

# INCAP studies of kwashiorkor and marasmus

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## Abstract

*This article summarizes thirty years of intensive clinical metabolic and therapeutic studies of the consequences of severe protein deficiency relative to calories, which results in kwashiorkor, and of a balanced deficiency of protein and calories that results in marasmus. Evidence is provided that these are two different metabolic diseases, but kwashiorkor is usually superimposed on some degree of chronic marasmus and hence most cases studied were marasmic kwashiorkor. The value of the creatinine/height index to indicate the degree of lean body cell mass with any disease is demonstrated.*

**Key words:** anemia, calories, erythropoiesis, kwashiorkor, marasmus, protein, protein–energy malnutrition

## Part 1

(Written mainly by Nevin S. Scrimshaw)

In 1950, a little over a year after the founding of the Institute of Nutrition of Central America and Panama (INCAP), I participated in the second Food and Agriculture Organization/World Health Organization (FAO/WHO) Expert Committee on Nutrition. There, John Brock (WHO) and Marcel Autret (FAO) detailed

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their tour of Africa investigating the prevalence of a disease first reported by Cicely Williams before World War II in what is now Ghana [1, 2]. Williams's excellent descriptions of "kwashiorkor," the local name, were eclipsed by World War II, which she spent in a Japanese prison camp in Malaysia. The Brock-Autret report [2] indicated the disease to be common and widespread in Africa under a variety of names.

I recognized kwashiorkor as a form of malnutrition that we saw frequently in Central America. On this basis, WHO provided funds for INCAP to investigate the disease in Central America and FAO sent Marcel Autret to assist. By a fortunate coincidence, a young Guatemalan pediatrician, Moisés Béhar, had recently returned from 2 years of fellowship in the Children's Institute in Paris and was already working with INCAP as a volunteer. He was appointed to lead the investigation, and the classic report of Autret and Béhar [3] established the high prevalence of kwashiorkor in Central America and confirmed its clinical and epidemiologic identity with the disease in Africa. It was almost always superimposed on some degree of marasmus and was really marasmic kwashiorkor.

Béhar also learned that the syndrome had been well described by Julio Meneghello in Chile, under the name of "síndrome pluricausal de la infancia" [4]. Unfortunately, his comprehensive monograph was unknown outside of Chile. Meneghello stressed, as had Williams, the apparent role of diarrhea and other infectious diseases in precipitating kwashiorkor in an already chronically malnourished child. The report by Autret and Béhar was followed by a similar WHO/FAO study by Waterlow and Vergara on kwashiorkor in Brazil [5]. Soon the disease was being recognized as common in nearly all developing countries at the time [6].

Williams's concept of the etiology of the disease and its treatment was not entirely accepted. A book written in South Africa [7] described it as infantile pellagra, which later led to this name being applied to marasmic kwashiorkor in Yucatan, Mexico, replacing the term *culebrilla* [8]. During this period, INCAP was a major contributor to understanding the nature and

management of the disease, along with John Waterlow, in Jamaica, and John Brock and John Hansen, in South Africa. Peter Dean, Ruth Schwartz, and Hugh Trowell in Africa also made important contributions [9, 10].

To begin our research on kwashiorkor and marasmus, Béhar negotiated three beds in the large, overcrowded pediatric ward of the Guatemala City General Hospital, headed by Dr. Ernesto Cofiño.\* These beds were dedicated to the study of the numerous cases of kwashiorkor and the occasional case of marasmus coming to the hospital. These are the most severe forms of protein–energy malnutrition.

With a nutritionist to supervise their food intake, and with Fernando Viteri, then a medical student, as Béhar's assistant, INCAP soon began to produce pioneering observations, studying intensively both kwashiorkor and marasmus. In 1955, the first detailed publications from INCAP on hospitalized children and their recovery from kwashiorkor appeared [12, 13]. We demonstrated that the acute signs and symptoms of kwashiorkor (edema, pigmented skin lesions, profound apathy, and serum biochemical changes) disappeared after skim milk alone was administered by nasogastric tube [14].

Concurrently, Brock and Hansen, in South Africa, achieved initial recovery in children with kwashiorkor within days given a nutritionally balanced amino acid mixture and glucose as an energy source [15]. Of course, it soon became ethically and metabolically necessary to add vitamins and minerals for full recovery. It took longer for pathologic changes, such as fatty liver and atrophy of the pancreas and other organs, to resolve [16, 17].

As the children lost edema and their skin lesions cleared, they regained appetite, started smiling, and progressively corrected biochemical changes characteristic of kwashiorkor, and the roots of their hair began to grow out dark once again [6, 16] (fig. 1).

Case fatalities due to pneumonia and other infections were still high. Autopsies by Tejada showed “wet lungs” and pneumonia to be almost universal in fatal cases, which suggested that cardiac failure was a major factor in the high case fatality rates of these children. With prophylactic penicillin, the careful administration of vitamin and electrolyte mixtures, and a less aggressive initial dietary treatment regimen, case fatalities declined dramatically [18]. However, the children studied in the pediatric hospital ward failed to gain weight for many weeks after their edema had disappeared [14].

When Cofiño observed our efforts to conduct in-depth studies in severely malnourished children under great difficulties, he facilitated negotiations between INCAP and the Sociedad Protectora del Niño. This is

a nonprofit charitable organization in Guatemala that has served for many years as a day nursery for families whose parents have to work to make ends meet and, importantly, that had a school for auxiliary nurses. Within its facilities was a small hospital, with six isolation cubicles for children with contagious diseases.

Beginning in late 1955, INCAP was allowed to use three of the cubicles for metabolic studies. In this facility, we never again saw a stationary period in recovery in our treatment of kwashiorkor or marasmus. It was then that we realized how much the adverse impact of multiple cross-infections on the open ward prevented these children from gaining weight, even when their diet was adequate [19].

Nitrogen and fat balance studies in children recovering from kwashiorkor and free of intestinal infection showed normal absorption and retention, helping to explain the rapid recovery as the child with kwashiorkor receives protein-rich food and recovers from anorexia [20]. We also wrote extensively on the epidemiology and prevention of protein–energy malnutrition based on what we learned from village studies, hospital case reviews, and interviews with parents [18, 21, 22].

A broad scope of preventive measures, including control of infections, was reviewed in some early papers [23, 24]. We also focused on the epidemiology and prevention of kwashiorkor in Central America [18, 24]. We did not ignore its association with poverty, poor hygiene, imbalanced diets, and ignorance of health matters in the underprivileged population of Central America and the world. The need for a low-cost, protein-rich beverage to be administered to children



FIG. 1. “Flag sign” in the hair of a child recovering from kwashiorkor. The band depigmentation corresponds to the period of acute deficiency. It was first described and named by Antonio Peña Chavarría, Director of the Children's Hospital San Juan de Dios in San José, Costa Rica. Reprinted with permission. From Scrimshaw and Béhar [16]

\* Cofiño and Klee were the first to publish on hypoalbuminemia in protein–energy malnutrition [11].

whose parents cannot afford animal protein food sources became obvious. The successful development of such a product, Incaparina, is described elsewhere in this Special Issue [25, 26].

In 1955, Béhar and Viteri traveled to Kampala, Uganda, on a WHO fellowship grant to observe the work of Peter Dean, Hugh Trowell, and Ruth Schwartz, who were trying to understand the metabolic aspects underlying kwashiorkor. This experience, plus exchanges with researchers at the Children's Hospital in Mexico and the Tropical Metabolism Research Unit in Jamaica, strengthened our understanding of the scientific knowledge required to treat kwashiorkor. We also established close contact with research groups in Chile, Brazil, and other countries.

With marasmus cases in the population, gradual loss of body mass due to partial starvation occurred over many weeks or months before death threatened, whereas kwashiorkor developed rapidly and, if untreated, was soon fatal once the classical symptoms appeared. This difference is explained by the fact that the metabolic consequences of any degree of starvation are quite different from those of a diet in which protein is much more limiting than calories. Kwashiorkor may be acutely and fatally superimposed on any degree of chronic protein–energy malnutrition before it reaches the stage of severe and potentially fatal marasmus (starvation). It is appropriate to call such cases “marasmic kwashiorkor.” It gradually became clear that kwashiorkor and marasmus are quite different diseases, with kwashiorkor almost always superimposed on some degree of chronic protein–energy malnutrition. We concluded that the child with protein–energy malnutrition was wasting from lack of food and living partially on its own tissues [16]. The latter supplied a balance of energy and protein of good quality, so signs of protein deficiency did not develop. At first, both body fat and lean body mass, mainly muscle, are metabolized, but once body fat is gone and the child must depend only on lean body mass for all nutritional needs, death is near.

The multiple biochemical changes and signs and symptoms of kwashiorkor (marasmic kwashiorkor), were described in detail in early INCAP publications [16, 27]. These are not seen in marasmus. The child with chronic protein–energy malnutrition is not protein deficient because it is living on high-quality protein—its own lean body mass. The child is mobilizing amino acids for the production of glucose in the liver. These amino acids are also available to meet protein needs. However, the endocrine mechanisms responsible for this response are not activated, as long as energy intake is high relative to protein intake and the child is free of infections [16, 27]. Infections also activate this catabolic response and result in increased loss of nitrogen in the urine as urea.

The multiple mechanisms whereby any infection, no

matter how mild, has an adverse effect on nutritional status are described in other papers in this Special Issue [28, 29]. The main pathways include the endocrine responses that reduce appetite and increase catabolic loss of nitrogen as urea, as well as decreased protein absorption when the gastrointestinal tract is affected. Infections can also influence changes in the liver and pancreas in kwashiorkor [17].

We recognized that, in addition to the signs, symptoms, and pathology of protein deficiency (relative to calories), some variation in clinical characteristics could be expected, with a different mix of other nutritional deficiencies in different populations [21]. Waterlow's early studies on severely malnourished infants in Jamaica also indicated awareness that nutritional deficiencies other than those of protein and energy can affect the local characteristics of protein–energy malnutrition [30].

In a 2-year study of four highland villages in Guatemala, 40% of the postneonatal deaths of children under 5 years of age were associated with the full spectrum of signs and symptoms of kwashiorkor, and none were due to marasmus alone [23]. As we explored the epidemiology of kwashiorkor, we concluded that in Central America it was almost always acutely superimposed on some degree of Marasmus. It was associated with a diet mainly of starchy maize meal gruel (*atole de maicena*) and one or more preceding episodes of infection. It was usually precipitated by diarrheal episodes or one of the common communicable diseases of childhood, including measles, whooping cough, chickenpox, and German measles [31].

We conceptualized severe malnutrition in Central America, and by extension in the developing world, as an obtuse triangle with the hypotenuse representing increasing degrees of chronic undernutrition and kwashiorkor superimposed as an acute episode on any degree of marasmus [16] (fig. 2). Marasmus alone was characterized by wasting but did not show the clinical signs and symptoms nor the biochemical and pathologic changes characteristic of kwashiorkor [33].

When children were first admitted, we usually observed a mild normocytic anemia and a small and brief reticulocyte response when protein therapy was started. We hypothesized that with severe protein deficiency, children with kwashiorkor could not synthesize sufficient globin, the protein moiety of hemoglobin. Later, Viteri explored the anemia of kwashiorkor in greater detail [34, 35].

The cases of kwashiorkor that we treated in Guatemala, like most kwashiorkor in developing countries at the time, were almost always marasmic kwashiorkor. However, cases of “pure” kwashiorkor were described from Jamaica, in which the child develops the signs and symptoms of kwashiorkor with excess weight from consumption of cassava, which provides starch calories but almost no protein. These cases were identified as

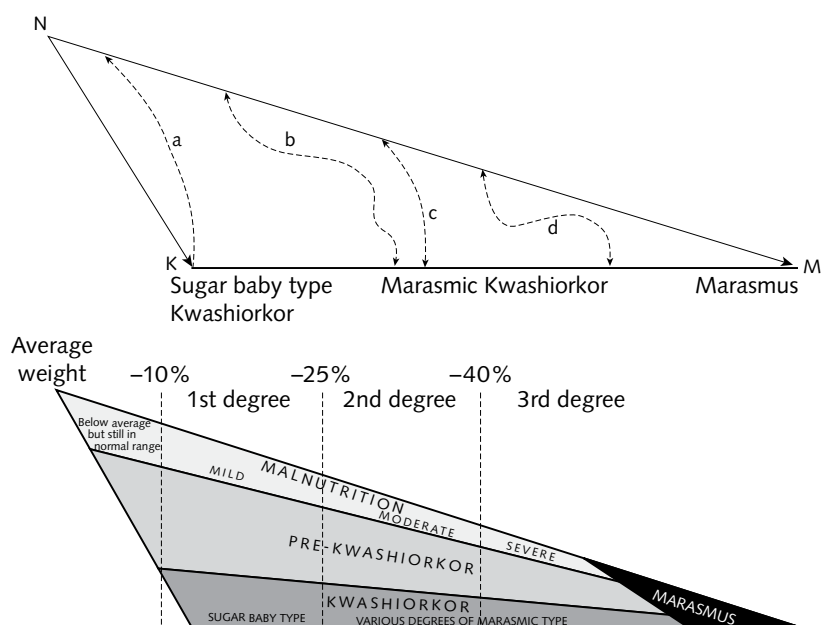


FIG. 2. Schematic representation (top) and classification (bottom) of the development of the different types of protein malnutrition in children. Areas between vertical dashed lines indicate the degree of malnutrition according to the classification scheme of Gómez et al. [32]. Reprinted with permission.

the “sugar baby type of kwashiorkor” [36]. A search of the literature revealed a similar form of the disease common in Europe until the early 20th century due to feeding only starch after weaning that was given the name *Mehlnarschaden* (starch dystrophy) [37, 38].

## Part 2

(Written mainly by Fernando Viteri)

In 1954, when I was still a medical student working in the pediatric ward, I was recruited by Moisés Béhar to work with him caring for these children. After 3 years of intensive clinical evaluations of malnourished children and during their recovery, I left INCAP in 1957 to study in the United States. The Panamanian pediatrician, Dorothy Wilson, took over responsibility for INCAP’s clinical and metabolic studies initiated by Béhar and Scrimshaw, including the work on kwashiorkor and marasmus, exploring functional and epidemiologic aspects of protein–energy malnutrition and its complications.

I returned after 5 years with a Ph.D. in physiology and board certification in internal medicine, with 4 years at the University of Cincinnati under the internist/hematologist Richard Vilter and the physiologist William Lotspeich, and a year at the National Laboratories,

Oak Ridge, Tennessee–University of Tennessee. In Guatemala, a large facility had been built by the Society for the Protection of Children, with a whole wing (El Hogar de Niños Convalescientes) in use by INCAP. It included a small playground, an experimental kitchen, examining and procedure rooms, and 6 metabolic beds. It was a paradise compared with the conditions in the General Hospital of Guatemala City.

In these expanded facilities, our first efforts were to study the body composition of malnourished children and during their recovery, in order to quantify the severity and type of protein–energy malnutrition and to quantify its changes during recovery. This would allow us to correlate functional alterations with quantitative body composition and overall metabolic activity. This article emphasizes these studies. Studies of hematologic, immunologic, gastrointestinal, and water and electrolyte homeostasis in protein–energy malnutrition and during recovery appear elsewhere in this Special Issue [34].

In 1969, I was able to obtain funds from the government of Guatemala for a special building dedicated to the study of the metabolism and function of malnourished children and adults, erected within INCAP’s grounds. It had 16 metabolic beds for children, 6 for adults, a complete laboratory to study body composition and physical capacity, an x-ray facility, an experimental kitchen, a playground, a small auditorium, and

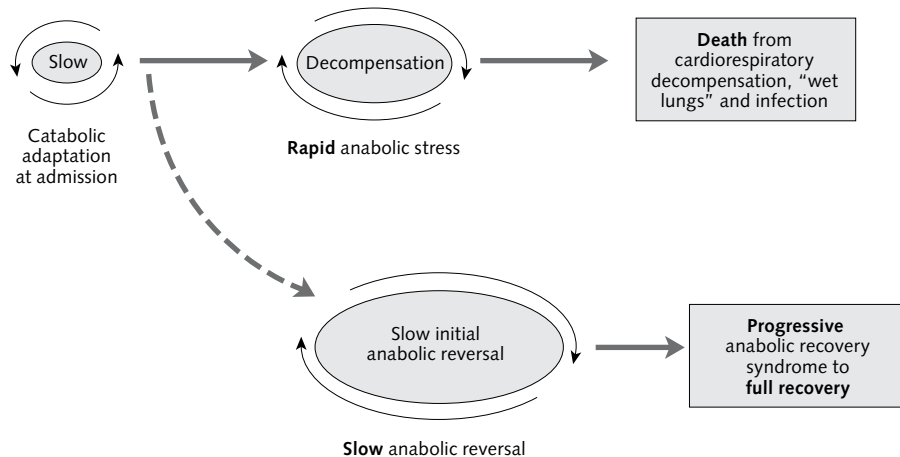


FIG. 3. A slow and prudent initial realignment plus the early use of antibiotics resulted in a marked reduction of mortality in children with severe protein–energy malnutrition

offices that included outpatient care. These facilities greatly enhanced our research capacity.<sup>7</sup>

A metabolic/physiological concept of the importance of infection in the different forms of severe malnutrition had emerged from earlier metabolic balance and clinical studies and from research performed in other parts of the world. This concept led us to modify treatment of the different types of malnourished children as follows. These children were in a slow catabolic state that had to be reversed slowly to an anabolic state [39, 40]. An abrupt nutritional load leads to a metabolic and cardiorespiratory decompensation that favors infection, increasing the risk of death (fig. 3).

This research was based on our conceptual framework of the adaptation to starvation and to the more severe protein deficiency induced by excess carbohydrate, summarized in part 1 of this article. We observed the response to treatment when body weight increases rapidly during the phase of consolidation of cure. It became important to be able to determine the composition of weight gain (hydration, adiposity, bone mass and lean body mass, or active tissue mass) in order to understand the changes in functioning of different organ systems in relation to overall nutritional status.

Bone mass in severe protein–energy malnutrition was reduced, indicating an extra need of nutrition for generation of bone during recovery [41]. It was important to keep in mind, on the one hand, that during the protein deficiency of marasmus, the catabolism of the muscle compartment constitutes the primary internal body supply of amino acids and of some electrolytes.

\* Senior researchers at INCAP's Biomedical Division included Jorge Alvarado, Benjamin Torún, Oscar Pineda, Roberto Schneider, Maarten Immink, Juan Urrutia, and Noel Solomons. Many outstanding interns and residents, laboratory technicians, dietitians, fieldworkers, and nursing staff made the Biomedical Division of INCAP an outstanding institution.

Therefore, we thought that the ratio of muscle mass measured in a malnourished child in relation to the muscle mass of normal children of the same height could indicate the relative degree of depletion or repletion of body protein.

As far as we knew, the rates of production and excretion of creatinine were not impaired in well-hydrated malnourished children, so we measured, in a serial fashion, the 24-hour creatinine excretion of malnourished children throughout recovery and compared it with the 24-hour creatinine excretion of healthy, normal children of the same height. We called the rate of creatinine excretion of a child divided by the mean rate of creatinine excretion of a normal child of the same height the "creatinine height index" (CHI) [42].

Our results showed not only that the CHI complemented the clinical picture of protein–energy malnutrition, but also that the change in CHI reflected the rate of recovery of muscle mass and active tissue mass, reaching a plateau when the CHI was essentially 1. Active tissue mass was measured by basal oxygen consumption and by body surface area multiplied by CHI [43–45] (fig. 4). CHI also corresponded to relative total body potassium.\*\* These results confirmed the value of CHI for measuring relative lean body mass [41].

The relative protein nutrition of the children studied was measured prior to and during the studies, along with weight and height and any other biochemical and functional variables essential for the aims of the studies being performed. Many pediatric and adult nutrition specialists in the world, including those involved in enteral and parenteral nutrition, began using CHI as a reliable indicator of body protein status or relative lean mass of their patients and continue to use it even now.

\*\* Measured in collaboration with the Tropical Metabolism Research Unit, Jamaica, where the facilities to measure total body potassium existed.

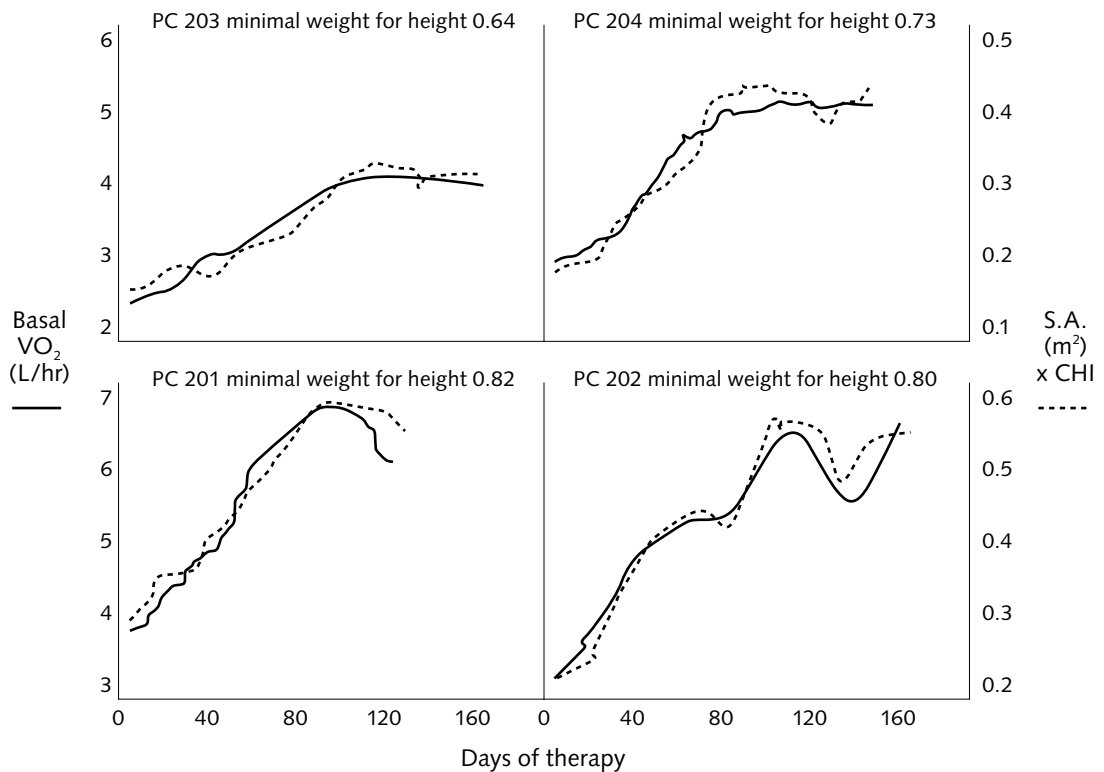


FIG. 4. Relationship between basal oxygen consumption ( $\text{VO}_2$ ) and relative body protein mass as estimated by body surface area (BSA)  $\times$  creatinine height index (CHI) in four children with protein–energy malnutrition and during recovery

The rate of muscle protein and electrolyte accretion and correction of altered electrolytes during early treatment of children with severe protein–energy malnutrition and during consolidation of cure were studied in collaboration with Dr. Buford Nichols of Texas Children's Hospital and the US Department of Agriculture Nutrition Center in Houston, and with Dr. George Alleyne of the Tropical Metabolism Research Unit in Jamaica. We showed that muscle recovery correlated with muscle potassium content and electrolyte balances measured by repeated quadriceps biopsies, total body potassium, and oxygen consumption [46–48]. The rate of change of these measurements could be modified by the amount of dietary protein administered when no other nutrient or energy intake was limiting, being faster with protein intake of 4 g/kg than with intake of 3g/kg and faster with intake of 3 g/kg than with intake of 2 g/kg [49], and by the effect of infection on body composition [50].

We also showed that the additional administration of magnesium during recovery accelerated these results, suggesting that magnesium deficiency existed in protein–energy malnutrition and that its correction, as well as the correction of potassium deficiency, accelerated

muscle protein anabolism [51]. The detailed balance studies, including careful measurements of insensible losses, suggested the mineral requirements during recovery as well as in normal children based on data in fully recovered children. Many of these results have been used by WHO in proposing the safe therapeutic nutritional handling of malnourished children.

### Concluding comments

INCAP made seminal contributions to the understanding, treatment, and prevention of kwashiorkor, marasmus, and less severe forms of protein–energy malnutrition. In the 1950s and 1960s, we could demonstrate cases of kwashiorkor on almost any pediatric ward in the developing world, except for those few countries in which marasmus was the predominant form of protein–energy malnutrition. Kwashiorkor has largely disappeared from the world, except for some refugee populations and a few countries. Lesser forms of protein–energy malnutrition are still widespread, but it is unlikely that the INCAP studies of kwashiorkor and marasmus described in this paper can ever be repeated.

## References

1. Williams CD. Kwashiorkor, a nutritional disease associated with a maize diet. *Lancet* 1934;2:1151–2.
2. Brock JF, Autret M. Kwashiorkor in Africa. *FAO Nutritional Studies No. 8*. Geneva: World Health Organization, 1952.
3. Autret M, Béhar M. Síndrome policarencial infantil (kwashiorkor) and its prevention in Central America. *FAO Nutritional Studies No. 13*. Rome: Food and Agriculture Organization, 1954.
4. Meneghello JR. Desnutrición en el lactante mayor (distrofia policarencial). Santiago, Chile: Central de Publicaciones, 1949.
5. Waterlow J, Vergara A. Protein malnutrition in Brazil. *FAO Nutritional Studies No. 14*. Rome: Food and Agriculture Organization, 1956.
6. Guzmán MA, Ascoli W, Scrimshaw NS. Nutrition research in Spanish-Portuguese speaking countries. In: Brock JF, ed. *Recent advances in human nutrition with special reference to clinical medicine*. London: J & A Churchill, 1961:226–51.
7. Gillman J, Gillman T. *Perspectives in human malnutrition: a contribution to the biology of disease from a clinical and pathological study of chronic malnutrition and pellagra in the African*. New York: Grune & Stratton, 1951.
8. Patrón Correa J. ¿Que es la culebrilla? (What is culebrilla?) *Rev Med Yucatan* 1908;3:89–96.
9. Dean RF, Schwartz R. The serum chemistry in uncomplicated kwashiorkor. *Br J Nutr* 1953;7:131–47.
10. Trowell H, Davies J, Dean R. *Kwashiorkor*, 1st ed. London: Edward Arnold, 1954.
11. Cofiño UE, Klee A. Contribución al estudio de ciertos edemas de la infancia (Síndrome debido a carencia alimenticia múltiple). *V Congreso Médico Centroamericano y de Panamá*. San Salvador, El Salvador: 1938.
12. Béhar M, Viteri FE. Análisis evolutivo de ventidós casos de síndrome de pluricarencia infantil tratados a base de proteínas de leche. *Rev Col Med Guatem* 1955; 6(1):48–60.
13. Scrimshaw NS, Béhar M, Guzmán M, Viteri F, Arroyave G. Biochemical and hematological findings in infantile pluricarencial syndrome (kwashiorkor). *Fed Proc* 1955;14:449–50.
14. Scrimshaw NS, Béhar M, Arroyave G, Tejada C, Viteri F. Kwashiorkor in children and its response to protein therapy. *J Am Med Assoc* 1957;164:555–61.
15. Hansen J, Brock J. Potassium deficiency in the pathogenesis of nutritional oedema in infants. *Lancet* 1954;264(6836):477.
16. Scrimshaw NS, Béhar M. Protein malnutrition in young children. *Science* 1961;133:2039–47. INCAP I-204.
17. Scrimshaw NS, Tejada C, Arroyave G, Béhar M. Changes in the liver and pancreas in kwashiorkor with reference to the role of antecedent infections and infestations. In: *Proceedings of the World Congress of Gastroenterology*. Baltimore, MD, USA: Williams & Wilkins, 1959:677–86.
18. Béhar M, Scrimshaw NS. Epidemiology of protein malnutrition. In: Galdston I, ed. *Human nutrition historic and scientific*. New York: International Universities Press, 1960:257–73.
19. Scrimshaw NS, Wilson D, Bressani R. Infection and kwashiorkor. *J Trop Pediatr* 1960;6:37–43. INCAP I-146 (E-302).
20. Tandon OB, Bressani R, Scrimshaw NS, Beau FL. Nutritive value of beans. *J Agric Food Chem* 1957;5:137–42. INCAP I-53 (E-175).
21. Waterlow JC, Scrimshaw NS. The concept of kwashiorkor from a public health point of view. *Bull World Health Organ* 1957;16:458–64. INCAP I-62 (E-134).
22. Béhar M, Bressani R, Scrimshaw NS. Treatment and prevention of kwashiorkor. In: Bourne GH, ed. *World review of nutrition and dietetics*. London: Pitman Medical Publishing Co, 1959:73–101.
23. Béhar M, Ascoli W, Scrimshaw NS. An investigation into the causes of death in children in four rural communities in Guatemala. *Bull World Health Organ* 1958;19:1093–102. INCAP I-110 (E-176).
24. Scrimshaw NS, Béhar M, Viteri F, Arroyave G, Tejada C. Epidemiology and prevention of severe protein malnutrition (kwashiorkor) in Central America. *Am J Public Health* 1957;47:53–62. INCAP I-71 (E-137).
25. Bressani R. INCAP studies of vegetable proteins for human consumption. *Food Nutr Bull* 2010; 31:95–110.
26. Scrimshaw NS, Squibb RL, Bressani R, Béhar M, Viteri F, Arroyave G. Vegetable protein mixtures for the feeding of infants and young children. In: *Amino acid malnutrition: XIII Annual Protein Conference*. New Brunswick, NJ, USA: Rutgers University Press, 1957:28–46.
27. Robinson U, Béhar M, Viteri F, Arroyave G, Scrimshaw NS. Protein and fat balance studies in children recovering from kwashiorkor. *J Trop Pediatr* 1957;2:217–23. INCAP I-63 (E-156).
28. Scrimshaw NS. INCAP studies of nutrition and infection. *Food Nutr Bull* 2010;31:54–67.
29. Scrimshaw NS. Historical concepts of interactions, synergism and antagonism between nutrition and infection. *J Nutr* 2003;133:316S–21S.
30. Waterlow JC. Fatty liver disease in infants in the British West Indies. *Medical Research Council Special Report Series 263*. London: His Majesty's Stationery Office, 1948.
31. Scrimshaw NS, Béhar M. Malnutrition in underdeveloped countries. *N Engl J Med* 1965;272:137–44, 193–8. INCAP I-360.
32. Gómez F, Galván R, Frenk S, Cravioto J, Chávez R, Vásquez J. Mortality in second and third degree malnutrition. *J Trop Pediatr* 1956(2):77–83.
33. Burch HB, Arroyave G, Schwartz R, Padilla AM, Béhar M, Viteri F, Scrimshaw NS. Biochemical changes in liver associated with kwashiorkor. *J Clin Invest* 1957;36:1579–87.
34. Viteri FE. INCAP studies of hematologic and gastrointestinal function in healthy individuals and those with protein-energy malnutrition and infection. *Food Nutr Bull* 2010;31:130–40.
35. Viteri F. Functional and health consequences of nutritional anemia and iron, iodine and vitamin A deficiencies. In: Gueri M, Viteri F, eds. *Report of the II Subregional Workshop on the Control of Nutritional Anemias and Iron Deficiency*. United Nations

- University/Pan American Health Organization/World Health Organization/Fundación Cavendes, 1996: 29–35.
36. Jelliffe D, Bras G, Stuart K, Kwashiorkor and marasmus in Jamaican infants. *West Indian Med J* 1954;3(1):43–45.
  37. Brock JF. Dietary protein deficiency. *Ann Intern Med* 1960;64:1170.
  38. Czerny A, Keller A. Des Kindes Ernährung, Ernährungsstörungen und Ernährungstherapie. *Ein Handbuch für Ärzte*, 2. Leipzig and Wein: 1923–5.
  39. Alvarado J, Viteri FE, Béhar M. Tratamiento hospitalario de la desnutrición proteínico-calórica severa. *Rev Col Med Guatem* 1971;21:231–45. Also published as: El problema de la desnutrición proteínico-calórica en el Istmo Centroamericano. INCAP Monografía No. 7, 1971:231–45.
  40. Viteri FE, Torún B. Protein-calorie malnutrition. In: Goodhart R, Shils M, eds. *Modern nutrition in health and disease*. Philadelphia, Pa, USA: Lea & Febiger, 1980:697–720.
  41. Garn SM, Rohmann CG, Béhar M, Viteri F, Guzmán MA. Compact bone deficiency in protein-calorie malnutrition. *Science* 1964;145:1444–5.
  42. Viteri F, Alvarado J. The creatinine height index: its use in the estimation of the degree of protein depletion and repletion in protein calorie malnourished children. *Pediatrics* 1970;46:696–706.
  43. Viteri F, Alvarado J. Body composition and oxygen consumption in protein-calorie malnourished children and during recovery. *Am J Clin Nutr* 1970;23:675–6.
  44. Viteri F. Creatinine-height index in malnourished children. *Nutr Rev* 1972;30:24–6.
  45. Viteri FE. Primary protein-energy malnutrition: clinical, biochemical and metabolic changes. In: Suskind R, ed. *Pediatric nutrition*. New York: Raven Press, 1981:189–215.
  46. Nichols BL, Alvarado J, Hazlewood CF, Viteri F. Clinical significance of muscle potassium depletion in protein-calorie malnutrition. *J Pediatr* 1972;80:319–30.
  47. Nichols BL, Alvarado J, Rodriguez J, Hazlewood CF, Viteri F. Therapeutic implications of electrolyte, water, and nitrogen losses during recovery from protein-calorie malnutrition. *J Pediatr* 1974;84:759–68.
  48. Nichols B, Alvarado J, Kimzey S, Hazlewood C, Viteri F. Anomalies of the regulation of salt and water in protein calorie malnutrition. In: Gardner LI, Amacher P. *Endocrine aspects of malnutrition: marasmus, kwashiorkor and psychosocial deprivation*. Santa Inez Valley, Calif, USA: Kroc Foundation, 1973:363–98.
  49. Nichols B, Viteri F. On the pathogenesis of deranged nitrogen metabolism in protein calorie malnutrition. *J Pediatr* 1975;86:650–1.
  50. Nichols B, Bilbrey G, Hazlewood C, Kimzey S, Liu C, Viteri FE, Alvarado J, Beisel WR. Sequential changes in body composition during infection. *Electron probe study*. *Am J Clin Nutr* 1977;30:1439–46.
  51. Nichols BL, Alvarado J, Hazlewood CF, Viteri F. Magnesium supplementation in protein-calorie malnutrition. *Am J Clin Nutr* 1978;31:176–88.