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Bias correction of nutritional status estimates when reported age is used for calculating WHO indicators in children under five years of age

Amado D Quezada, MSc,⁽¹⁾ Armando García-Guerra, MSc,⁽¹⁾ Leticia Escobar, MSc.⁽²⁾

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Abstract

Objective. To assess the performance of a simple correction method for nutritional status estimates in children under five years of age when exact age is not available from the data. **Materials and methods.** The proposed method was based on the assumption of symmetry of age distributions within a given month of age and validated in a large population-based survey sample of Mexican preschool children. **Results.** The main distributional assumption was consistent with the data. All prevalence estimates derived from the correction method showed no statistically significant bias. In contrast, failing to correct attained age resulted in an underestimation of stunting in general and an overestimation of overweight or obesity among the youngest. **Conclusions.** The proposed method performed remarkably well in terms of bias correction of estimates and could be easily applied in situations in which either birth or interview dates are not available from the data.

Keywords: nutritional status; bias; data quality; age distribution; child, preschool

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Resumen

Objetivo. Estudiar el desempeño de un método simple de corrección para los estimadores del estado de nutrición en niños menores de cinco años cuando no se cuenta con la edad exacta en los datos. **Material y métodos.** El método se basó en el supuesto de simetría en las distribuciones de las edades dentro de un mes de edad dado y se validó utilizando una encuesta representativa de la población mexicana de preescolares. **Resultados.** El principal supuesto distribucional utilizado por el método fue consistente con los datos. Ninguna de las prevalencias obtenidas a partir del método propuesto presentó sesgos estadísticamente significativos. Cuando se utilizó la edad cumplida sin corregir, se subestimó la prevalencia de talla baja y se sobreestimó la prevalencia de sobrepeso u obesidad en el grupo de menor edad. **Conclusiones.** El método tuvo un desempeño sobresaliente para la corrección de sesgos y podría ser aplicado cuando no se tienen fechas de entrevista o de nacimiento en los datos.

Palabras clave: estado de nutrición; sesgo; calidad de los datos; distribución de edad; preescolares

(1) Centro de Investigación en Nutrición y Salud, Instituto Nacional de Salud Pública. Cuernavaca, Morelos, México.

(2) Hospital Regional de Alta Especialidad del Bajío. León, Guanajuato, México.

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Corresponding author: Amado D. Quezada. Centro de Investigación en Nutrición y Salud, Instituto Nacional de Salud Pública.
Av. Universidad 655 col. Santa María Ahuacatlán. 62100 Cuernavaca, Morelos. México.
E-mail: amado.quezada@insp.mx

The World Health Organization (WHO) child growth standards are commonly used to assess the nutritional status of populations; three of these indicators are height/length for age, weight for age and body mass index (BMI) for age scores, all of which are defined in terms of standard deviations with respect to the median of a healthy population for a given sex and a given age.¹ For the correct calculation of such indicators, age must be first obtained from birth and interview dates. This procedure is a very good approximation to the exact age and matches the age unit (days) in the most recent WHO reference tables and software macros.² Unfortunately, in some circumstances anthropometric data have been generated from ill-designed instruments that did not include birth and interview dates but attained age in months was reported instead. These sources may include historical records or surveys not specifically designed for anthropometry; additionally, data quality of either interview or birth dates may not be assured due to bad practices in data gathering or in data management.

The use of reported attained age in months for the construction of age-based nutritional status indicators could result in biased estimators of means or prevalence. This problem may be especially relevant for preschool children given the rapid changes in weight or length/height as the child becomes older at this stage development.³ Gorstein⁴ compared nutritional status estimates obtained from calculated or exact ages, from age rounded off to the nearest month and from age rounded off to the most recent attained month. Old international reference tables were commonly presented in month intervals so that child age had to be rounded off to a month of age, or alternatively, reference values near to the given exact age were interpolated before the calculation of nutritional status indicators. Results from the aforementioned study found that rounding to the most recently attained month of age resulted in important biases, especially among the youngest (0 to 5 months of age). On the other hand, estimates from age rounded off to the nearest month of age resulted in nutritional status estimates closer to those obtained from computed or exact age. Given the implied inaccuracies of using reported age, using calculated ages from birth and interview dates is generally preferable.⁵

In this paper, the estimation performance of a simple age adjustment method are studied for situations in which reported age in months are available from the data but exact age is not. This method is based on few and reasonable assumptions that were tested against the data from the Mexican 2006 National Health and Nutrition Survey (*Encuesta Nacional de Salud y Nutrición* - Ensanut).⁶

Materials and methods

Proposed methodology

It is reasonable to assume that exact age (y) is distributed as a uniform random variable for any given month of attained age (a). That is, the probability density function given a is

$$(1) \quad f(y|a) = \begin{cases} 1 & a \leq y < a+1 \\ 0 & \text{otherwise} \end{cases}$$

The mean or expected value of age for this distribution⁷ can be shown to be

$$(2) \quad E[Y|a] = \int_a^{a+1} y dy = a + 0.5$$

Thus, an unbiased prediction of exact age under this model and for a given a would consist of adding up 0.5 to the reported attained age in months. This correction could then be applied before the construction of WHO nutritional status indicators. Under any other distribution of ages, the very same adjustment applies provided that the distribution is symmetric. Furthermore, the mean always corresponds to the median under any symmetric distribution.

The age of a child determines which reference values of length/height, weight or BMI are used to calculate the z scores for each sex. As it was pointed out before, z scores calculation involves standardizing anthropometric measurements with respect to a healthy population. Therefore, a calculated z score expresses how far an observation is from the median or reference value of a healthy population at a given age and sex, this quantity is expressed in standard deviation units of the reference distribution.

Since the reference values of height and weight are a non-decreasing function of age and therefore the slope does not change of sign, using the expected value of age $a + 0.5$ instead of the attained age in months (a) implies that the median reference values within the age window $[a, a + 1)$ are used for the calculation of length for age and weight for age z scores. The only exception to this occurs for the weight for age indicator during the first three days from birth, weight naturally decreases right after birth.⁸ In terms of the reference values from the WHO growth standards, birth weight is soon recovered before reaching the first week of age, therefore, imputed age would still map to the median reference value within the first age window $[0, 1)$. In the case of BMI for age, the reference values are increasing or decreasing depending

on the age interval considered. The slope changes from negative to positive at 7-8 days (0 months) of age and from positive to negative around the middle of the sixth month of age in both sexes, although the slope within the latter period is practically zero. In relation to the first month of age, birth BMI reference values are recovered before reaching the midpoint of the age window [0, 1). Therefore, the mapping of the mean of age within a given age window to the median reference value would be generally maintained even for BMI.

Data for validation

The proposed correction was validated using data from Ensanut 2006, a Mexican multi-stage and stratified nationwide representative survey sample for which child length/height and weight were measured using standardized procedures.⁹ Informed consent was obtained from the parents or caregivers of children. Ethical clearance for conducting the Ensanut 2006 was provided by the Human Subject Ethics, Research and Biosecurity Board committees of the *Instituto Nacional de Salud Pública*.

Analyses were restricted to children under five years of age ($n=7\,702$) and only 16 cases (0.2%) were excluded due to invalid anthropometric measurements.¹ Exact biological age in months was calculated with the difference in days between interview (data collection) and birth dates and dividing this difference by 365.25 and multiplying the result by 12.¹⁰ Attained age in months was obtained as completed months based on the calendar. Nutritional status indicators were calculated with the WHO macro for Stata.² Stunting was defined as a length/height for age score below -2 standard deviations (sd) and overweight or obesity was defined as BMI for age above 2 sd.¹¹ These indicators were constructed using calculated exact ages, attained ages and corrected attained ages with the proposed method described above.

Validation

The distribution of ages in the observed sample was plotted using an histogram for comparing it to a uniform (0,1) distribution by first subtracting biological attained age in months from the corresponding exact age. A Kolmogorov-Smirnov test¹² was also applied to this age measure with the uniform (0, 1) distribution as the null hypothesis.

Survey-based estimates were obtained for the mean or prevalence of all indicators. Estimation bias was calculated by subtracting indicator values obtained with exact age from indicators obtained with attained age

and from indicators obtained with corrected attained age as well; these differences were then averaged over the sample. Analyses of means and bias were stratified by age categories (0 to 5, 6 to 11, 12 to 23 and 24 to 59 months of age), these correspond to key age intervals for nutritional interventions focused on improving child development and growth, particularly during the first 1 000 days of life (from pregnancy to 2 years of age).¹³ All standard errors of means or prevalence were adjusted for survey design using Taylor series linearization.¹⁴ All analyses were conducted in Stata v.13

Distribution of birth days within calendar months

In order to assess whether heaping on certain days of the month is observed for registered birth dates, separate discrete histograms were plotted for months with 30 days and months with 31 days, respectively.

Results

Table I shows the sample sizes by age group, where there was a relative high proportion of subjects in the older age groups but absolute sample sizes were from moderate to large. Graphical representation of the distribution of exact ages (figure 1) within attained biological months suggested that the uniform distribution is adequate for modeling exact ages. Furthermore, the null hypotheses from the Kolmogorov-Smirnov test was not rejected ($p=0.211$), indicating adequacy of the uniform model given the large sample size ($n=7\,702$).

Table II shows the estimates and associated biases of nutritional status by type of age used. In regard to continuous-type nutritional status indicators, all length for age mean estimates derived from attained age showed an upward bias and the magnitude of such bias was greater for the youngest age group. For example,

Table I
SAMPLE SIZES BY AGE GROUP, CHILDREN UNDER FIVE YEARS. MEXICO, ENSANUT 2006

| Age group (months) | Survey weighted percentage | Expanded sample (thousands) | Sample size |
|--------------------|----------------------------|-----------------------------|-------------|
| 0 - 5 | 6.7 | 631.6 | 459 |
| 6 - 11 | 9.3 | 875.5 | 668 |
| 12 - 23 | 18.3 | 1 720.2 | 1 451 |
| 24 - 59 | 65.7 | 6 185.1 | 5 124 |
| Total | 100.0 | 9 412.3 | 7 702 |

Source: estimated with data from reference 6

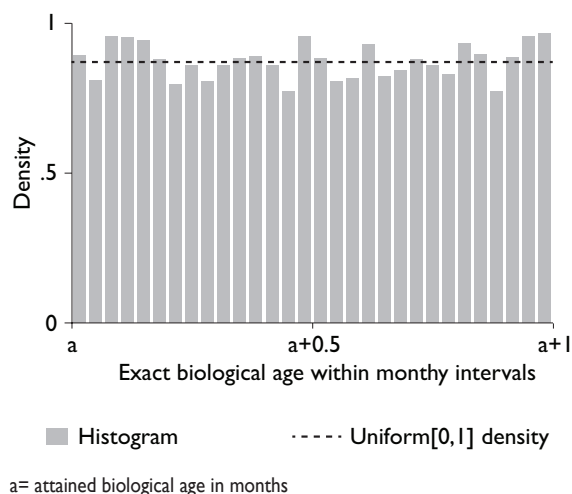


FIGURE 1. DISTRIBUTION OF EXACT AGE FOR CHILDREN UNDER FIVE YEARS OF AGE. MEXICO, ENSANUT 2012

among children 0 to 5 months of age, average length for age was more than 0.5 standard deviations (SD) greater when attained age was used compared to the mean estimate obtained from exact age. Weight for age mean estimates obtained from attained age also showed an upward bias, mainly among the youngest. Although all BMI estimates from attained age presented statistically significant bias, only in the 0 to 5 months of age group this bias was of practical significance (an observed bias of approximately 0.14 sd). Almost all mean estimates obtained from corrected-attained age showed no statistically significant bias, although statistically significant biases in the 12-23 months of age group were practically zero with very narrow confidence intervals. In regard to the prevalence of stunting, attained age derived estimates showed a negative bias with respect to the actual prevalence, again, especially among the youngest. Stunting was underestimated by approximately 4 percentage points in the 0 to 5 months age group. Statistically significant bias of the attained age derived prevalence of overweight or obesity was limited to the youngest. All prevalence estimates derived from corrected attained ages showed no statistically significant bias.

As indicated by the width of confidence intervals, standard errors of estimators were practically the same regardless of the type of age used.

Discrete histograms of day of the month in which birth was registered showed no evident heaping (figure 2). These histograms correspond to calendar days. The

distribution of exact days within attained biological months (i.e. months with equal number of days), was shown in figure 1.

Discussion

When exact age cannot be obtained for the assessment of the nutritional status of children under five years of age, adding up 0.5 to the reported attained age in months can be used as a method for predicting exact age provided that the uniform distribution is a reasonable model to describe the distribution of exact age, this method would also work under any other symmetric distribution of ages. This is a useful adjustment in light of the practical application of the WHO child growth standards.¹⁵ The validation exercise performed in a large and nationwide representative sample of Mexican children indicated that under the aforementioned conditions, failing to adjust age would result in an over estimation of length/height and therefore and under estimation of the prevalence of stunting so nutritional status of children would be perceived to be better than the correct assessment based on exact ages. In contrast, bias in BMI for age estimates when reported age was used was not perceptible in all but the 0 to 5 months of age group. Among the youngest, failing to adjust attained age resulted in an over estimation of weight excess. These results were in the expected direction; when attained age is used the WHO growth standards that are applied for the construction of nutritional status indicators correspond to younger ages than the actual ages, for example, if a child has an exact age of 3 months and 29 days the WHO growth standard at 3 months and 0 days of age would be applied instead of the correct one and therefore some of the height deficit would not be detected and weight excess would be overemphasized. With the proposed correction, approximately half of the children would have an overestimation of their exact age and the other half an underestimation, but these age differences cancel out each other when averaging. As pointed out before, our method replaces attained age with the expected value of exact age under the uniform distribution model or any other symmetric distribution for which the first moment exists. Once this correction was performed on the validation sample practically none of the nutritional status estimates showed a significant bias.

Other type of adjustments are similar to adding up 0.5 to attained months of age, specifically, rounding off age to the nearest month of age would have generally the same properties as adding up 0.5 to attained age. Age windows are just shifted by 0.5 months resulting in age intervals of the form $[a - 0.5, a + 0.5)$ instead of

Table II
ESTIMATES AND ASSOCIATED BIASES OF NUTRITIONAL STATUS IN CHILDREN UNDER FIVE YEARS OF AGE,
BY TYPE OF AGE USED AND AGE GROUP. MEXICO, ENSANUT 2006

| Age group (months) | Mean estimates according to age used | | | Bias | |
|-----------------------------|--------------------------------------|----------------------------|----------------------------|----------------------------|----------------------------|
| | Exact age | Attained age | Corrected attained age | Attained age | Corrected attained age |
| Length or height for age, Z | | | | | |
| 0 - 5 | -0.467 (-0.668, -0.266) | 0.097 (-0.122, 0.315) | -0.481 (-0.699, -0.262) | 0.564 (0.512, 0.615) | -0.014 (-0.059, 0.032) |
| 6 - 11 | -0.492 (-0.667, -0.318) | -0.213 (-0.389, -0.037) | -0.509 (-0.684, -0.334) | 0.279 (0.257, 0.301) | -0.017 (-0.038, 0.004) |
| 12 - 23 | -0.772 (-0.876, -0.669) | -0.606 (-0.711, -0.502) | -0.784 (-0.887, -0.681) | 0.166 (0.158, 0.174) | -0.011 (-0.019, -0.004) |
| 24 - 59 | -0.804 (-0.869, -0.740) | -0.728 (-0.793, -0.663) | -0.806 (-0.871, -0.742) | 0.076 (0.074, 0.079) | -0.002 (-0.004, 0.000) |
| Weight for age, Z | | | | | |
| 0 - 5 | -0.125 (-0.289, 0.039) | 0.288 (0.123, 0.453) | -0.137 (-0.305, 0.032) | 0.413 (0.370, 0.457) | -0.011 (-0.045, 0.022) |
| 6 - 11 | -0.134 (-0.268, -0.001) | 0.006 (-0.127, 0.139) | -0.143 (-0.276, -0.010) | 0.141 (0.128, 0.153) | -0.009 (-0.020, 0.003) |
| 12 - 23 | -0.044 (-0.116, 0.028) | 0.036 (-0.036, 0.108) | -0.049 (-0.121, 0.023) | 0.079 (0.076, 0.083) | -0.005 (-0.009, -0.002) |
| 24 - 59 | -0.160 (-0.210, -0.111) | -0.115 (-0.165, -0.065) | -0.161 (-0.211, -0.112) | 0.045 (0.044, 0.047) | -0.001 (-0.002, 0.000) |
| Body mass index for age, Z | | | | | |
| 0 - 5 | 0.196 (0.015, 0.377) | 0.337 (0.159, 0.515) | 0.194 (0.014, 0.373) | 0.141 (0.114, 0.169) | -0.002 (-0.014, 0.010) |
| 6 - 11 | 0.209 (0.060, 0.358) | 0.181 (0.032, 0.330) | 0.210 (0.061, 0.359) | -0.027 (-0.031, -0.024) | 0.001 (-0.001, 0.004) |
| 12 - 23 | 0.595 (0.517, 0.673) | 0.565 (0.487, 0.643) | 0.596 (0.518, 0.674) | -0.030 (-0.031, -0.028) | 0.002 (0.000, 0.003) |
| 24 - 59 | 0.516 (0.467, 0.565) | 0.511 (0.462, 0.559) | 0.516 (0.467, 0.565) | -0.005 (-0.006, -0.005) | 0.000 (-0.000, 0.000) |
| Stunting,* % | | | | | |
| 0 - 5 | 13.9 (8.2, 19.5) | 10.1 (4.7, 15.6) | 14.1 (8.4, 19.8) | -3.8 (-5.9, -1.6) | 0.2 (-1.0, 1.4) |
| 6 - 11 | 13.0 (9.6, 16.4) | 11.4 (8.1, 14.7) | 14.1 (10.4, 17.8) | -1.6 (-2.6, -0.6) | 1.1 (-0.8, 3.0) |
| 12 - 23 | 16.1 (12.8, 19.3) | 13.7 (10.5, 16.8) | 17.1 (13.7, 20.4) | -2.4 (-3.2, -1.5) | 1.0 (-0.0, 2.0) |
| 24 - 59 | 15.9 (13.9, 17.9) | 14.6 (12.7, 16.5) | 15.8 (13.8, 17.7) | -1.3 (-1.8, -0.8) | -0.2 (-0.6, 0.3) |
| Overweight or obese,† % | | | | | |
| 0 - 5 | 5.2 (2.6, 7.9) | 7.9 (4.3, 11.4) | 4.9 (2.4, 7.3) | 2.6 (0.1, 5.1) | -0.4 (-1.1, 0.4) |
| 6 - 11 | 6.0 (3.9, 8.0) | 5.9 (3.8, 8.0) | 6.1 (4.0, 8.1) | -0.1 (-0.2, 0.1) | 0.1 (-0.2, 0.4) |
| 12 - 23 | 10.0 (7.9, 12.1) | 9.9 (7.8, 11.9) | 10.2 (8.1, 12.2) | -0.1 (-0.3, 0.1) | 0.2 (-0.0, 0.4) |
| 24 - 59 | 8.7 (7.5, 9.8) | 8.6 (7.5, 9.7) | 8.7 (7.5, 9.8) | -0.0 (-0.1, 0.0) | 0.0 (-0.1, 0.1) |

* Length or height for age Z score below -2 standard deviations

† Body mass index for age Z score above 2 standard deviations

95% confidence intervals in parenthesis

Source: Estimated with data from reference 6

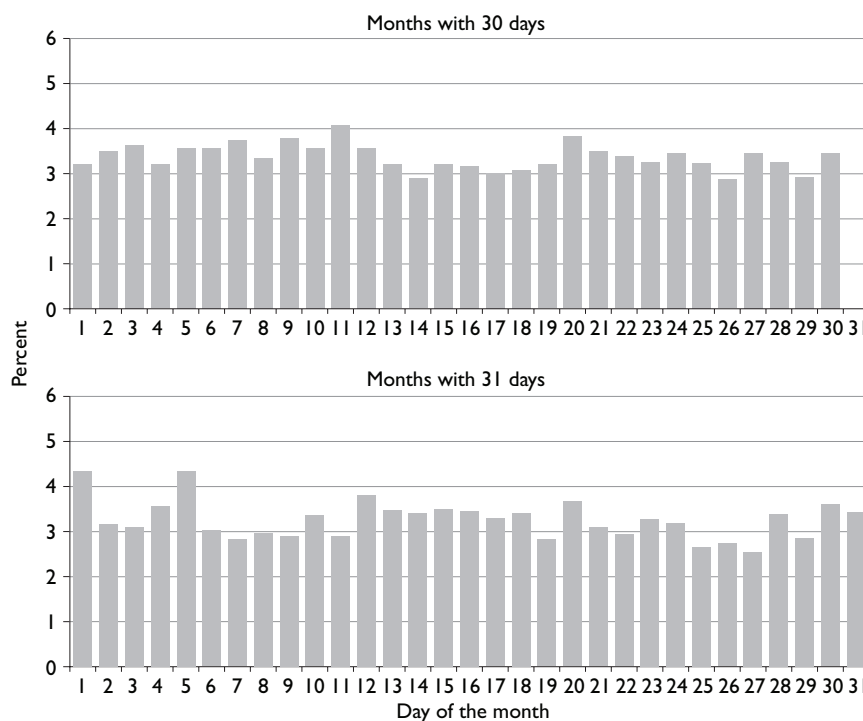


FIGURE 2. DISCRETE HISTOGRAMS OF DAY OF THE MONTH IN WHICH BIRTH WAS REGISTERED, FOR MONTHS WITH 30 AND 31 DAYS. MEXICAN CHILDREN UNDER FIVE YEARS OF AGE. MÉXICO, ENSANUT 2012

intervals of the form $[a, a + 1)$ for $a = 1, 2, \dots$. Exact age would be equally distributed within age intervals with both methods. The only difference is found in the first age interval (0 to 14 days of age) where subjects are rounded off to a lower age (except for age at day 0). Therefore, underestimation of age is not compensated with overestimation in the first age interval. This may not be noticeable if few subjects are in this age group. Furthermore, since reference tables are currently available in days, it would not be necessary to round off to the nearest month of age if age in days is known. When age in days is not known, reported age from surveys usually refers to attained months of age.

Unavailability of exact age for the construction of nutritional status indicators can be originated from ill-designed instruments with no birth dates or interview dates but also as a consequence of bad quality date records or instruments not specifically designed for anthropometry assessment. Given the implied inaccuracies of using reported age, calculating ages from birth and interview dates is generally preferable.^{5,10} In some contexts, reliability of birth dates may be compromised or absent to a large extent. This situation is quite challenging, especially in populations with lack of proper

registration systems.¹⁶ Under unreliable information on birth dates, it is expected to see heaping on certain days of the month. We did not find noticeable heaping for the analyzed survey.

The proposed method for correcting bias in nutritional status estimates is very simple, takes into account a distribution of exact ages that is reasonable to assume in most situations and performed remarkably well on the validation sample. Nevertheless if reported age cannot be considered to be reliable (e.g. populations with very low education, in rural areas where a substantial part of the population may not have birth certificates), additional methods would be required to estimate age.¹⁶

Although in our analysis we used key age groups to define subpopulations, heterogeneity in nutritional status estimates also depends on other characteristics of the population; for example, children in households with severe food insecurity are more likely to be stunted as compared to those without food insecurity.¹⁷ Additional sources of heterogeneity include educational level of the caregivers, urbanization, and access to health services.^{17,18} Consequences on estimation bias are expected to be more important for subpopulations

with a high prevalence of stunting or of overweight-obesity.

Finally, it should be noted that we applied the correction to attained age in months based on the calendar and not on biological attained months, in practice, months of age are generally counted based on the calendar. However, we performed additional analyses and found that attained biological age matched in 97% of the sample with attained age calculated from the calendar, estimates were almost exactly the same independently on whether biological attained age or calendar-based attained age was used.

Declaration of conflict of interests. The authors declare that they have no conflict of interests.

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