Validation of a Body Mass Index Nomogram for Children as an Obesity Screening Tool in Young Children

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Introduction

Attempting to curtail the growing epidemic of obesity is a daunting task. The American Academy of Pediatrics (AAP) obesity statement recommends early intervention.[1] Prompt evaluation and treatment of early childhood obesity requires early recognition of an obese child or one who is at-risk for overweight with rapidly increasing body mass index (BMI).[1]

Childhood obesity is often underrecognized by medical providers.[2-4] The youngest children and those at-risk for overweight are least likely to be recognized.[4] There are multiple barriers to screen and treat obese children including lack of patient motivation, parent involvement, support services, time, and reimbursement.[5] In addition, recognition of obesity by a medical provider depends on correct calculation and plotting of BMI.[1] This calculation requires an electronic device, which may not be available. Furthermore, calculation of BMI alone is not adequate. To accurately determine a child's weight category, BMI must then be plotted regardless of how it is determined.

We hypothesize a nomogram, using height and weight to generate BMI, coupled with the BMI curve would be an acceptable alternative to screen for obesity in young children. Although a validated BMI nomogram exists for adults,[6] the heights and weights are too large for young children. Thus, the objectives of this study were: to create a child-specific BMI nomogram, and to test the accuracy of that nomogram as an obesity screening tool.

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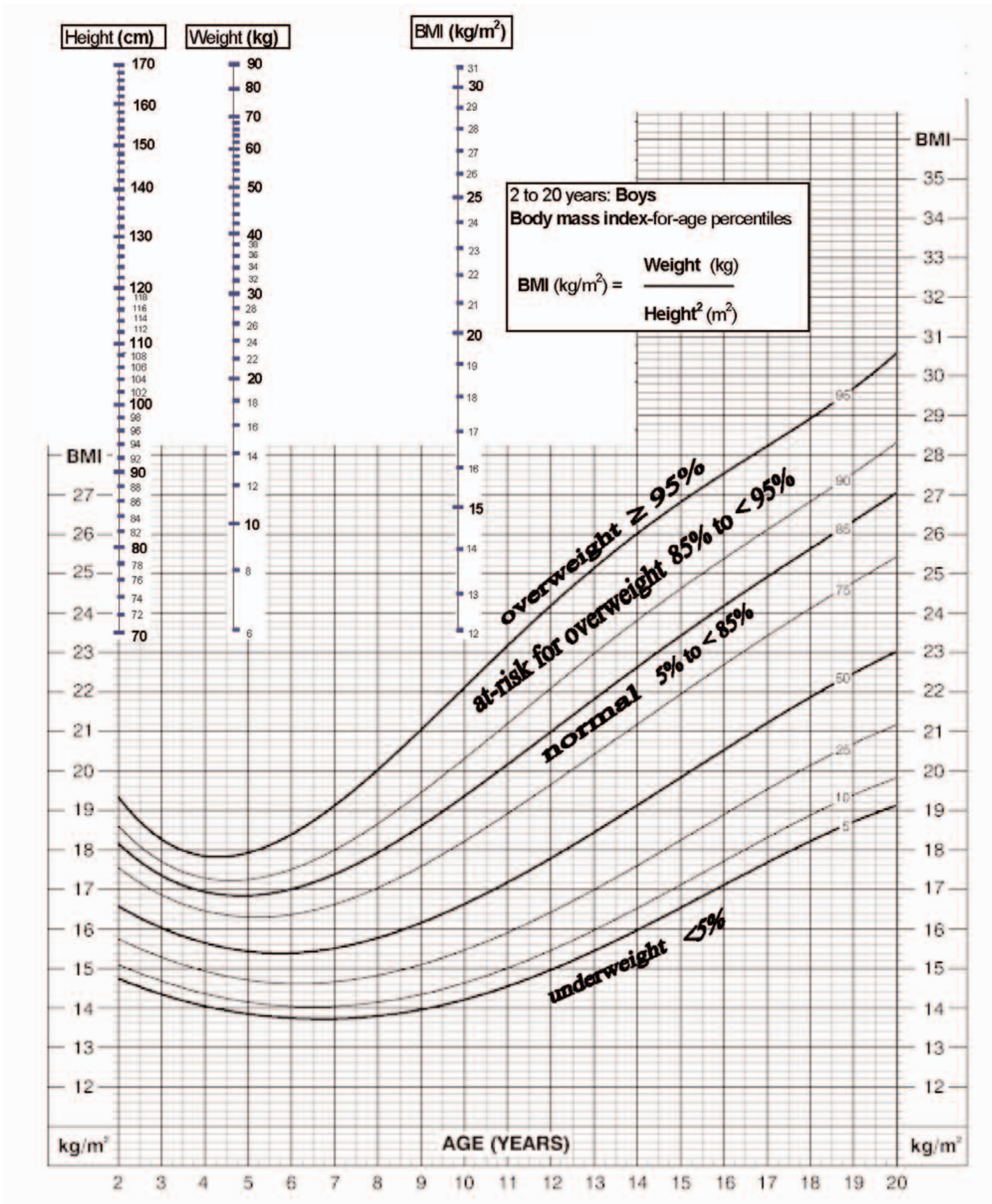
Methods

Creating the Nomogram

The child-specific BMI nomogram was created (Figures 1 and 2) by using a geometrical model and mathematical derivation (see Supplement). The scale was adjusted to represent children ages 2 to 12, covering weights and heights of the 3rd to the 97th percentiles for boys and girls in this range. Spacing of the lines was proportioned to fit on the upper-left corner of the existing BMI curve, requiring no additional pages in a patient chart.

Testing the Nomogram

The nomogram was initially tested by 2 providers familiar with the nomogram (group A). They determined BMIs for 98 weight/height combinations. These combinations were real patients selected from a sample of 350 3- to 10-year-olds using a random number generator; 2 had BMI values of more than 31. Then, it was tested by 10 pediatric providers for 28 weight/height/



SOURCE: Developed by the National Center for Health Statistics in collaboration with the National Center for Chronic Disease Prevention and Health Promotion (2000). http://www.cdc.gov/growthcharta

Figure 1. Body mass index (BMI) nomogram embedded on Boys' Centers for Disease Control (CDC) growth curve.

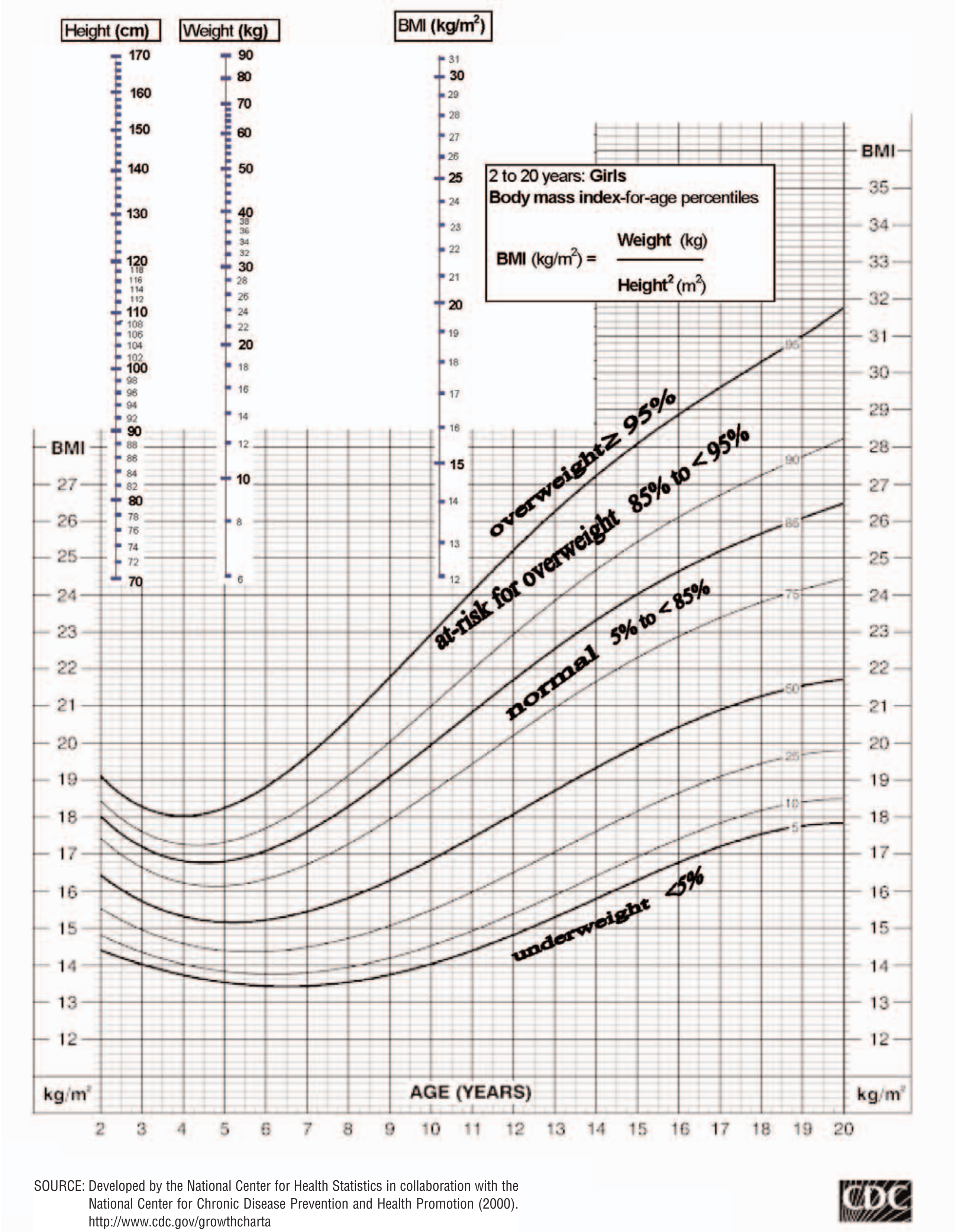


Figure 2. Body mass index (BMI) nomogram embedded on Girls' Centers for Disease Control (CDC) growth curve.

age/sex combinations with BMI <31, (group B). Group B consisted of 7 attendings, 2 residents, and 1 nurse practitioner, who had never seen the nomogram before. They were given brief instructions on how to use the nomogram, plot BMI, and determine weight classifications: normal (BMI 5 to <85 percentile), at-risk for overweight (BMI 85 to <95th percentile), or overweight (BMI 95 percentile).[1] Providers practiced once with supervision, and that value was discarded in the analysis. True BMI percentile and weight classification were determined by using a BMI calculator at www.keepkidshealthy.com. Providers' nomogram weight classifications were compared to true weight classifications. Sensitivity, specificity, and accuracy of the nomogram/BMI curve to screen for obesity were determined. Sensitivity = (true overweight + true at-risk)/(true overweight + true at-risk + overweight and at-risk misclassified as normal), specificity = true normal/(true normal + normal misclassified as at-risk and overweight), and accuracy = (true overweight + true at-risk + true normal)/total.

Results

For the initial 196 points (group A), there were no statistical differences between nomogram and calculated BMIs. A total of 94% of values were within 3%, and 100% were within 5%, of the calculated BMI. For the providers' 270 points (group B), there were no statistical differences between nomogram and calculated BMIs. A total of 87% of values were within 3%, and 95% were within 5%, of the calculated BMI. A plot of group B's error versus calculated BMI is shown (Figure 3). There were no statistical difference between providers' weight classifications and true weight classifications. For overweight and at-risk for overweight points, 123 of 130 were correctly classified. For normal weight points, 139 of 140 were correctly classified. Thus, in screening for overweight and obesity, the

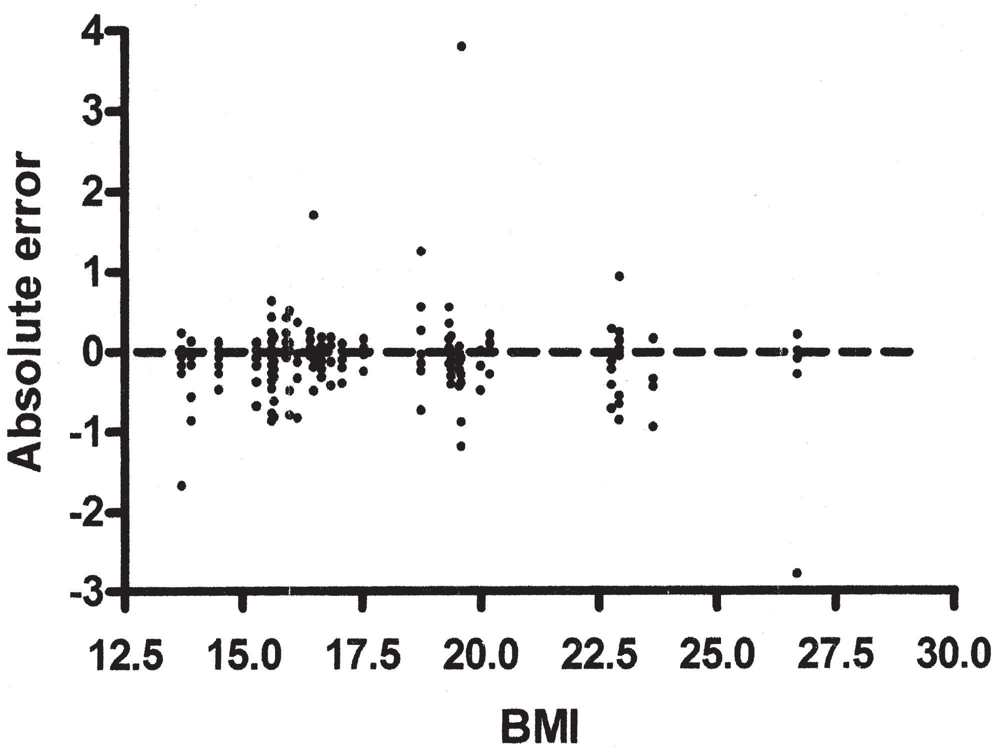


Figure 3. Calculated body mass index (BMI) versus absolute error.

nomogram/BMI curves yielded a sensitivity of 95%, specificity of 99%, and accuracy of 97%. Of the 8 misclassifications, 7 of 8 were due to plotting errors. These nomogram BMIs had less than 4% error, and replotting them yielded correct classification.

Discussion

The use of this child-specific BMI nomogram coupled with the BMI curves enabled providers to accurately screen for obesity in young children. Group A data points demonstrate people familiar with the nomogram could determine BMI values without a calculator. Group B data points demonstrate that people unfamiliar with the nomogram could quickly learn to use it with the BMI curves to screen for obesity. It is important to note that Group B does not represent an actual clinical setting, but rather an approximation: asking clinicians to implement a newly learned technique in a time-controlled setting. In many settings, medical assistants, not providers, do chart plotting. Regardless, the high rate of correct classifications in this group is encouraging. It is reasonable to expect that implementation of this nomogram into a busy pediatric practice may be successful in screening for obesity. Although the nomogram does not include BMIs over 31, all of these children would be considered overweight. Even without determining BMI, these more extreme overweight children are more likely to be recognized.

It is important to underscore that any screening tool for pediatric obesity be able to ensure the following two things: First, the provider can correctly assess the patient's current BMI and weight classification. Second, the provider can quickly and easily determine the patient's BMI trend over time including identifying critical changes, rapidly increasing BMI, or early adiposity rebound. For tracking obese children with BMIs over 31, the Bray nomogram may be utilized. However, sole reliance upon any nomogram to determine BMI is not recommended. It is not designed to detect small changes in BMI. Although it cannot measure the impact of weight management interventions where small changes in BMI are followed, we believe it is most clinically useful as a screening tool for larger trends and changes.

In spite of the method of BMI calculation used, whether it is a computer system, a calculator, or this nomogram, it is imperative that recognition of pediatric obesity be maximized among providers especially at younger ages. We hope that this nomogram/BMI curve will contribute to accurate identification of obese children.

Supplement

To make a nomogram that calculates:

$$z = ax^m y^n$$

First choose:

a, m, n	**Constants for the nomogram equation above**
x_{min}, x_{max}	**minimum and maximum values for the x scale**
y_{min}, y_{max}	**minimum and maximum values for the y scale**

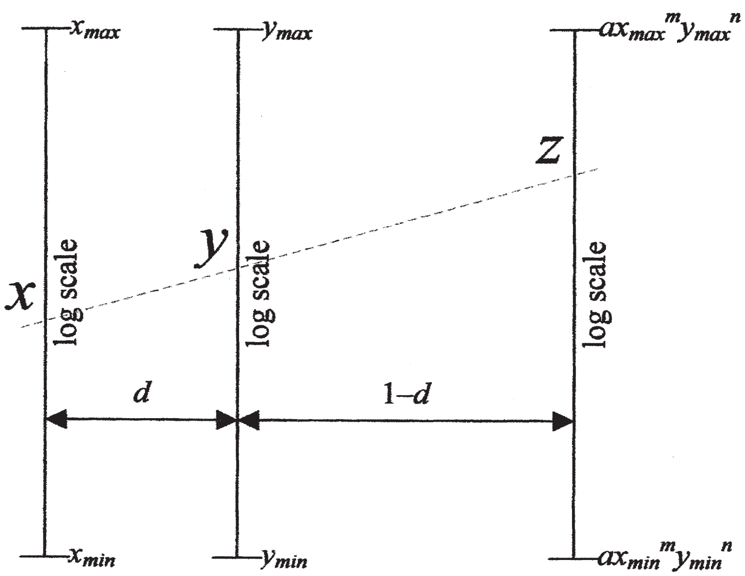
Then calculate:

$$d = \frac{m(\log x_{max} - \log x_{min}) + n(\log y_{max} - \log y_{min})}{n(\log y_{max} - \log y_{min})}$$

If $d \geq 1$ or $d \leq 0$, then you need to do one of the following and repeat the calculation:

- **swap x and y**
- **swap x_{min} and x_{max}**
- **swap y_{min} and y_{max}**

Now you can draw your nomogram:



Derivation

First, consider the simpler case of three linear scales ranging from $0 \le x \le s_x$, $0 \le y \le s_y$, and $0 \le z \le s_z$.

Geometrically, we know that:

$$\frac{x/s_x - y/s_y}{d} = \frac{x}{s_x} - \frac{z}{s_z}$$

Solving for z:

$$z = \left(\frac{s_z(1-1/d)}{s_x}\right)x + \left(\frac{s_z}{s_y d}\right)y$$

Thus, our linear nomogram can be used to calculate $z = mx + ny$, where:

$$m = \left(\frac{s_z(1-1/d)}{s_x}\right), \text{ and } n = \left(\frac{s_z}{s_y d}\right)$$

Given values for m and n, we can solve for d by eliminating s_z:

$$d = \frac{ms_x + ns_y}{ns_y}$$

How do we modify the argument above, if instead of linear scales, we have logarithmic scales ranging from $x_{min} \le x \le x_{max}$, $y_{min} \le y \le y_{max}$, and $z_{min} \le z \le z_{max}$?

We can use the same argument after making these substitutions:

$x \quad \rightarrow \quad \log x - \log x_{min}$

$s_x \quad \rightarrow \quad \log x_{max} - \log x_{min}$

(likewise for y, s_y, z, s_z)

Now:

$$z = ax^m y^n$$

and

$$d = \frac{m(\log x_{max} - \log x_{min}) + n(\log y_{max} - \log y_{min})}{n(\log y_{max} - \log y_{min})}$$

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