Nutrition, tooth development, and dental caries$^{1-3}$

José O Alvarez

**ABSTRACT** Many studies involving small animals have clearly shown that malnutrition affects tooth formation and causes increased dental caries. We have conducted two cross-sectional studies and one longitudinal study among Peruvian children to investigate the effect of early malnutrition on oral health. The cross-sectional studies have shown that in malnourished children the pattern of caries development as a function of age is significantly altered as a result of a delayed eruption and exfoliation of the deciduous teeth. This phenomenon has made difficult the observation by other scientists of a clear effect of nutritional status on total caries experience because the comparison of age-adjusted caries data between populations of children with different nutritional status is inappropriate. The use of peak caries activity has allowed the observation of a strong association between malnutrition and increased dental caries. The longitudinal study has confirmed the results of the cross-sectional studies and has demonstrated that one mild to moderate malnutrition episode occurring during the first year of life is associated with increased caries in both the deciduous and permanent teeth many years later. *Am J Clin Nutr* 1995;61(suppl):410S–6S

**KEY WORDS** Malnutrition, nutritional status, dental caries, tooth eruption, children, Peru

**Introduction**

It has been well documented in animals that early malnutrition affects tooth development and eruption (1–3) and results in increased dental caries later in life (3, 4). Rats undernourished during the time that molars are being formed and fed a caries-promoting diet develop 50% more caries than do the controls (3, 5). Also, a protein-deficient diet in young rats leads to delayed tooth eruption (6). Many factors may be responsible for the effect of malnutrition on increased dental caries in animals. Protein-energy malnutrition in rats has been shown to reduce salivary flow (7), affect salivary composition (7), alter the immune system (8), and increase the acid solubility of enamel (9).

In humans, a cause-effect relationship between nutritional status and dental caries has not been directly demonstrated (10). Indirect evidence in support of this effect can be found in studies showing a high prevalence of linear enamel hypoplasia and dental caries in the deciduous teeth of rural Guatemalan children and their association with early infectious episodes (11, 12). Infante and Gillespie (13) observed a strong correlation between the degree of linear enamel hypoplasia and caries experience in the deciduous teeth of undernourished Guatemalan children.

In 1986, we initiated a series of epidemiological studies in Peru to specifically address the question of whether malnutrition in children caused changes in tooth development and led to increased dental caries. We conducted two cross-sectional studies and one longitudinal study in children living in a northern suburb of the city of Lima that have provided direct evidence linking nutritional status, tooth eruption, and dental caries.

**Cross-sectional studies**

The purpose of the two cross-sectional studies was to investigate whether there is a significant association between current nutritional status and dental caries. The first cross-sectional study (14) was conducted in 285 children, 133 boys and 152 girls, aged 3–9 y. They were chosen at random from children attending two elementary schools and two daycare centers in Cantogrande, a poor suburb located 16 km north of Lima, Peru. This is a community with nonfluoridated water, established by poor Andean migrants, that has grown to a population of $\approx$500 000 in 15 y. Although electricity is generally available, running water, sewage disposal systems, and other public services are not available to the majority of the households. Child malnutrition is a prevalent problem and can be found in $\approx$50% of the population aged <5 y. Drinking water is bought by the barrel by 90% of the households and has a low fluoride content (<0.1 ppm). The protocol for this study was approved by the human subjects committees at both the University of Alabama at Birmingham and the Universidad Peruana Cayetano Heredia, Lima, Peru.

Oral examinations were conducted at midmorning by three dentists using mouth mirror, explorer, and direct sunlight. The World Health Organization basic methods for oral health surveys (15) were used for dental-caries scoring and the National Institutes of Health/National Institute of Dental Research (NIH/NIDR) Dental Calibration Manual (16) was used for dentist calibration. Weight and height measurements were taken for each child (dressed in light clothes and no shoes) by a

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1 From the Departments of International Health and Nutrition Sciences, University of Alabama at Birmingham.

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3 Address reprint requests to JO Alvarez, Department of International Health, University of Alabama at Birmingham, Tidwell Hall Room 106, Birmingham, AL 35294-0008.

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nutritionist-dietitian. The classification of Waterlow et al (17) for chronic (stunting) and acute (wasting) malnutrition was used and the National Center for Health Statistics (NCHS) growth tables were used as the standard. Children whose height-for-age was <95% of the NCHS median (50th percentile) were classified as stunted (mild, 90% < height for age < 95%; moderate, 85% < height-for-age < 90%; severe, height for age < 85%). Children whose weight-for-height was <90% of the NCHS median were classified as wasted (mild, 80% < weight-for-height < 90%; moderate, 70% < weight-for-height <80%; severe, weight-for-height <70%). Stunting is a measure of past or chronic malnutrition whereas wasting indicates current or acute malnutrition.

The pattern of caries development as a function of age (Figure 1) showed a significant shift to the right in the malnourished children. This phenomenon appeared to be a direct consequence of a delayed eruption and exfoliation of the deciduous teeth. Because of the age of the cohort no eruption data were obtained; however, a clear delay in the exfoliation of the deciduous teeth was observed, as shown in Figure 2.

Because no direct caries comparison at any particular age could be made because of the shifted pattern of caries development that existed between the two groups of children, we decided to compare the percent of carious teeth. This comparison, shown in Figure 3, clearly demonstrated that malnourished children had 40% of the deciduous dentition affected by caries; ie, an average of eight carious teeth compared with only six for the normal children.

The second cross-sectional study (18) involved a larger sample, 1481 children aged 1–13 y (737 boys and 744 girls) from the same community. In this study, children were also classified according to anthropometric indexes as either 1) normal, 2) wasted (acute malnutrition), 3) stunted (chronic malnutrition), or 4) stunted and wasted. Figures 4 and 5 demonstrated again a significant shift to the right of the age distribution of caries among all malnourished groups. Wasting and stunting and wasting were associated with a greater delay than stunting alone, suggesting that acute malnutrition (ie, low weight-for-height) has a more pronounced effect on tooth exfoliation than does chronic malnutrition (ie, low height-for-age). A delay in the eruption and exfoliation of the deciduous teeth was indeed confirmed in these children as shown in Figure 6.

FIGURE 1. Mean decayed, extracted, and filled deciduous teeth (DEFT) vs age in well-nourished (●) and chronically malnourished (○) (stunted) children. From reference 14.

FIGURE 2. Number of deciduous teeth as a function of age in well-nourished (●) and chronically malnourished (○) (stunted) children. From reference 14.

FIGURE 3. Percent carious deciduous teeth as a function of age in well-nourished (●) and chronically malnourished (○) (stunted) children. From reference 14.
A question that remained unclear was whether malnutrition in children led to an increased caries experience. It is likely that the effect of nutritional status on the timing of tooth eruption and caries development, described above, has been an important confounder that has prevented epidemiologists and clinicians from observing a clear-cut effect of malnutrition on caries experience in children. One way to separate the effect of nutritional status on the timing of caries development from that on the number of caries is to examine peak caries activity, as shown in Figures 4 and 5. The peak caries activity in the deciduous teeth of the malnourished children, particularly the wasted (DEFT = 7, where DEFT is the number of decayed, extracted, and filled teeth) and the stunted and wasted (DEFT = 7), was found to be higher than that in normal, well-nourished children (DEFT = 5.5). These results indicate that malnutrition is indeed associated with increased caries in the deciduous dentition. Furthermore, examination of the caries prevalence in specific teeth (Figure 7) shows that, at ages 8–11, first and second deciduous molars in malnourished children developed more caries than did first and second deciduous molars in normal, well-nourished children. Malnutrition is indeed associated with increased dental caries in the deciduous teeth.

When the caries experience of the permanent teeth was examined in these children, an important observation was made. Stunted and wasted children also had significantly higher decayed, missing, and filled (DMF) values at ages 13 and 14 y than did normal, well-nourished children, as shown in Figure 8. These findings suggest that malnutrition is associated with increased dental caries in both the deciduous and the permanent teeth.

The significant changes in the age distribution of dental caries in the deciduous teeth reported in this study of malnourished children may have important implications for epidemiological studies of dental caries. First, comparisons of age-adjusted dental caries data between different countries or between different regions within a country cannot be made without the nutritional factor (ie, skeletal growth) being taken into account. Second, the fact that infected, carious molars stay 2–3 additional years in the oral cavities of children with malnutrition at an age when most of the permanent teeth emerge (8–11 y), particularly the first permanent molar, may increase the amount of cariogenic bacteria in the mouth and thus may increase the risk for caries development in the permanent dentition.

In conclusion, malnutrition in children not only delayed tooth development and affected the age distribution of dental caries, but also had an important effect on the development and eruption of the permanent dentition.
Longitudinal study

The longitudinal study (19) was conducted from 1986 to 1990 in 209 children residing in Canto Grande, a poor, perurban community of 500,000 located ~16 km north of Lima, Peru.

The children were recruited as infants, aged 6–11 mo, from the outpatient population of the Canto Grande Health Center, or from the outpatient population of the Universidad Peruana Cayetano Heredia Hospital and the Collique Hospital of mothers residing in Canto Grande. All children in the study were of full-term gestation and normal birth weight (>2500 g), and entered the study at age 6–11 mo. Upon recruitment into the project, each child was assigned to one of four study groups, dependent on his or her nutritional status, ascertained by weight and height measurements, employing the following NCHS standards as the reference.

1) Normal: children who were normal height-for-age (>95% of standard) and normal weight-for-height (>95% of standard).

2) Wasted: children aged 6–11 mo who were of normal height-for-age but low weight-for-height (<90% of standard), indicating current acute malnutrition.

3) Stunted: children aged 6–11 mo who were of normal weight-for-height, and low height-for-age (<95% of standard), indicating past or chronic malnutrition.

4) Stunted and wasted: children aged 6–11 mo who were both of low weight-for-height and low height-for-age, indicating not only acute malnutrition but malnutrition that had occurred soon after birth.

The degree of malnutrition in all cases was mild to moderate and did not require hospitalization. Acutely malnourished children recuperated within 3 mo after recruitment solely on the basis of nutritional and medical counseling provided by the health personnel participating in the study. This counseling was provided equally to the mothers of all children participating in the study. The children in the study were followed until approximately 4 y and no additional episodes of acute malnutrition occurred after the initial one during infancy. Throughout the follow-up period, each child was given a dental examination regularly, usually every 4–6 mo. Tooth eruption and DEFT were recorded. Caries criteria included both the visual and tactile method according to the World Health Organization’s basic guidelines for oral health surveys (15). All examinations were carried out under the same lighting conditions by one of three dentists. The examination techniques and diagnostic criteria were standardized, and the intra- and interobserver variability were minimized at the outset of the study by a series of standardization procedures according to the NIH/NIDR Dental Calibration Manual (16).

The data, composed of 2700 examinations, were analyzed by using the Statistical Analysis System (SAS Institute Inc, Cary, NC) General Linear Models (GLM) program to compute analysis of variance (ANOVA) tables and statistical significance was determined by the GLM procedure with Tukey’s studentized range HSD and LSD r test options. The alpha level was 0.05. The variables of interest included the number of teeth and the number of DEFT, at specific ages, with the nutritional status of the child at the time of recruitment into the study, indexed by group, as the independent factor. Number of teeth and DEFT by group were analyzed at ages 1, 1.5, 2, 2.5, 3, and 4 y. The examinations included in the analysis had an age range of the specific age plus or minus 1 mo for all the ages except 4 y. Age 4 had a range of plus or minus 2 mo to capture the majority of the final clinical exams.

The results of this study confirmed that the eruption of deciduous teeth is delayed by malnutrition, as shown in Table 1. These findings are consistent with similar observations made in several other studies. Researchers in India (20–23), Guatemala (11, 12), Tunisia (24), Australia (25), Norway (26), Gambia (27), and Nigeria (28) among others have reported that malnutrition is associated with a delayed eruption of the deciduous teeth. Also, our previous cross-sectional studies from Cantogrande (Peru) have documented this effect (14, 18). The present study has shown that one malnutrition episode

<table>
<thead>
<tr>
<th>Age (years)</th>
<th>Normal</th>
<th>Wasted</th>
<th>Stunted</th>
<th>Stunted and wasted</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 y</td>
<td>7.4 ± 2.3 [72]²</td>
<td>5.7 ± 2.8 [34]²</td>
<td>5.7 ± 2.1 [46]²</td>
<td>5.9 ± 2.2 [21]²</td>
</tr>
<tr>
<td>2 y</td>
<td>14.6 ± 2.2 [65]²</td>
<td>13.5 ± 2.6 [37]²</td>
<td>12.8 ± 2.6 [46]²</td>
<td>12.9 ± 2.6 [19]²</td>
</tr>
<tr>
<td>2.5 y</td>
<td>17.4 ± 1.7 [69]²</td>
<td>16.9 ± 2.0 [40]²</td>
<td>16.5 ± 1.6 [48]²</td>
<td>16.3 ± 1.6 [21]²</td>
</tr>
<tr>
<td>3 y</td>
<td>19.5 ± 1.0 [69]²</td>
<td>19.5 ± 1.3 [36]²</td>
<td>18.9 ± 1.4 [52]²</td>
<td>19.3 ± 1.1 [22]²</td>
</tr>
<tr>
<td>4 y</td>
<td>20.0 ± 65 [65]²</td>
<td>19.9 ± 0.4 [41]²</td>
<td>19.8 ± 0.5 [50]²</td>
<td>19.8 ± 0.5 [26]²</td>
</tr>
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</table>

² n in brackets.
²² Significantly different from the other three groups; P < 0.05.
²³ Significantly different from the stunted and stunted and wasted groups, P < 0.05.
²⁴ Significantly different from stunted, P < 0.05.
occurring during the first year of life is sufficient to cause a significant delay in the eruption of all deciduous teeth, even though some of the teeth erupted 2 y after the malnutrition episode (Figure 9). Moreover, it is apparent that stunting, ie, retarded linear growth, is more strongly associated with delayed tooth eruption than is wasting. The smaller effect of wasting on tooth eruption was observed until age 1.5 y whereas the effect of stunting only disappeared by age 3 y (Table 1).

It would be expected that chronic malnutrition (stunting) would have a greater impact than acute malnutrition (wasting) on tooth eruption. Stunted children suffered the nutritional insult soon after birth, ie, before the age of 6 mo, and this insult was more prolonged than that of wasting. At this time, most of the teeth are still being formed, and therefore, a nutritional injury at this age would likely have a deleterious effect on all deciduous teeth. For the wasted children, the nutritional insult occurred immediately before or during recruitment, right at or after 6 mo of age. An episode of malnutrition at this stage of a child's development would likely affect the formation of the second deciduous molars only, and partially that of first deciduous molars. This time difference in the onset and duration of stunting vs wasting may explain the difference in the extent of their effort on the eruption pattern of the deciduous teeth.

The caries data have clearly demonstrated that a nutritional injury occurring early in the life of a child, when most of the deciduous teeth are still being formed (10), will make that child more susceptible to dental caries 3-4 y later. Our study has shown that a prolonged malnutrition episode in infancy that leads to both stunting and wasting results in more caries by the age of 4 y (Figure 10). It is important to note here that although no differences in caries were observed by the age of 4 between the normal, the stunted, and the wasted groups, the malnourished children had a delayed tooth eruption that likely resulted in delayed caries development (14, 18). Therefore, additional differences in DEFT could be expected at a later age.

This longitudinal study has confirmed the strong association between malnutrition and increased dental caries in the deciduous teeth. Thus, children who suffered a single but prolonged malnutrition episode during infancy (ie, stunting and wasting) had more caries by the age of 4 y than did children who either had no malnutrition at all or less severe forms of malnutrition. Interestingly, the stunted and wasted cohort showed a bimodal distribution of DEFT as presented in Figure 11, suggesting that there was a subgroup of children who had an unusually high incidence of caries. A closer examination of these children's nutritional and clinical data in terms of the severity of the

FIGURE 9. Eruption pattern for the deciduous teeth according to nutritional status. (●) normal children; (○), wasted children; (■), stunted children; (□), stunted and wasted children.

FIGURE 10. Decayed, extracted, and filled deciduous teeth (DEFT) as a function of age for children who were either normal, wasted, stunted, or stunted and wasted before the age of 1 y. The DEFT for stunted and wasted children at the age of 4 y is significantly different from the other three groups (P < 0.01). From reference 17.

malnutrition episode, sex, and age could not explain the differences in dental caries observed within the group (data not shown). Despite the fact that the stunted and wasted group showed a bimodal DEFT distribution, this group of children showed not only a significantly higher mean DEFT but also a significantly lower proportion of these children (3.4%) had ≤3 caries compared with 20-29% in the other three groups, as shown in Figure 12. This suggests that even though there were two distinctly defined caries populations in the stunted and wasted group, all of the children in this group had relatively high numbers of caries. Additional studies of these children may help to clarify this matter.

More recent findings from the longitudinal study

In 1992, we reexamined 94 of the children who participated in the longitudinal study. The children were 6 y old at the time

FIGURE 11. Percent frequency distribution of decayed, extracted, and filled teeth (DEFT) at the age of 4 y for children who were either normal, wasted, stunted, or stunted and wasted by the age of 1 y. From reference 17.
of this evaluation. Examinations included not only tactile and visual exams but also periapical and bitewing radiographs to assess interproximal caries.

The results of this study showed that, surprisingly, the eruption of the permanent teeth (ie, incisors and first molars) is accelerated in malnourished children, as shown in Figure 13. Also, a significantly higher number of caries was observed in both the deciduous teeth (Figure 14) and the permanent teeth (Figure 15).

In summary, this longitudinal study has shown that a single, moderate malnutrition episode occurring in infancy (<1 y of age) is associated with increased dental caries later in life, possibly as a consequence of a deleterious effect on the formation of tooth enamel early in life. This finding agrees with previous experimental studies in animals and confirms the indirect evidence from cross-sectional epidemiological studies in human populations that had suggested a cause-effect relationship between malnutrition and increased dental caries.

Conclusion

Our cross-sectional studies have shown that in malnourished children, the pattern of caries development as a function of age is significantly altered, showing a delay that is the direct consequence of a delay in the eruption and exfoliation of the deciduous teeth. This phenomenon has made difficult the observation by other scientists of a clear effect of nutritional status on total caries experience because the comparison of age-adjusted caries data between populations of children with different nutritional status is inappropriate. However, the use of peak caries activity or percent of carious teeth has allowed us to demonstrate clearly that malnutrition is associated with increased dental caries in the deciduous teeth. Moreover, these studies also suggested that malnourished children develop more caries in the permanent teeth.

Our longitudinal study has confirmed the previous observations and has demonstrated a clear association between early malnutrition (ie, a malnutrition episode occurring during the first year of life) and increased caries in the deciduous teeth. Interestingly, our most recent findings suggest that although malnutrition delays the eruption of the deciduous teeth, it appears to accelerate the eruption of the permanent teeth.
Nevertheless, malnutrition results in increased dental caries in both the deciduous and the permanent dentitions.

Because our studies were conducted in children with mild to moderate malnutrition, this effect is likely to be quite pervasive among children of low socioeconomic condition in both developed and developing nations. Thus, these children are at higher risk for developing dental caries, and preventive measures should be applied early on. Also, future epidemiological studies of dental caries prevalence, particularly comparisons of different populations, should take into consideration the confounding effect of nutritional status.

References