European Journal of Clinical Nutrition (2016) 70, 647–649
© 2016 Macmillan Publishers Limited All rights reserved 0954-3007/16
www.nature.com/ejcn

EDITORIAL

Stunted growth

European Journal of Clinical Nutrition (2016) **70,** 647–649; doi:10.1038/ejcn.2016.47

Evidence that body height is determined by socioeconomic circumstances can be traced back to Louis René Villermé (1782–1863), a French hygienist who used data collected by the military services of the French army in 1812 and 1813, and the report to the Minister of War in 1817. In 1829 (cited by Boyd[1]), he published that 'the stature of man becomes higher, and growth is completed earlier, all things being equal, when the country is rich, and comfort widespread; when clothing and especially food are good, and when difficulties, fatigues and privations experienced in childhood and youth are few. In other words, poverty, that is to say the circumstances accompanying it, produces short stature and retards the period of complete development of the body'. Even though Villermé did not literally mention health status, the terms 'difficulties, fatigues and privations' may be interpreted in this sense. The significance of his words has remained relevant since. In the second half of the 19th century, the laws of genetics became apparent completing the four basic conditions known to us for appropriate human growth—genetics, nutrition, health, and the psycho-social and economic circumstances. Maternal health and prenatal development have recently been added as additional conditions for appropriate growth and later health. In 2013, Christian *et al.*[2] summarised evidence that low birthweight was associated with 2.5–3.5-fold higher odds of wasting, stunting and underweight. The population attributable risk for overall small-for-gestational age (SGA) for outcomes of childhood stunting and wasting was shown to be 20 and 30%, respectively.

Villermé's statement 'poverty, that is to say the circumstances accompanying it, produces short stature' is valid. Ample evidence suggests that, at the population level, the association between stature and poverty is statistically significant. This has prompted the assumption that shortness of stature may be an appropriate tool for detecting poverty and accompanying circumstances, and that improvements in growth may be valid indicators for the efficacy of health and nutrition interventions. Yet, we feel that such assumptions may still be premature.

Shortness of stature is relative. Defining shortness requires a reference. However, which reference is appropriate? The World Health Organization (WHO) designed a Multicentre Growth Reference Study, a community-based, multi-country project, performed on populations raised under conditions favourable to growth, that is, single-term birth, appropriate feeding, with no apparent health or environmental constraints on growth, such as maternal smoking or significant morbidity.[3] The design combined a longitudinal study from birth to 24 months with a cross-sectional study of children aged 18–71 months.[4] The design is based on a selected population raised under favourable conditions and thus no longer describes how children grow (descriptive reference), but how children should grow (prescriptive standard) if raised under optimum circumstances. By April 2011, already 125 countries had adopted these *prescriptive* standards. Weight-for-age was adopted almost universally, followed by length/height-for-age (104 countries) and weight-for-length/height (88 countries) to optimally realise 'the children's right to achieve their full genetic growth potential'.[5]

Yet, many of these countries are populated by people who greatly differ in height and weight from these references. Following United Nations Children's Emergency Fund (UNICEF) definition of stunting as height below minus two s.d.'s from median height for age, Prendergast and Humphrey[6] summarised evidence of a 'stunting syndrome' in developing countries and claimed that linear growth failure is the most common form of undernutrition globally, with an estimated 165 million children below 5 years of age affected. They identified stunting as a major public health priority. In 2013, Black *et al.*[7] showed that the prevalence of stunting of children younger than 5 years has decreased in recent decades, but is still higher in south Asia and sub-Saharan Africa than elsewhere. For example, in Indonesia, based on a multistage cluster sample of 497 districts (urban and rural) of 33 provinces, including 2 94 959 household with 1 027 763 household members, the average prevalence of stunting in children below age 5 years was 36.8% in 2007 and 37.2% in 2013. Average height was − 12.5 cm below WHO reference in 18-year-old males and − 9.8 cm in 18-year-old females (Madarina Julia, Jogjakarta, Indonesia, personal communication 2016). These numbers and the estimated costs of undernutrition and micronutrient deficiencies of some 2.1 trillion US dollars (http://www.fao.org/zhc/detail-events/en/c/238389/) underscore the need of world-wide efforts in combating these conditions.

Haddad *et al.*[8] recently summarised the actions and accountability to accelerate the world's progress on nutrition, but in spite of world-wide efforts the efficacy of nutrition interventions has been questioned. Already in 2001, Uauy *et al.*[9] observed that providing food to low-income stunted populations may be beneficial for some, but 'it may be detrimental for others' and induce obesity especially in urban areas. In a 2005 Cochrane Database Systematic Review, Sguassero *et al.*[10] reported a positive effect on length (cm) in a nutrition-supplemented group compared with controls (weighted mean differences 1.3 (0.03–2.57)) after 12 months of intervention conducted in Jamaica ($n = 65$ children). However, they found no similar benefit in growth after 12 months of supplementation in a trial from Indonesia ($n = 75$ children). In 2012, the same authors[11] meta-analysed community-based supplementary feeding in children under 5 years of age in low- and middle-income countries and concluded that although the scarcity of available studies still made it difficult to reach firm conclusions— there is a need for additional studies —supplementary feeding has a negligible impact on child growth. Kristjansson *et al.*[12] showed in randomised controlled trials in socioeconomically disadvantaged children that even these children when supplemented only grew an average of 0.27 cm more over 6 months than those who were not supplemented. In a meta-analysis of seven controlled before-and-after studies, they found no evidence of an effect on height, whereas meta-analyses of randomised controlled trials demonstrated benefits for weight-for-age *z*-scores.

These data question a strict association between stunting and undernutrition. More evidence for a lack of such an association is found in historic material. The general shortness of body stature in 18th and 19th century upper class Europeans is very difficult to explain. Up to 50% of the 7–18-year-old students of a 18th century elite school (Karlsschule, Stuttgart[13–15]) and sons of the wealthy upper-class Hamburg society of the second half of the 19th century,[16] students of ancient languages and humanity were stunted according to modern criteria (Figure 1). Only students from royal families appear to have nearly reached modern average height. Scientific food protocols from those days are not available, but anecdotal evidence questions that undernutrition may have

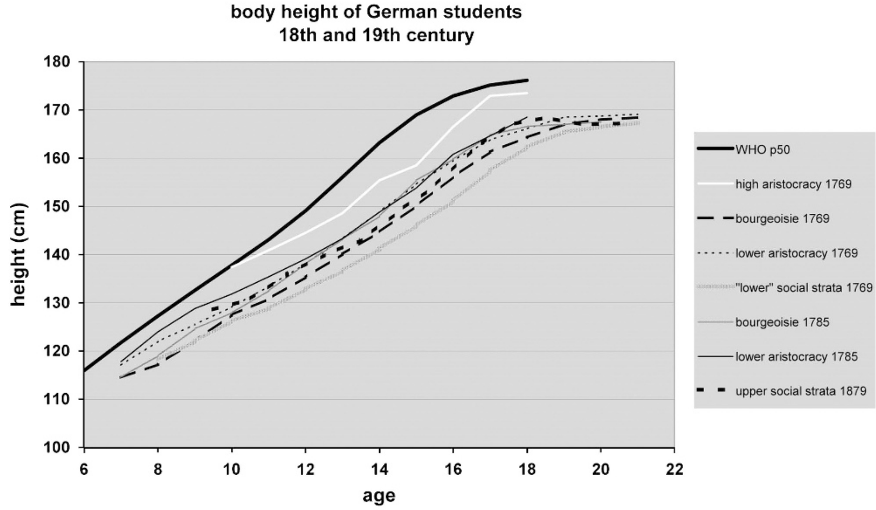

Figure 1. Mean values of historic body height. Measurements were performed in two German elite schools in 1769 (Karlsschule, Stuttgart: students from high aristocracy ($N=91$), bourgeoisie ($N=3808$), lower aristocracy ($N=2590$) and 'lower' social strata ($N=1557$)), in 1785 (Karlsschule, Stuttgart: students from bourgeoisie ($N=806$) and lower aristocracy ($N=566$))[13–15] and in 1879 (Johanneum, Hamburg: 'upper' social strata ($N=509$)).[16] The term 'lower' social strata of 1769 Karlsschule students was not well defined and possibly differs from a modern perception of lower social strata; the term 'upper' social strata of Johanneum students refers to the well-educated, wealthy urban society. Except for students from royal families, body height ranged up to 20 cm below modern WHO references.[3]

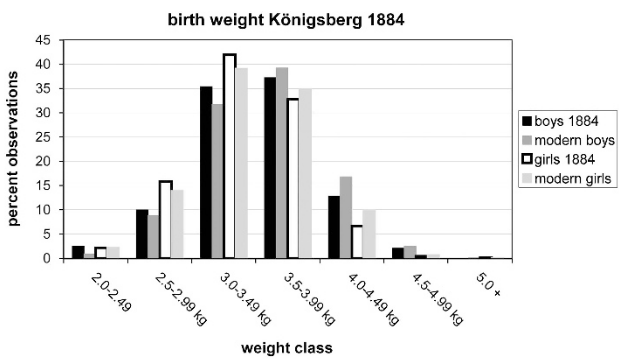

Figure 2. Birthweight in 500 g classes obtained from historic healthy newborns (released from hospital 7–14 days after birth) from Königsberg, Prussia and Germany 1884.[17] Modern German birthweights[18] are added for comparison. The percentages of small-for-gestational-age newborns (<2.5 kg) are apparently similar.

accounted for the shortness in height. Similarly, chronic health impairment may hardly be made responsible for the growth impairment in these social circles. Figure 2 illustrates that also SGA was not an issue, at least not in late 19th century birth cohorts. Healthy newborns from Königsberg, Prussia and Germany[17] were only slightly lighter than modern German newborns,[18] with no evidence of a significant portion of SGA infants.

Why have these people been so short, and why are so many children in the developing countries still so short? Are they really too short, or do they need a 'historically appropriate' growth chart to be referred to? The present collection of seven manuscripts tries to bring us closer to an understanding of the complicated interactions between growth, nutrition, living condition and the appropriateness of currently used charts.

First of all, it is obvious that more data are needed. 'Deep data' are an issue. Ines Varela-Silva and co-workers introduce a large, longitudinal, intergenerational database on Maya people, a population where 50% of infants and children are stunted—in some rural Maya regions the portion may even be $>70\%$—and discuss the impact of such an approach.

The provision of large databases is essential to use the analytical potential of existing data sets and collections. Christian Aßmann discusses multiple imputation as one tool to provide access to existing data sets in case data protection issues need to be addressed. Given that long-term data access is established, existing data sets can be used for reanalysis when new modelling approaches become available or comparison with new data is useful. Marcel Preising and co-workers present a statistical approach towards model comparison that allows for addressing missing values typically occurring in longitudinal studies on height and weight. The approach is illustrated within hierarchical linear regression models.

Modern discussions on growth and nutrition usually exclude the historic perspective. Historic data are difficult to obtain—one has to rely on documented information, with methodological problems, sample biases and an overall uncertainty about data structure and representativity—but historic data need an audience. Vincent Tassenaar and Erwin H Karel exemplify the association between body stature and living conditions in rural non-Jewish and Jewish Dutch conscripts of the 19th century in a fascinating collection of anthropometric, demographic, economic and social data. They show the impact of religion on height; they even found a significantly stimulatory effect of parental absence on height in the Jewish community, which certainly contrasts common expectations about growth of orphan children. Growth as a matter of psychology, rather than a matter of food?

Rebekka Mumm and co-workers meta-analysed a set of 833 growth studies from 78 countries published between 1920 and 2013. Using multiple regressions for the interactions between weight, sex, historic year of study, continent and within-study s.d. at age 2 and 7 years, they were able to show marked discrepancies between the within-population variation in height and the within-population variation in weight, indicating that height and weight are subject to different regulations.

Similar results were obtained by Nowak-Szczepanska and co-workers when reinvestigating the variation in height and body mass index in Polish children between 1966 and 2012, a period when Poland had undergone vast political and socioeconomic changes. They conclude that body mass index is affected by the quality of life and that height is differently regulated.

© 2016 Macmillan Publishers Limited

Historic material is retrospective. Envisaging studies in historic data is apparently absurd. Yet, the last manuscript tries to overcome this classic dilemma by introducing an approach that is known as Monte Carlo simulation. Monte Carlo simulations are used in social sciences, in game theory and in general equilibrium theory.[19] Instead of asking 'does a certain effect exist in a historic set of data?' we can use this approach to ask 'what would be the consequences if such an effect exists in an artificial society?' Monte Carlo simulations have never been used in growth and nutrition research. However, it is a fascinating tool, and when applied in historic data it may be viewed as a tool for quasi-prospective studies: we estimate 'what could have been possible'. Certainly future studies are needed to evaluate the benefit of this methodology for the study of growth.

The seven manuscripts are far from offering final answers to the complex network of nutrition, health, environment and psychology on the one hand, and child growth and development on the other. However, they question concepts. The association between nutrition and growth is clearly less obvious than generally assumed. There is not such a thing as one global growth standard applicable to everybody on this globe. Growth consists of highly flexible patterns of height and weight increments. They do not only depend on genetics, prenatal development, nutrition, health and economic circumstances but reflect social interactions—within a given ethnic group and within a given historic window—to a much stronger degree than hitherto assumed. These manuscripts try to target the complexity of this field. They are intended to question current thought patterns and to stimulate young researches to try new intellectual paths and to play with new scientific tools.

CONFLICT OF INTEREST

The author declares no conflict of interest.

M Hermanussen
Department of Pediatrics, University of Kiel, Kiel, Germany
E-mail: michael.hermanussen@gmail.com

REFERENCES

1 Boyd E. *Origins of the Study of Human Growth*. University of Oregon Health Science Foundation: Eugene, OR, USA, 1980.
2 Christian P, Lee SE, Donahue Angel M, Adair LS, Arifeen SE, Ashorn P *et al.* Risk of childhood undernutrition related to small-for-gestational age and preterm birth in low- and middle-income countries. *Int J Epidemiol* 2013; **42**: 1340–1355.
3 de Onis M, Garza C, Victora CG, Onyango AW, Frongillo EA, Martines J. The WHO Multicentre Growth Reference Study: planning, study design, and methodology. *Food Nutr Bull* 2004; **25**: S15–S26.
4 Garza C, de Onis M. Rationale for developing a new international growth reference. *Food Nutr Bull* 2004; **25**: S5–S14.
5 de Onis M, Onyango A, Borghi E, Siyam A, Blössner M, Lutter C. Worldwide implementation of the WHO Child Growth Standards. *Public Health Nutr* 2012; **15**: 1603–1610.
6 Prendergast AJ, Humphrey JH. The stunting syndrome in developing countries. *Paediatr Int Child Health* 2014; **34**: 250–265.
7 Black RE, Victora CG, Walker SP, Bhutta ZA, Christian P, de Onis M *et al.* Maternal and child undernutrition and overweight in low-income and middle-income countries. *Lancet* 2013; **382**: 427–451.
8 Haddad L, Achadi E, Bendech MA, Ahuja A, Bhatia K, Bhutta Z *et al.* The Global Nutrition Report 2014: actions and accountability to accelerate the world's progress on nutrition. *J Nutr* 2015; **145**: 663–671.
9 Uauy R, Albala C, Kain J. Obesity trends in Latin America: transiting from under- to overweight. *J Nutr* 2001; **131**: 893S–899S.
10 Sguassero Y, de Onis M, Carroli G. Community-based supplementary feeding for promoting the growth of young children in developing countries. *Cochrane Database Syst Rev* 2005; **4**: CD005039.
11 Sguassero Y, de Onis M, Bonotti AM, Carroli G. Community-based supplementary feeding for promoting the growth of children under five years of age in low and middle income countries. *Cochrane Database Syst Rev* 2012; **6**: CD005039.
12 Kristjansson E, Francis DK, Liberato S, Benkhalti Jandu M, Welch V, Batal M *et al.* Food supplementation for improving the physical and psychosocial health of socio-economically disadvantaged children aged three months to five years. *Cochrane Database Syst Rev* 2015; **3**: CD009924.
13 Komlos J. Height and social status in eighteenth-century Germany. *J Interdiscipl Hist* 1990; **20**: 607–621.
14 Komlos J. Körpergröße und soziale Stellung von Schülern der Hohen Karlsschule im 18. *Jahrhundert Scr Mercaturae* 1996; **30**: 95–120.
15 Komlos J, Tanner JM, Davies PS, Cole T. The growth of boys in the Stuttgart Carlschule, 1771-93. *Ann. Hum. Biol.* 1992; **19**: 139–152.
16 Kotelmann L. *Die Körperverhältnisse der Gelehrtenschüler des Johanneums in Hamburg: Ein statistischer Beitrag zur Schulhygiene*. Zeitschrift des Königlich Preussischen statistischen Bureau's: Berlin, Germany, 1879.
17 Wagner G, Beobachtungen über Gewicht und Maasse der Neugeborenen. Diss 1884. Königsberg in Preußen. R. Leupold, 1884.
18 Voigt M, Friese K, Schneider KTM, Jorch G, Hesse V. Kurzmitteilung zu den Perzentilwerten für die Körpermaße Neugeborener. *Geburtsh Frauenheilk* 2002; **62**: 274–276.
19 Epstein JM, Axtell R. *Growing Artificial Societies*. Brookings Institution Press: Washington, DC, USA, 1996.

© 2016 Macmillan Publishers Limited