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Linear Growth Deficit Continues to Accumulate beyond the First 1000 Days in Low- and Middle-Income Countries: Global Evidence from 51 National Surveys[1,2]

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Abstract

Growth faltering is usually assessed using height-for-age Z-scores (HAZs), which have been used for comparisons of children of different age and sex composition across populations. Because the SD (denominator) for calculating HAZ increases with age, the usefulness of HAZs to assess changes in height over time (across ages) is uncertain. We posited that population-level changes in height as populations age should be assessed using absolute height-for-age differences (HADs) and not HAZs. We used data from 51 nationwide surveys from low- and middle-income countries and graphed mean HAZs and HADs by age. We also calculated annual changes in HAZs and HADs and percentage of total height deficit accumulated annually from birth to age 60 mo using both approaches. Mean HAZ started at −0.4 Z-scores and dropped dramatically up to 24 mo, after which it stabilized and had no additional deterioration. Mean HAD started at −0.8 cm, with the most pronounced faltering occurring between 6 and 18 mo, similar to HAZ. However, in sharp contrast to HAZ, HAD curves had continued increases in the deficit of linear growth from 18 to 60 mo, with no indication of a leveling off. Globally, 70% of the absolute deficit accumulated in height (HAD) at 60 mo was found to be due to faltering during the first ''1000 days'' (conception to 24 mo), but 30% was due to continued increases in deficit from age 2 to 5 y. The use of HAZ masks these changes because of age-related changes in SD. Therefore, HAD, rather than HAZ, should be used to describe and compare changes in height as children age because detecting any deficit compared with expected changes in height as children grow is important and only HAD does this accurately at all ages. Our findings support the current global programmatic momentum to focus on the first 1000 d. Research is needed to better understand the dynamics and timing of linear growth faltering using indices and indicators that accurately reflect changes over ages and to identify cost-effective ways to prevent growth faltering and its consequences throughout the lifecycle. J. Nutr. 144: 1460–1466, 2014.

Introduction

With 165 million stunted children, linear growth retardation continues to be a major global health problem (1). Current evidence suggests that effective interventions to reduce stunting should be targeted to mothers and children during the first "1000 days" of life (from conception to age 2 y) and aim to prevent (rather than treat or reverse) stunting (1–3). An increasing number of health and nutrition programs currently focus on this "window of opportunity for preventing undernutrition."

The focus on the first 1000 d builds on 3 main sources of evidence. First, a longitudinal intervention study in Guatemala demonstrated that the growth impact of a high-protein/energy food supplement was largest among children who were exposed to the intervention during their first 2–3 y of life compared with those exposed at older ages (4). This was true not only for anthropometric outcomes in early childhood but also for a wide range of physical, cognitive, educational, health, and economic productivity outcomes throughout adulthood (5,6). Second, an analysis of 54 nationally representative surveys from low- and middle-income countries shows a universal pattern of steep decline in children's height-for-age Z-scores (HAZs) from birth until age 23 mo, with no evidence of additional deterioration between ages 24 and 59 mo (7). Third, the importance of the prenatal period for stunting is well established. A recent meta-analysis estimated that being small-for-gestational age is responsible for an estimated 20% of stunting in children aged 12–60 mo (8).

Growth faltering is usually assessed using HAZs. By adjusting each child's height for the median expected height for his or her age and sex, HAZ provides a mean value for groups of

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children with different sex and age compositions, which has been used for comparisons across populations (9). HAZ also provides a way to evaluate the nutritional status of children at a particular age relative to the growth standards. For both of these purposes, which involve an assessment at 1 point in time, HAZs have proven to be invaluable. However, measuring growth across time or ages presents different challenges for both population- and individual-level assessments. The calculation of HAZ uses as denominator the SD of the growth standard. The SD is cross-sectional in nature because it reflects the dispersion of height values at a specific age. The SD changes (increases) with age. The usefulness of HAZ to assess changes in height over time or across ages is thus uncertain, and its implications for describing patterns of growth faltering in aging populations over time has not been adequately examined.

For this reason, we argue in this study that population-level changes in mean growth deficits over time (as populations age) should be assessed using the absolute height-for-age difference (HAD) (in centimeters) and not HAZ. We use data from 51 nationwide surveys conducted in developing countries to describe growth patterns of children using the absolute HAD relative to WHO 2006 growth standards up to 60 mo and compare them with the patterns obtained using HAZ. We also describe the timing of growth faltering and the percentage of growth faltering accrued each year from 0 to 5 y when using HAD vs. HAZ.

Methods

Theoretical background. Groups of infants and young children from diverse ethnic groups whose nutrition, health, and care needs are met grow similarly for the first 5 y of life (10,11). A single set of international growth standards can thus be used across countries to assess the growth of children up to age 5 y (12). The mean height at each age in a population of healthy well-nourished children in any country is expected to be at the median of the growth standards.

Growth deficits in height for groups of children are expressed as the mean of the individual deficits, which are calculated as the difference between the measured height and the median age- and sex-specific height obtained from the growth standards. This HAD can be used in absolute terms (as proposed in this study) or relative to the SD (standardized by dividing HAD by the SD from the growth standards to calculate HAZ):

$$HAZ = \frac{observed\ height - median\ height\ growth\ standard}{SD} = \frac{height\text{-}for\text{-}age\ difference}{SD} = \frac{HAD}{SD}.$$

This formula can be used because the growth standards for height are normally distributed. Because HAD and HAZ are calculated from height data, both statistics will be normally distributed in nearly all populations of young children.

The SDs for height increase substantially from birth to age 5 y (12). As a consequence, changes in HAZ with age can be due to changes in the numerator (the magnitude of the difference, HAD) or to changes in the denominator (the increasing SD with age), which means that a change in HAZ does not directly correspond to the absolute change in height across ages. If the height deficit (HAD) remains constant as children age (reflecting the absence of improvement over time), HAZ will converge toward 0 (suggesting improvement) with age simply because the denominator (i.e., the SD) increases with age.

Data sets and data analyses. For reasons of comparability, our objective was to analyze data from the 54 countries used in the study by Victora et al. (7) We used the most recent survey data available for each country. A total of 51 surveys were available for analyses: 49 demographic and health surveys (13) and 2 multiple indicator cluster surveys (14). The data from Yemen and Eritrea were not available for public use from demographic and health surveys. Data from Nepal could not be analyzed because the birth and survey dates (expressed in the Nepali lunar calendar) could not be converted to the Gregorian calendar dates necessary to calculate children's age.

For ~11% of all children, the day (but not the month or year) of birth were missing. To maximize the number of observations that could be included, a random day of birth was generated for these children. After creating the age in days for all children, we calculated HAD (in centimeters) and HAZ (in SD units) using the WHO 2006 standard (12). Observations with an absolute value of HAZ > 5 were dropped from the analyses.

Two types of analyses were conducted. First, we computed the mean HAD and HAZ and graphed both variables and their smoothed values (using the kernel-weighted local polynomial smoothing algorithm in Stata version 13.2) by age in completed months. Children younger than age 1 mo were thus considered to be age 0 mo for the analyses. Only postnatal measurements were used. HAZ graphs are similar to those presented by Victora et al. (7), with small differences in the number and year of the surveys included. Using the smoothed values, we then calculated the change in HAD and HAZ by year (i.e., the change from birth to 11 mo, from 12 to 23 mo, etc.) and compared the percentage of the total linear growth deficit at age 5 y accumulated from year to year using HAD vs. HAZ.

Results are presented for all 51 countries combined and aggregated by region using the same 5 regions used in the study by Victora et al. (7): *1*) Eastern Europe and Central Asia; *2*) Latin America and the Caribbean; *3*) North Africa and the Middle East; *4*) South Asia; and *5*) Africa South of the Sahara. Following the study by Victora et al. (7), all analyses were done by pooling children from countries without using country sample or region population weights.

Results

The characteristics and sample sizes of the surveys included in the analyses are shown in **Table 1**. The large majority of surveys were conducted since 2000. Data used in this study were collected in children aged 0–59 mo, except in Kyrgyzstan, the Central African Republic, and the Comoros, where data was collected in children aged 0–35 mo. The percentage of observations that could be included in the analyses varied from 23% in Malawi to 96% in Peru. The main reasons for exclusion were missing birth date or height data. In 33 of the countries, at least 70% of the observations were available for analyses. Data on a total of 309,215 children were included in the analyses.

Figure 1 confirms the findings of Victora et al. (7). The mean HAZ started below the standard (at approximately −0.4 Z-scores) and dropped dramatically up to ~24 mo, after which it stabilized and slightly increased. The mean HAD curve showed that children started with an average height deficit of ~0.8 cm. Similar to the HAZ curve, the most pronounced increase in deficit (i.e., the steepest slope) was found between ages 6 and 18 mo. However, in sharp contrast with the HAZ curves, the HAD curves suggest that growth deficits continued to increase after 18 mo, albeit at a lower rate than before 18 mo. HAD continued to decrease up to age 5 y, with no indication that it leveled off. The noticeable bumps just after 24, 36, and 48 mo were due to age rounding and heaping, i.e., the tendency to report age in completed years rather than in exact months, reported previously by Victora et al. (7) and confirmed in our analysis.

Figure 2, *A* and *B*, shows the patterns of accumulating height deficit by region using HAZ and HAD, respectively. The patterns by region in Figure 2*A* were similar to those documented by Victora et al. (7) using HAZ. Although growth deficits were

TABLE 1 Data sets analyzed[1]

Region and country	Survey Type	Survey Year	Age range	Sample size Total	Sample size Included
			mo	*N*	*n (%)*
Eastern Europe and Central Asia					
Armenia	DHS	2010	0–59	1473	1345 (0.91)
Kazakhstan	DHS	1999	0–59	1345	571 (0.42)
Kyrgyzstan	DHS	1997	0–36	1127	973 (0.86)
Moldova	DHS	2005	0–59	1552	1324 (0.85)
Mongolia	MICS	2005	0–59	3568	3286 (0.92)
Montenegro	MICS	2005	0–59	1072	852 (0.79)
Turkey	DHS	2004	0–59	4533	4046 (0.89)
Latin America and Caribbean					
Bolivia	DHS	2008	0–59	8605	7742 (0.90)
Brazil	DHS	1996	0–59	5045	4129 (0.82)
Colombia	DHS	2010	0–59	17,756	16,001 (0.90)
Dominican Republic	DHS	2007	0–59	11,149	9368 (0.84)
Guatemala	DHS	1999	0–59	4943	3860 (0.78)
Haiti	DHS	2012	0–59	7247	3992 (0.55)
Honduras	DHS	2012	0–59	10,888	9971 (0.92)
Nicaragua	DHS	2001	0–59	6986	5952 (0.85)
Peru	DHS	2012	0–59	9620	9219 (0.96)
North Africa and Middle East					
Egypt	DHS	2008	0–59	10,872	9691 (0.89)
Jordan	DHS	2009	0–59	9650	4388 (0.45)
Morocco	DHS	2003	0–59	6180	5468 (0.88)
South Asia					
Bangladesh	DHS	2011	0–59	8753	7635 (0.87)
Cambodia	DHS	2010	0–59	8232	3701 (0.45)
India	DHS	2006	0–59	51,555	41,320 (0.80)
Africa South of the Sahara					
Benin	DHS	2006	0–59	16,075	12,129 (0.75)
Burkina Faso	DHS	2010	0–59	15,044	6549 (0.44)
Central African Republic	DHS	1994	0–35	2816	2339 (0.83)
Cameroon	DHS	2011	0–59	11,732	5035 (0.43)
Chad	DHS	2004	0–59	5635	4343 (0.77)
Comoros	DHS	1996	0–35	1145	957 (0.84)
Congo	DHS	2011	0–59	9329	4464 (0.48)
Cote d'Ivoire	DHS	2012	0–59	7776	3205 (0.41)
Ethiopia	DHS	2003	0–59	11,654	9449 (0.81)
Gabon	DHS	2012	0–59	6067	3367 (0.55)
Ghana	DHS	2008	0–59	2992	2399 (0.80)
Guinea	DHS	2005	0–59	6364	2637 (0.41)
Kenya	DHS	2009	0–59	6079	5114 (0.84)
Lesotho	DHS	2009	0–59	3999	1614 (0.40)
Liberia	DHS	2007	0–59	5799	4333 (0.75)
Madagascar	DHS	2009	0–59	12,448	5018 (0.40)
Malawi	DHS	2010	0–59	19,967	4598 (0.23)
Mali	DHS	2006	0–59	14,238	10,932 (0.77)
Mauritania	DHS	2000	0–59	4764	3754 (0.79)
Mozambique	DHS	2011	0–59	11,102	9301 (0.84)
Namibia	DHS	2007	0–59	5168	3725 (0.72)
Niger	DHS	2006	0–59	9193	3608 (0.39)
Nigeria	DHS	2008	0–59	28,647	19,451 (0.68)
Rwanda	DHS	2010	0–59	9002	4056 (0.45)
Senegal	DHS	2011	0–59	12,326	3736 (0.30)
Tanzania	DHS	2010	0–59	8023	6771 (0.84)
Uganda	DHS	2011	0–59	7878	2064 (0.26)
Zambia	DHS	2007	0–59	6401	5108 (0.80)
Zimbabwe	DHS	2010	0–59	5563	4323 (0.78)

[1] DHS, demographic and health survey; MICS, multiple indicator cluster survey.

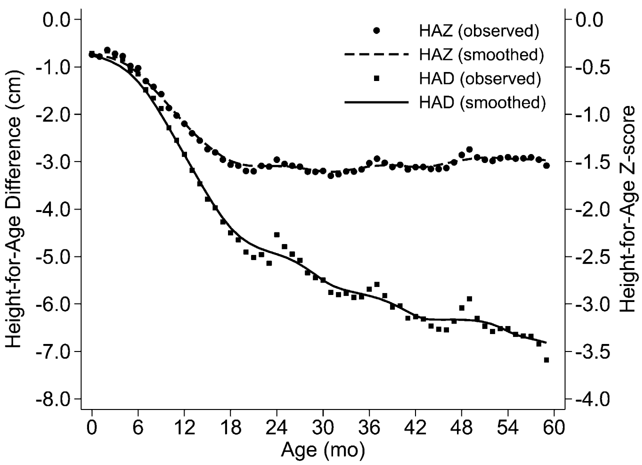

FIGURE 1 Mean HAZ (*A*) and HAD (*B*) relative to the WHO standard (1–59 mo) by completed month and kernel-weighted local polynomial smoothed values. Data from *n* = 309,215 children from 51 demographic and health surveys and multiple indicator cluster surveys. HAD, height-for-age difference; HAZ, height-for-age Z-score.

present in all regions, the magnitude of the deficit differed greatly between regions (Fig. 2*A*). In Eastern Europe and Central Asia and in North Africa and the Middle East, the mean HAZ was between 0 and −0.5 Z-scores the first year of life and dropped to approximately −1 Z-score between 12 and 24 mo. Children in Latin America and the Caribbean started at −0.5 Z-scores and then followed a pattern parallel to that of children in the first 2 regions. Children in South Asia and Africa South of the Sahara started at different levels (−0.5 and −0.3 Z-scores, respectively) but followed a similar pattern starting at 6 mo, characterized by a steep drop in HAZ and reaching −1.8 Z-scores between ages 18 and 24 mo. In all 5 regions, HAZ bottomed out by 24 mo and then remained stable or even slightly increased with age up to 60 mo.

The growth patterns observed when using HAD were similar to those found using HAZ for the period between ages 0 and 18 mo (and the ranking of regions is the same), but the patterns were remarkably different from 18 to 60 mo. Mean HAD deficits at birth ranged from 0.3 cm in Eastern Europe and Central Asia to 1.1 cm in South Asia (Fig. 2*B*). Similar to the HAZ curves in Figure 2*A*, the steepest increases in growth deficit happened in the first 2 y of life. However, substantial accumulation of height deficit continued up to age 5 y in all regions. The slope of the curves suggests that growth faltering may continue past 60 mo. The total accumulated height deficit by 60 mo was ~4.5 cm in Eastern Europe and Central Asia, North Africa and the Middle East, and Latin America and the Caribbean. The deficits in Africa South of the Sahara (7.5 cm) and South Asia (8.4 cm) were much larger.

The changes in HAZ and HAD by yearly age intervals and regions during the first 5 y are shown in **Figure 3**. As would be expected from the previous results, globally and in all regions, most of the drop in HAZ occurred during the first 2 y of life, after which little or no changes in HAZ were observed. However, the change in HAD by year showed a different picture. First, children lost ground with respect to the standard during every single year of the first 5 y of life. The only exceptions were children in year 5 of life in the Eastern Europe and Central Asia region. Second, the largest loss happened during year 2 in all regions, with drops ranging from −1.7 cm in Eastern Europe and Central Asia to −2.7 cm in Africa South of the Sahara. Third, according to the changes in HAD, the height deficits continued to accumulate up to (and possibly beyond) 60 mo of age, especially in North Africa and the Middle East, South Asia, and Africa South of the Sahara.

With regards to the timing of increases in the height deficit, **Figure 4***A* shows that, at birth, 17% (Eastern Europe and Central Asia) to 40% (Latin America and the Caribbean) of the maximum HAZ deficit was already established. In most regions, with the exception of Eastern Europe and Central Asia and North Africa and the Middle East, in which ~10% of HAZ deficit was accrued in year 3, the entire HAZ deficit was accumulated by the end of year 2. Results using HAD (Fig. 4*B*) show a very different picture, with ~30% of the total height deficit (ranging from 27% in Africa South of the Sahara to 34% in North Africa and the Middle East) having occurred after 24 mo of age.

Discussion

Using cross-sectional data from 51 nationwide surveys, we show markedly different patterns of growth deficit accumulation when using HAD vs. HAZ. As documented previously, growth patterns based on HAZ had a steep drop during ages 18–24 mo, followed by a leveling off of the curves and an absence of additional deterioration up to age 60 mo. The growth curves

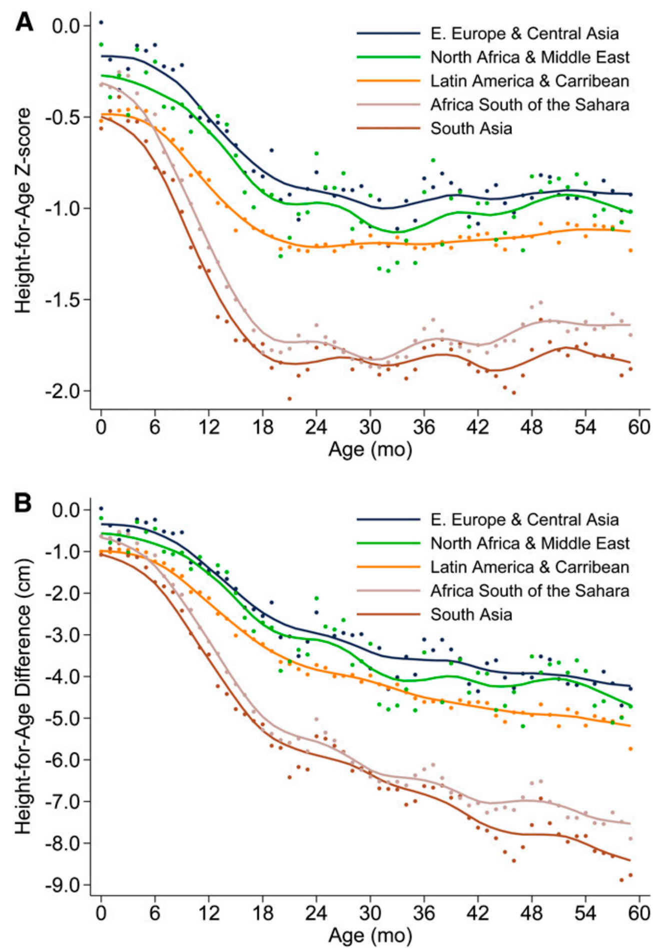

FIGURE 2 Mean height-for-age Z-scores (*A*) and height-for-age difference (*B*) relative to the WHO standard (1–59 mo) by completed month and kernel-weighted local polynomial smoothed values. Results are presented by region (*n* = 12,397–154,379).

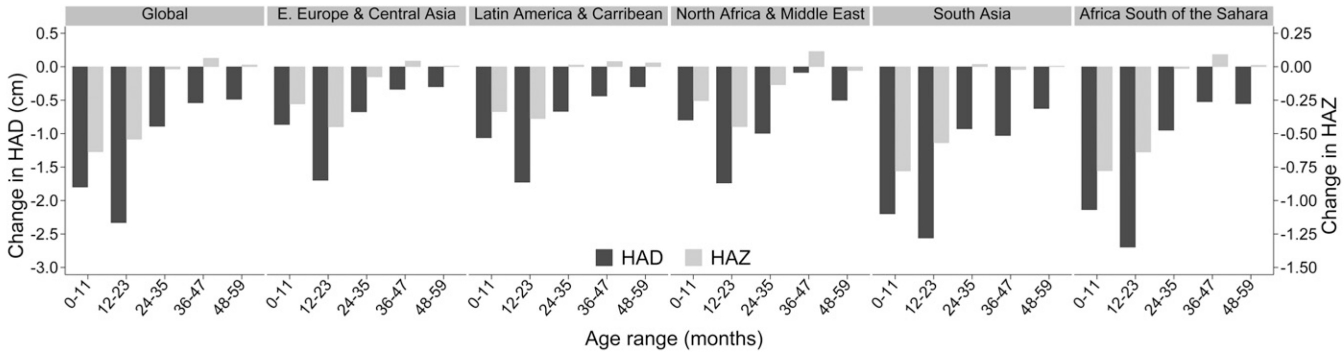

FIGURE 3 Mean changes in HAZ and HAD by year for all 51 surveys (1–59 mo). Global results for all 51 demographic and health surveys and multiple indicator cluster surveys (*n* = 309,215) are presented, as are results by region (*n* = 12,397–154,379). HAD, height-for-age difference; HAZ, height-for-age Z-score.

based on HAD revealed a remarkably different picture, showing a continued decline (increase in deficit) from birth to 60 mo and no sign of improvements or flattening of the curve between ages 24 and 60 mo. Using HAD, we estimated that ~30% of the total linear growth deficit at 60 mo was accumulated after 24 mo.

These findings raise important questions regarding the measurement of growth faltering and the selection of the most accurate index to reflect changes in growth patterns over time in children in low- and middle-income countries. As noted above, HAZ was used to compare attained growth of population groups with different age and sex composition or to assess an individual child's attained growth at a certain age. HAZ was not designed to assess changes in growth over time as populations or individual children age, and for this purpose, HAZ yields different results than does HAD. The use of HAZ to track linear growth of groups of children across ages masks the actual continued accumulation of growth deficit that occurs between 24 and 59 mo in all regions. Our results suggest that absolute differences in height expressed as HAD should be used rather than relative differences expressed as HAZ for describing patterns of changes in linear growth as children age (15) and to compare those patterns across regions or countries because detecting any deficit compared with expected changes in height as children grow is important and only HAD does this accurately at all ages.

Our finding showing that ~30% of the total deficit in height at 60 mo was accrued after age 24 mo raises important questions related to the best timing for interventions aimed at improving nutrition. Although the importance of the first 1000 d as a critical period for preventing undernutrition has been well established, the question as to what (if anything) can be done to prevent additional deterioration beyond 2 y of life remains open. The curves derived from the survey data are merely descriptive and do not reflect the potential to benefit from interventions. The continued increases in height deficit observed between 24 and 60 mo may reflect the long-term consequence of insults experienced during the first 1000 d and may or may not be reversible with interventions targeted after 2 y of age. The continued deterioration may also be due to the sustained exposure beyond age 2 y to the same poor, unhealthy and unsanitary environment that gave rise to undernutrition in the first place. It is also important to note that early life is the period

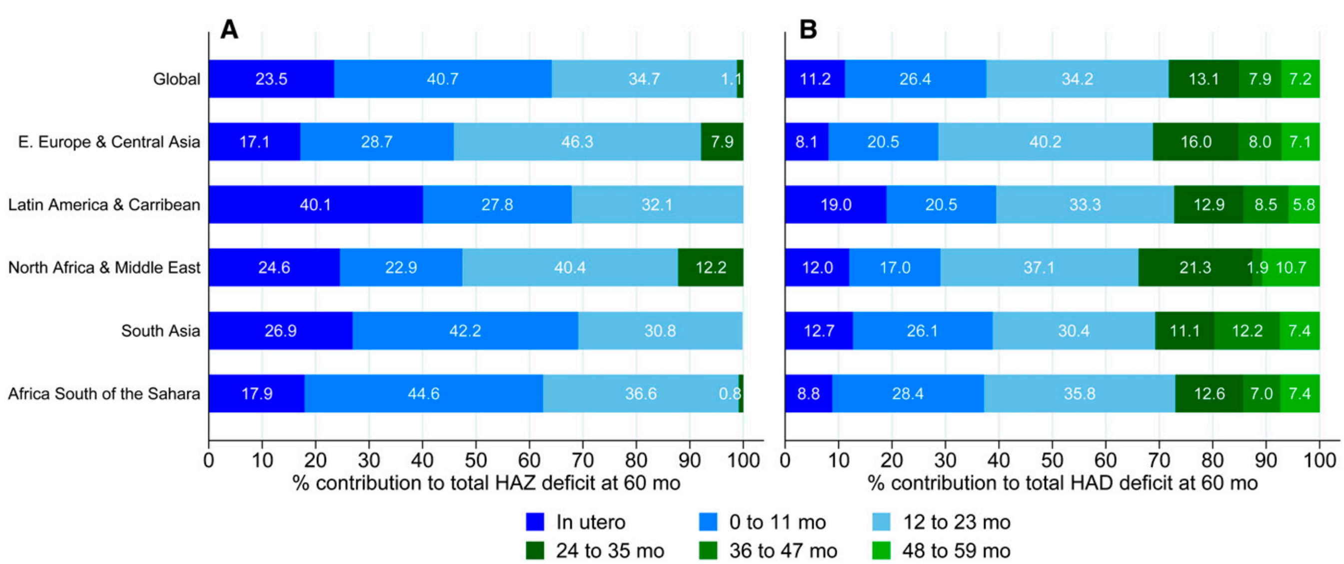

FIGURE 4 The timing of growth faltering using HAZ (*A*) and HAD (*B*) by year for all 51 surveys by region. The numbers show the percentage of the total faltering at 60 mo accumulated in each period. Blue colors correspond to the period from conception through age 2 y (the first ''1000 days''), and green colors correspond to the period from ages 2–5 y. Global results for all 51 demographic and health surveys and multiple indicator cluster surveys (*n* = 309,215) are presented, as are results by region (*n* = 12,397–154,379). HAD, height-for-age difference; HAZ, height-for-age Z-score.

of rapid brain growth and lean-mass accumulation, whereas later nutritional interventions may lead to substantial fat-mass accumulation with increased risk of chronic diseases (16,17). Therefore, focusing solely on height faltering may not provide the full picture regarding the ideal timing of nutritional interventions.

However, that children's growth continues to deteriorate beyond the first 2 y of life should not distract from the current focus on intervening during the first 1000 d. It remains that globally the bulk (~70%) of the absolute deficit at 5 y is due to growth faltering during the first 1000 d. In addition, better nutrition, health, and care during the first 1000 d may (at least partially) help avert continued faltering beyond age 2 y.

The primary purpose of our study was to compare HAZ and HAD for assessing population-level changes in mean growth deficits over time (as populations age). Achieving this purpose required having high-quality anthropometric data from multiple countries so that both HAZ and HAD could be calculated for each child but did not require producing nationally or regionally representative results. Therefore, we did not account for sample or population weights or for potential selection bias from children who could not be included because of missing data. Accounting for these factors would not have changed our main finding regarding the comparison of HAD and HAZ. The data we used are cross-sectional and do not reflect changes in the growth of individual children over time. Therefore, differences seen in attained growth in groups of children from different ages could be due to differences in the growth environment to which children from different ages have been exposed. However, it is unlikely that environments could have changed drastically over a 5-y period across 51 nations. Furthermore, environmental influences would affect both HAZ and HAD in the same way and therefore would not alter our results related to the comparison between HAZ and HAD. A possible limitation of the data used is measurement error in infants younger than 1 mo whose length may be more difficult to measure accurately. If the error in this age group is systematically different from the error in older children, it might have biased the estimates of the contribution of the in utero period to the total deficit (for both HAD and HAZ) shown in Figure 4. When we used 1 completed month rather than 0 completed months as the cutoff to define the in utero period, the estimates were similar.

New research should assess the potential to improve growth beyond age 2 y, test different packages of interventions, and identify the optimal timing for improving nutrition in a cost-effective manner. Research should also assess whether improvements in growth after 24 mo result in meaningful improvements in the functional consequences of undernutrition and whether such interventions may lead to increased risk of chronic diseases. Child linear growth faltering is associated with a number of important outcomes throughout the lifecycle, such as increased mortality, poor cognitive development, reduced school achievement, losses in economic productivity, and increased risks of chronic diseases (1). However, it is not known whether child growth is part of the biologic causal pathway linking the determinants of malnutrition to these outcomes, whether it is codetermined with these outcomes, or whether it is merely indicative of future risk. The question as to whether interventions aimed at improving population-level growth after age 2 y would also successfully improve the functional correlates of growth retardation—without increasing chronic disease risk—thus remains open. If major strides in preventing growth faltering are to be achieved, it is also important to invest in research and interventions to improve the nutritional status of adolescent girls and young women before pregnancy (18) and to identify the appropriate platforms to deliver these interventions at scale.

Our findings do not challenge the continued monitoring of subnational, nation, regional, and global prevalence of stunting for children younger than age 5 y (and changes over time in prevalence) that has contributed substantially to understanding which populations are most nutritionally compromised and gauging progress in reducing growth retardation over time. Our results support the current global programmatic momentum to focus on the first "1000 days" and the commitment of a growing number of countries to scale up nutrition interventions [SUN (Scaling Up Nutrition) initiative, see http://scalingupnutrition.org/] targeted to mothers and children during this window of opportunity. However, our study calls for research to better understand the dynamics and timing of linear growth faltering using suitable indices and indicators that accurately reflect changes over time and to identify cost-effective ways to prevent growth faltering and its consequences at different stages of the lifecycle.

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