idiopathic short stature by 1.2 to 2.8 in. (3.0 to 7.1 cm), with wide variation in the incremental gain. In 2003, the Food and Drug Administration (FDA) approved human growth hormone treatment for children with idiopathic short stature and height below the 1st percentile (−2.25 SD). Accordingly, at least 500,000 children in the United States (i.e., approximately 1% of children 4 to 13 years of age) were considered to have a condition for which there is available, effective, and expensive treatment (approximately $10,000 to $60,000 per patient per year). The FDA approval gave rise to controversies, uncertainties, and inconsistencies regarding therapeutic options that often overshadow the problem of short stature itself.

**STRATEGIES AND EVIDENCE**

**EVALUATION**

Clinicians who evaluate children with short stature must consider many potential causes (Fig. 2). Although evaluation is needed to rule out disorders such as true growth hormone deficiency and hypothyroidism, the Turner syndrome, and chronic diseases, the majority of children with short stature ultimately receive a diagnosis of
idiopathic short stature due to physiological variants such as familial short stature, constitutional delay of growth and puberty (CDGP), or both. In general, a growth rate that is abnormally slow for chronologic and bone age should prompt a thorough examination and possible laboratory evaluation. Growth patterns in a child that differ markedly from the midparental height (estimated by averaging the two parents’ sex-specific height percentiles) are also of concern, although these estimates are less accurate when parental-height percentiles are more disparate and are based on the assumption that parental height was not itself diminished by a growth-restricting condition. A family history of late onset of puberty and the age at attainment of adult height may suggest a slowed “tempo” of growth and development (as in CDGP). A history of intrauterine growth restriction should also be assessed, since about 15% of children with this condition continue to have short stature throughout life.

Physical examination should assess for the following: abnormal body proportions (e.g., an increased ratio of the upper to lower body segment, calculated by comparing the height in a sitting position with the height in a standing position, which suggests bone dysplasia or the Turner syndrome); characteristics that suggest genetic conditions (e.g., lymphedema or a low posterior hairline, both of which occur in the Turner syndrome; or a murmur related to pulmonic-valve stenosis, which occurs in the Noonan syndrome); or findings (e.g., goiter) that suggest hypothyroidism. Poor weight gain (i.e., weight gain that is disproportionate to height gain) may suggest a nutritional disturbance or chronic disease. Although children with true growth hormone deficiency may have classic physical findings such as increased subcutaneous fat, most present primarily with attenuated growth from infancy (congenital growth hormone deficiency) or later (acquired growth hormone deficiency).

Familial short stature, CDGP, or both are the most common causes of short stature. However, when the height for age is less than the 1st percentile, the growth rate is less than the 10th percentile for bone age, the predicted adult height differs significantly from midparental height, or the body proportions are abnormal, laboratory evaluation is warranted (Fig. 2). Screening laboratory studies target potential hormonal disorders (e.g., with measurement of thyroid hormone levels), renal disorders (with measurement of electrolyte and creatinine levels), inflammatory and immune disorders (with measurement of the erythrocyte sedimentation rate and tests for tissue transglutaminase antibodies), and hematologic disorders (with a complete blood count). Genetic testing for specific syndromes may be indicated by physical findings or simply by a growth pattern and height projection that differ significantly from those in other members of the family. Assessment of the growth hormone–IGF-I axis begins with measurement of the serum IGF-I level, but since levels increase rapidly with the onset of puberty, results must be interpreted relative to bone age rather than to chronologic age. A normal IGF-I level for bone age
The predicted adult height is calculated with the use of the Bayley–Pinneau Figure 1. Growth Curve and Clinical Data for the Patient.

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Observation and Reassurance with No Treatment

Observation is a reasonable strategy for most children with familial short stature or CDGP. Although a child may be teased or feel sad about being short, comparisons of children with short stature that is not related to growth hormone deficiency with taller peers and psychosocial assessment of short adults indicate that psychological stress can be but is not predictably related to stature. Furthermore, increases in the growth rate and height resulting from androgen or human growth hormone treatment (including increases in one double-blind, placebo-controlled trial) have not predictably improved psychosocial well-being, even when the surrogate measure of final height was increased. Without treatment, although short stature as compared with the stature of peers may temporarily worsen in late childhood because of delayed puberty (Fig. 3), psychological distress can be addressed with counseling, and predicted adult height (and height eventually achieved) will probably approximate the low end of the normal range of target height that is consistent with parental heights.

Height-Promoting Treatment with Human Growth Hormone

FDA approval of human growth hormone for children with idiopathic short stature implies that the cause of short stature and the growth hormone secretory status are not critical factors in decisions about whether such children should be treated. Data from randomized, controlled trials, observational dose–response studies, and systematic reviews indicate that human growth hormone therapy in children with idiopathic short stature has not predictably improved psychosocial well-being, even when the surrogate measure of final height was increased. Without treatment, although short stature as compared with the stature of peers may temporarily worsen in late childhood because of delayed puberty (Fig. 3), psychological distress can be addressed with counseling, and predicted adult height (and height eventually achieved) will probably approximate the low end of the normal range of target height that is consistent with parental heights.

**Figure 2. Conceptual Approach to the Evaluation and Differential Diagnosis of Slow Growth and Short Stature in Childhood.** Slow growth and short stature are defined as height below the 3rd percentile for age, growth rate less than the 10th percentile for bone age, predicted adult height that differs significantly from the midparental height, or abnormal body proportions. Percentiles are based on growth-curve percentiles. If the evaluation for failure to thrive is negative, the potential differential diagnosis for failure to grow should be reconsidered (dashed arrow). GHD denotes growth hormone deficiency, IBD inflammatory bowel disease, and IUGR intrauterine growth restriction. Data are from Nicol et al.7

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<table>
<thead>
<tr>
<th>Therapy</th>
<th>Diagnosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observation and Reassurance with No Treatment</td>
<td>Inadequate caloric intake, Excess caloric needs, Intrinsic Shortness</td>
</tr>
<tr>
<td></td>
<td>Familial short stature, Constitutional delay of growth and puberty</td>
</tr>
<tr>
<td></td>
<td>Acquired growth limitation</td>
</tr>
<tr>
<td>Height-Promoting Treatment with Human Growth Hormone</td>
<td>Endocrine disorders (e.g., GHD, hypothyroidism, Cushing syndrome, hypogonadism)</td>
</tr>
<tr>
<td></td>
<td>Marked delay of puberty, Severe chronic disease (chronic renal insufficiency, IBD, celiac disease)</td>
</tr>
<tr>
<td></td>
<td>Medications (e.g., stimulants, glucocorticoids)</td>
</tr>
</tbody>
</table>

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**Table:** Differential Diagnosis of Slow Growth and Short Stature

<table>
<thead>
<tr>
<th>Condition</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Failure to Thrive</td>
<td>Inadequate caloric intake, Excess caloric needs</td>
</tr>
<tr>
<td>Intrinsic Shortness</td>
<td>Familial short stature, Constitutional delay of growth and puberty</td>
</tr>
<tr>
<td>Delayed Growth</td>
<td>Endocrine disorders (e.g., GHD, hypothyroidism)</td>
</tr>
<tr>
<td>Attenuated Growth</td>
<td>Acquired growth limitation, Severe chronic disease</td>
</tr>
</tbody>
</table>

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**Diagrams:**

- Conceptual Approach to the Evaluation and Differential Diagnosis of Slow Growth and Short Stature in Childhood.
- Acute Assessment of Small Size by Percentile.
Human growth hormone treatment to maximum height, with increased dosing in puberty
Human growth hormone treatment until growth complete
Human growth hormone treatment until onset of puberty or normal-range height
Oxandrolone until onset of puberty
Observation without treatment

**Figure 3. Approximate Projections of the Growth Trajectory and Adult Height Associated with Various Treatments for Short Stature.**

In the child in the case vignette, approximate projections are plus or minus 1.3 in. (3.3 cm) according to the Bayley–Pinneau predictions of adult height at 11.5 years of age with a bone age of 9 years and are based on published reports of the effects of the treatments. The curve for oxandrolone (orange) assumes an increase in the growth rate to approximately 3.1 in. (7.9 cm) per year until the onset of puberty.

The curve for human growth hormone treatment until puberty (yellow) assumes normal pubertal growth and mean adult height of 5′10.5 in. (148.6 cm) according to the Bayley–Pinneau predictions of adult height at 11.5 years of age with a bone age of 9 years.

The curve for human growth hormone treatment until growth complete (blue) assumes normal pubertal growth and sustained normal growth to normal height after the onset of puberty, a 4- to 6-month period without human growth hormone (with reinstitution of therapy if growth slows abnormally) can be considered when signs of puberty are evident (Fig. 3). The effect of such an approach on adult height has not been examined in randomized trials.

Extensive clinical experience indicates that the risks of adverse effects from human growth hormone during treatment (e.g., occurrences of intracranial hypertension, glucose intolerance, or a slipped capital femoral epiphysis) are low. However, safety data from postmarketing surveillance studies probably underestimate risks associated with higher doses of human growth hormone and changing risk factors (e.g., an increased prevalence of obesity, which carries a higher risk of diabetes) and do not inform post-treatment metabolic risks or the risk of cancer. A long-term follow-up study from France involving persons who had growth hormone deficiency or idiopathic short stature or who were small-for-gestational-age infants showed an increased standardized mortality rate of 1.33 after human growth hormone treatment, as compared with the general population in France; assessment of cause-specific mortality identified increased risks of death attributable to bone cancer and

Stature increases the growth rate and mean adult height by 1.2 to 2.8 in., or approximately 0.4 in. (1.0 cm) per year of human growth hormone treatment. The response is variable and is influenced positively by younger age at baseline, delay in skeletal maturation, and taller parents (and negatively by shorter parents). Human growth hormone is administered subcutaneously at a dose of 0.2 to 0.375 mg per kilogram of body weight per week. Daily administration of human growth hormone is superior to less frequent administration. Dose modulation may influence the effect; doses at the higher end of this range and adjustment of the dose to achieve high-normal IGF-I levels lead to faster growth and perhaps to taller adult height, although this has not been assessed in randomized trials. In one controlled trial, doubling the dose of human growth hormone during puberty until epiphyseal closure further increased near-final height (Fig. 3). Treatment is typically continued until completion of growth or until the child grows to a height subjectively considered to be satisfactory by the child, family, and physician. Alternatively, since most children with equivocal results of growth hormone tests have normal endogenous growth hormone secretion and sustained normal growth to normal height, treatment may be stopped when signs of puberty are evident (Fig. 3).
circulatory system disorders among persons who received growth hormone and an increased risk of death with a dose of human growth hormone that was higher than 0.35 mg per kilogram per week. However, a similar surveillance study from Belgium, the Netherlands, and Sweden did not confirm these findings. In addition, human growth hormone treatment for idiopathic short stature is expensive (conservatively estimated at $35,000 to $50,000 per inch of height gained).

Higher-dose regimens and a longer duration of treatment increase costs and may also increase risks (Table 1).

### Other Treatments to Increase Growth

For short peripubertal boys, growth-promoting alternatives to human growth hormone are low-dose androgen therapy with injectable testosterone and low-dose androgen therapy with oral oxandrolone (e.g., 1.25 to 2.5 mg per day). Both regimens are relatively low in cost, and though they are not FDA-approved for growth acceleration, they increased the growth rate by 1.2 to 2.0 in. (3.0 to 5.1 cm) per year for 1 to 3 years in controlled trials. To avoid accelerated estrogen-mediated epiphyseal maturation, oxandrolone (not aromatized to estrogen) is theoretically preferred over testosterone when the bone age is less than 11 years. Oxandrolone is usually discontinued after a documented increase in endogenous testosterone; long-term follow-up studies indicate that treatment is followed by normal pubertal growth and eventual attainment of an adult height equal to or slightly greater than the predicted height before treatment (Fig. 3). Extensive clinical experience indicates that the risks of low-dose androgen treatment (e.g., adverse hepatic or lipid effects) are low.

Aromatase inhibitors (which reduce estrogen production and delay skeletal maturation) have been used experimentally in boys to prolong pubertal growth and increase height, but they are more expensive and have less of a growth-accelerating effect than androgens, and actual adult height gains have fallen short of prior predictions of 1.6 to 2.4 in. (4.1 to 6.1 cm). In view of concerns about potential adverse effects of estrogen deficiency during pubertal growth, including vertebral-body deformities, aromatase inhibitors cannot be recommended for treatment of short stature outside of investigative studies.

### Areas of Uncertainty

Decisions regarding the treatment of short stature that is not related to growth hormone deficiency are complicated by uncertainties about the adverse consequences of short stature, appropriate therapeutic goals, and risk:benefit and cost:benefit ratios. The assumption that short

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**Table 1.** Estimated Average Adult Height, Psychological Benefit or Harm, and Cost Associated with Various Management Options for Short Stature for the Child in the Case Vignette.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Estimated Adult Height in Inches (±1.3 in.)</th>
<th>Psychological Benefit or Harm</th>
<th>Estimated Treatment Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>No medication</td>
<td>65</td>
<td>Uncertain</td>
<td>No cost for drug with or without cost for counseling</td>
</tr>
<tr>
<td>Low-dose androgen (i.e., oxandrolone)</td>
<td>65</td>
<td>Uncertain</td>
<td>Oxandrolone, 2.5 mg/day, $2,920/yr × 2.5 yr = $7,300</td>
</tr>
<tr>
<td>Human growth hormone until onset of puberty</td>
<td>66</td>
<td>Uncertain</td>
<td>Human growth hormone at dose for idiopathic short stature (0.375 mg/kg/wk) × 2.5 yr = $76,050</td>
</tr>
<tr>
<td>Human growth hormone until normal range (e.g., 5th percentile) of adult height</td>
<td>66</td>
<td>Uncertain</td>
<td>Human growth hormone × 4 yr = $133,087</td>
</tr>
<tr>
<td>Human growth hormone until completion of growth</td>
<td>66–67</td>
<td>Uncertain</td>
<td>Human growth hormone × 5 yr = $176,962</td>
</tr>
<tr>
<td>Human growth hormone until maximum attainable height</td>
<td>68</td>
<td>Uncertain</td>
<td>Human growth hormone at dose for idiopathic short stature × 2.5 yr plus “pubertal” dose of human growth hormone (0.7 mg/kg/wk) × 2.5 yr = $264,420</td>
</tr>
</tbody>
</table>

* To convert the values for inches to centimeters, multiply by 2.54. Costs of therapy were based on estimates of weight derived from the 3rd percentile for age: a mean of 28 kg from 11 up to 13 years of age, 36 kg from 13 up to 15 years, and 45 kg from 15 to 16 years. Medication costs, obtained from Epocrates Online, were $50 per milligram of human growth hormone (the lowest current available per-milligram cost listed was $50 to $75 per milligram) and $8 per 2.5-mg tablet of oxandrolone.
stature is predictably associated with psychological distress is challenged by studies that show only minor difficulties in behavioral adaptation and normal psychological function in children and adults with short stature. It is therefore unclear whether or how to include psychosocial factors in determining therapeutic objectives.

If treatment is instituted, should the goal be acceleration of short-term growth or increased adult height? If the goal is the latter, should the aim be an adult height within the statistically normal range (e.g., the 5th to 10th percentile, which is approximately 5 ft 5 in. to 5 ft 6 in. (165 to 167 cm) for men and approximately 5 ft 0 in. to 5 ft 1 in. (152 to 155 cm) for women), a height matching that of other members of the family, or the tallest height that is safely attainable? These different goals are associated with markedly different costs; the last 1 to 3% of potential height gain may increase the total expenditure by 20%. Without evidence that the surrogate measure of increased height improves patient well-being, various treatment strategies cannot be differentiated according to quality-of-life outcomes.

Finally, more data are needed to inform our understanding of the potential risks of long-term therapy with human growth hormone. Given evidence supporting a role of the growth hormone and IGF-I system in the pathogenesis of various cancers, more data (preferably from large international collaborative studies with appropriate controls) are needed to identify and measure any long-term disease risks associated with the use of human growth hormone.

Guidelines and consensus statements on the treatment of short stature that is not related to growth hormone deficiency in children are available from professional societies, including the Growth Hormone Research Society, Pediatric Endocrine Society, and European Society for Paediatric Endocrinology. These recommendations review FDA guidelines, interpretation of growth hormone stimulation tests and IGF-I levels, possible doses and the risks and benefits of human growth hormone treatment, and aspects of treatment follow-up. However, they do not specify how to select among therapeutic options for short stature, the goals and cost-effectiveness of medical intervention, and when or whether to discontinue treatment.

**CONCLUSIONS AND RECOMMENDATIONS**

The peripubertal boy described in the vignette is markedly short but otherwise appears to be healthy. Although his growth pattern in earlier life and predicted height match those expected on the basis of parental heights, his slowed growth rate and the severity of his short stature warrant screening studies to rule out underlying disease and frank growth hormone deficiency. Normal findings on these tests support a diagnosis of idiopathic short stature (familial short stature combined with and exacerbated by CDGP). Options for treatment of idiopathic short stature should be discussed with the child and his parents; these options include observation and reassurance, human growth hormone therapy, and low-dose androgen therapy. Observation is a reasonable strategy that is supported by the lack of good evidence linking short stature with psychological harm or showing a long-term psychosocial benefit of growth-enhancing therapy, and the expectation of eventual achievement of adult height approximating midparental height. Alternatively, human growth hormone treatment has been shown to increase the growth rate and, to varying and albeit generally modest degrees (1.2 to 2.8 in.), eventual adult height. Although human growth hormone treatment has a strong safety record thus far, it is costly, requires daily injections, and could have adverse effects in the future that are relevant to treatment decisions for an otherwise healthy child. A third option is low-dose, oral oxandrolone treatment, which also stimulates growth and has a relatively low cost but no proven salutary effect on eventual attained height. Thus, management options for short stature are widely disparate, with important implications with respect to cost and complexity of care.

Whereas height augmentation has a role in some cases of short stature that is not related to growth hormone deficiency and in particular may benefit children with extreme, disabling short stature, benefits of treatment are uncertain for the vast number of otherwise healthy children with marginal short stature who are likely to reach a relatively short but normal adult height. Further-
more, for children who are treated, appropriate treatment goals and the most appropriate duration of therapy remain controversial. Thus, for a child such as the one described in the vignette (who is currently just below the 1st percentile for height but whose projected height is at the lower end of the normal range for adults), we would provide reassurance and recommend observation as a reasonable management option. If intervention is elected because of psychological distress, counseling, treatment with low-dose (and relatively low-cost) oxandrolone, or both could be considered. If human growth hormone is used, we would consider an appropriate treatment goal to be a height in the lower normal range (e.g., approximately the 5th to 10th percentile for U.S. adults rather than the maximal attainable height), and we would take into account both the costs of therapy and the potential risks of prolonged or high-dose therapy.

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