This review paper explores linear proportionality and its relation to health and socio-economic conditions. We review and critically examine medical, epidemiological and historical studies that have explored linear proportionality, its determinants, historical trends, and its association with health outcomes. While there are several methods for measuring proportionality in humans, this paper focuses on linear two-dimensional proportionality, the comparative dimensions of two linear segments of the human body, and specifically on the proportion between sitting and standing height, which reflects the relative lengths of legs and trunk.

Proportionality is influenced by gender, genetic endowments, age, stature and maturation. Males tend to be relatively more long-legged than females. There is some evidence from studies of twins that the size of individual body segments is highly heritable (Chatterjee et al., 1999). Several studies have reported important ethnic differences in proportionality (Palomino et al., 1978; Malina et al., 1987; Eveleth and Tanner, 1990). There is some evidence that climate may also have some effects on body proportions (Katzmarzyk and Leonard, 1998). However, it is difficult to disentangle genetics from nutrition and environment, since the interaction between genetic makeup and the environment is complex and non-additive (Rogol, Roemmich and Clark 2002:193).

Linear proportions change considerably throughout life. Babies have relatively short limbs and a bigger head as compared to adults. Before puberty, the legs grow faster than the trunk, whereas the trunk grows faster during puberty (Gasser et al., 1991). Leg length is especially sensitive to environmental factors and diet. Trunk growth on the other hand seems especially sensitive to serious illness and stress. The timing of puberty can influence adult proportionality, with individuals who experience puberty early having relatively shorter legs. Among persons of the same age and sex, those who are taller are relatively more long-legged than those who are shorter.

Adult proportionality is not fixed. A decrease in adult stature starts before the age of 40, possibly already after age 25, with females experiencing decreases at a greater rate than males (Chandler and Bock,1991). The principal mechanism underlying these stature declines in adults is shortening of the spine. Hence, stature decreases due to ageing entail increasing relative long-leggedness.

Secular trends in proportionality

Most populations on which long-term anthropometric measures have been collected have become taller and fatter since mid-19th century (Malina, 1990; Hauspie et al., 1997). The trend is generally attributed to better nutrition and living conditions and is leveling off in developed countries (Padez 2002:39; Sanna and Soro 2000:782). Secular trends in linear proportions have been characterized by different secular changes for different linear segments of the body. Several investigators have reported that, as part of the secular increases in stature, leg length increases much more than sitting height or stature (Udjus, 1964; Tanner et al., 1982; Gonzales et al., 1984; van Wieringen, 1986; Sanna and Soro, 2000). A Harvard study (Bowles 1932) of adult American men between 1840 and 1930 reported the development of relatively longer legs among men compared with their fathers. On the other hand, arms became relatively shorter in relation to total height. The observed secular increase in height was mostly due to the increase in leg length, which, in turn, was due to an increase in the length of the thigh, not knee height.

Meadows and Jantz (1995) find that upper limbs are isometric, keeping constant proportions with stature, whereas lower limbs are positively allometric, becoming relatively longer with increasing stature. They show that these trends follow the secular trend in stature closely.

We can ascribe the trend to long-leggedness, as the trend to increased stature, largely to changes in nutrition and socio-economic conditions. Since it may take several generations before improved conditions lead to full expression of the genetic growth potential, observed secular trends may have been triggered by improvements in conditions decades before. The mechanisms by which secular changes in nutrition and socio-economic conditions affect proportionality might be more intricate than is generally appreciated (Roche, 1979; Wolanski, 1994). Alternative explanations often turn to genetics. For example, it has been argued that the observed changes in proportionality could results from changing patterns of assortative mating (Wolanski, 1994; Hasstedt, 1995), or from the decreasing isolation of genetic groups (Little and Malina, 1986; Little et al., 1988).

Public health importance

Linear proportionality is an issue that cannot be ignored in public health. Congenital or acquired proportionality disorders are not rare and can substantially affect health, development and wellbeing. It has been shown that proportions in growth are greatly affected by resources, energy intake, and environmental conditions. Hence, health outcomes related to environmental conditions during childhood may be strongly associated with leg length and body proportions. Recent work reveals that childhood leg length shows a stronger association than overall height with adult mortality from cancers and coronary heart disease (Gunnell et al., 1998a; Gunnell et al., 1998b). A better understanding of the associations between linear proportionality and health outcomes may help identify health problems and motivate appropriate early interventions.

Conclusions

Much remains to be learned about the determinants of body proportions, and especially about the interplay between stimulating and inhibiting factors of leg growth, trunk growth, and timing of puberty. We present evidence that long bone lengths or limb lengths and their relative proportions are suitable indicators for the study of human growth, its environmental and genetic determinants, and the long-term health outcomes associated with it.

References

Bowles GT. New Types of Old Americans at Harvard. Harvard University press, Cambridge, massachusetts, 1932.

Chatterjee S, Das N, Chatterjee P. The estimation of the heritability of anthropometric measurements. Appl Hum Sci 1999;18:1-7.

Eveleth PB, Tanner JM. World-wide variation in human growth, 2nd edition, Cambridge University Press, Cambridge, 1990, pp.185-189.

Gasser T, Kneip A, Binding A, Prader A, Molinari L. The dynamics of linear growth in distance, velocity and acceleration. Ann Hum Biol 1991;18:187-205.

Gonzales GF, Valera J, Rodriguez L, Vega A, Guerra-Garcia R. Secular change in growth of native children and adolescents at high altitude Huancayo, Peru (3,280 meters). Am J Phys Anthropol 1984;64:47-51.

Gunnell DJ, Davey Smith G, Frankel S, Nanchahal K, Braddon FE, Pemberton J, Peters TJ. Childhood leg length and adult mortality: follow-up of the Carnegie (Boyd Orr) survey of diet and health in pre-war britain. J Epidemiol Community Health 1998a;52:142-152.

Gunnell DJ, Davey Smith GD, Holly JMP, Frankel S. Leg length and risk of cancer in the Boyd Orr cohort. Brit Med J 1998b;317:1350-1351.

Hasstedt SJ. Phenotypic assortative mating in segregation analysis. Genetic Epidemiol 1995;12:109-127.

Hauspie RC, Vercauteren M, Susanne C. Secular changes in growth and maturation: an update. Acta Paediatr 1997;423:20-27.

Katzmarzyk PT, Leonard WR. Climatic influences on human body size and proportions: ecological adaptations and secular trends. Am J Phys Anthropol 1998;106:483-503

Little BB, Malina RM, Buschang PH. Increased heterozygosity and child growth in an isolated subsistence agricultural community in the valley of Oaxaca, Mexico. Am J Phys Anthropol 1988;77:85-90.

Malina RM. Research on secular trends in auxology. Anthropol Anz 1990;48:209-227.

Malina RM, Brown KH, Zavaleta AN. Relative lower extremity length in Mexican American and in American black and white youth. Am J Phys Anthropol 1987;72:89-94

Meadows L, Jantz RL. Allometric secular change in the long bones from the 1800s to the present. J Forensic Sci 1995;40:762-767.

Padez, C. Stature and Stature Distribution in Portughese Male Adults 1904-1998: The Role of Environmental Factors. Am J Hum Biol 2002; 14:39-49.

Palomino H, Mueller WH, Schull WJ. Altitude, heredity and body proportions in northern Chile. Am J Phys Anthropol 1978;50:39-50.

Roche AF. Secular trends in human growth, maturation and development. Monogr Soc Res Child Dev 1979;44:1-120.

Rogol AD, Roemmich, JN, Clark, PA. Growth at Puberty. Journal of Adolescent Health 2002; 31:192-200

Sanna E, Soro MR. Anthropometric changes in urban Sardinian children 7 to 10 years between 1975-1976 and 1996. Am J Hum Biol 2000;12:782-791.

Tanner JM, Hayashi T, Preece MA, Cameron N. Increase in length of leg relative to trunk in Japanese children and adults from 1957 to 1977: comparison with British and with Japanese Americans. Ann Hum Biol 1982;9:411-423.

Udjus LG. Anthropometrical Changes in Norwegian Men in the Twentieth Century. Universitetsforlaget, Oslo, 1964.

van Wieringen JC. Secular Growth Changes. In: F Falkner and JM Tanner eds. Human Growth: a Comprehensive Treatise, vol 3. New York, Plenum Press, 1986, pp.307-331.

Wolanski N. Assortative mating in somatic traits and its consequences. Studies in Human Ecology 1994;11:73-111.