Introduction

It is the purpose of this book to describe and interpret some of the evolutionary, physiological, cultural, and mathematical patterns of human growth. Given this purpose, the title of this book requires some explanation. A cell biologist might think of the phrase 'patterns of growth' in terms of a series of genetically controlled cell duplication and division events. An embryologist might think of patterns of cell differentiation and integration leading to the development of a functionally complete human. The clinician interprets patterns of growth, especially deviations from expected or 'normal' growth, as evidence of disease or other pathology in the patient. All of these concepts of 'pattern' may be biologically valid and useful in their own areas of specialization, but this book is about none of them. The goal of this account is to consider the growth of the human body in a unified and holistic manner. The result, it is hoped, will be a synthesis of the forces that shaped the evolution of the human growth pattern, the biocultural factors that direct its expression in populations of living peoples, the intrinsic and extrinsic factors that regulate individual development, and the biomathematical approaches needed to analyze and interpret human growth.

The study of human growth in relation to evolutionary biology, biocultural factors, intrinsic and extrinsic factors, such as genes, hormones, the physical and social environment, and mathematics may seem like a strange brew of topics. In fact, it is a common mix for biological anthropologists. The rest of this book is designed to show the reader that the anthropological blend of scholarship and research is, in fact, a practical and rewarding combination.

Introductory students of human growth often assume that the field is primarily a part of pediatric medicine. Indeed, until the publication of the first edition of *Patterns of Human Growth* in 1988, all but one of the leading introductory texts were written by physicians, and were written with the medical student in mind, or as a practical guide for parents. The one exception is the book *Child Growth* (Krogman, 1972), written by a biological anthropologist, but focused primarily on pediatric topics. While it may seems logical for human growth to be a subfield of medicine, it is more accurate, however, to view pediatric medicine and 'parenting' as subfields

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of the study of human growth. In turn, human growth is a part of a much broader discipline, namely anthropology. A little bit of history, and an applied example, are provided here to justify this statement. Chapter 1 includes a more detailed history of the study of human growth.

Anthropology and growth

The study of human growth has been a part of anthropology since the founding of the discipline. European anthropology of the early to mid-nineteenth century was basically anatomy and anthropometry, the science of human body measurements (Malinowski & Wolanski, 1985). Early practitioners of American anthropology, especially Franz Boas, are known as much for their studies of human growth as for work in cultural studies, archaeology, or linguistics. Boas was especially interested in the changes in body size and shape following migration from Europe to the United States. At the time of those studies, around 1910, most anthropologists and anatomists believed that stature, and other measurable dimensions of the body such as head shape, could be used as 'racial' markers. The word 'race' is set in inverted commas here because it refers to the scientifically discredited notion that human beings can be organized into biologically distinct groups based on **phenotypes**[1] (the physical appearance and behavior of a person). According to this fallacious idea, northern European 'races' were tall and had relatively long and narrow heads, while southern European races were shorter and had relatively round skulls. Boas found that, generally, the children of Italian and Jewish European migrants to the United States were significantly taller and heavier than their parents. The children of the migrants even changed the shape of their heads; they grew up to have long narrow heads.

In the new environment of the United States, the children of recent southern European migrants grew up to look more like northern Europeans than their own parents. Boas used the changes in body size and shape to argue that environment and culture are more important than genes in determining the physical appearance of people. In terms of environment, life in the United States afforded better nutrition, both in terms of the quantity and the variety of food. There were also greater opportunities for education and wage-paying labor. These nutritional and socioeconomic gains are now known to correlate with large body size. In terms of culture, in particular child-rearing practices, there were other

[1] Formal definitions for all words in bold type are found in the Glossary.

changes. In much of Europe infants were usually wrapped up tightly and placed on their backs to sleep, but the American practice at the turn of the century was to place infants in the prone position. In order to be 'modern' the European immigrant parents often adopted the American practice. One effect on the infant was a change in skull shape, since pressure applied to the back of the infant's skull produces a rounder head, while pressure applied to the side of the skull produces a longer and narrower head. The sleeping position effect on skull shape was demonstrated first in Europe by Walcher (1905).

The work of Boas and his colleagues, shows that an interest in human growth is natural for anthropologists. This is because the way in which a human being grows is the product of an interaction between the biology of our species, the physical environment in which we live, and the social/economic/political environment that every human culture creates. Moreover, the basic pattern of human growth is shared by all living people. That pattern is the outcome of the four million year evolutionary history of the **hominids**, living human beings and our fossil ancestors. Thus, human growth and development reflect the biocultural nature and evolutionary history of our species.

Maya in Disneyland

The biocultural nature of human growth may be appreciated by the following example based on my own research in Guatemala and the United States on the impact of the economic and political environment on the growth and development of Maya children (Bogin & Loucky, 1997). Two samples of Maya are compared; one a group living in their homeland of Guatemala, and the other a group of migrants living in the United States. Both groups include individuals between the ages of 5 and 14 years old. The Guatemala sample live in a village with an irregular supply of water, no safe drinking water, and unsanitary means for waste disposal. The parents of these Maya children are employed, predominately, as tailors or seamstresses by local clothing manufacturers and are paid minimal wages. There is one public health clinic in the village, which administers treatment to infants and preschool children with clinical undernutrition – an omnipresent problem. The incidence of infant and childhood morbidity and mortality from infectious disease is relatively high. Deaths due to political repression, especially the civil war of late 1970s to early 1980s, is common for the Maya of Guatemala. The residents of this particular Maya village were caught up in the military hostilities of that time, but escaped the worst of the civil war. They also suffered from reduced food availability due to the collapse of the Guatemalan economy during the 1980s (Bogin, 1998).

The United States sample reside in two places, Indiantown, a rural agricultural community in central Florida, and Los Angeles, California (hence the title for this section 'Maya in Disneyland'). The political status of the Maya in the USA is heterogeneous. Some have applied for, and a few have won, political asylum. Others have temporary legal rights to reside and to work, but many remain undocumented. Adults in the Florida community work as day laborers in agriculture, landscaping, construction, child care and other informal sector jobs. Many of the Los Angeles Maya work in the 'sweatshops' of the garment industry, although a few have jobs in the service sector or technical professions.

The growth in height, weight and body composition of Maya children and youths living in Guatemala is significantly retarded compared with United States National Center for Health Statistics (NCHS) reference data.[2] Figure I.1 illustrates the mean height and weight of the Guatemalan Maya from the village of San Pedro during two time periods. Some researchers argue that the small size and delayed maturation of malnourished populations such as the Maya is a genetic adaptation to their poor environmental conditions. If this argument were true, then a change in the economic, social, or political environment would not influence growth. The notion that the small size of the Maya is primarily genetic is clearly wrong, for as also shown in Figure I.1, the United States-living Maya are significantly taller and heavier than Maya children living in Guatemala. The Maya in the United States attain virtually the same weight as the NCHS sample. The average increase in height is 5.5 cm between Maya in the United States versus Maya in Guatemala. This increase occurred within a single generation, that is, as children moved from Guatemala to the United States. Moreover, the change in average stature is, perhaps, the largest such increase ever recorded. By contrast, the immigrant children measured by Boas averaged about 2.0 cm taller than their European-born parents.

The reason for the increase in body size of the Maya children is the same as for the European immigrant children measured by Boas. In the United States there is both more food and a greater variety of food than in rural

[2] NCHS reference data represent the growth status of a healthy, well-nourished population from the United States in the year 1977. These reference data are recommended by the World Health Organization for the evaluation of human growth for all populations so as to provide a common baseline for international comparison. The NCHS reference data are used throughout this book for all such comparisons.

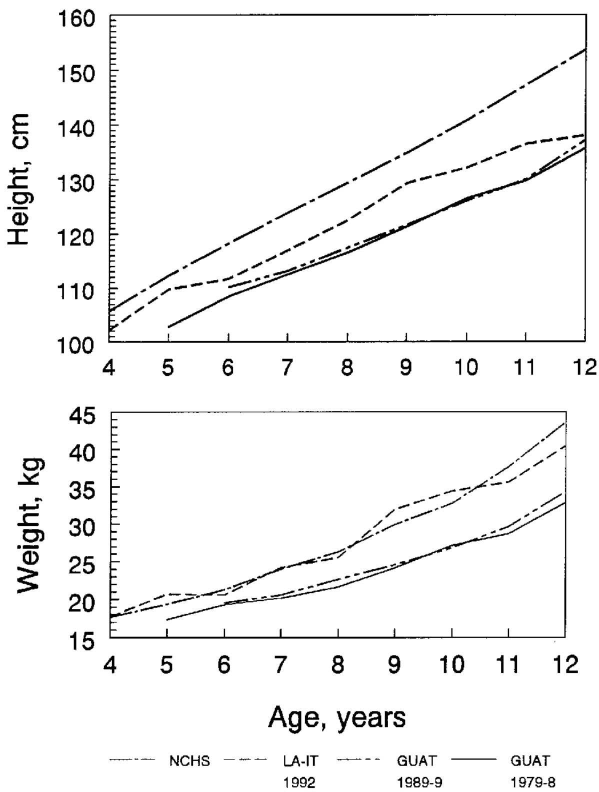

Figure I.1. The mean height, or weight, by age of the Los Angeles and Indiantown Maya sample (LA-IT), the Maya samples from Guatemala measured in 1979–80 and 1989–90 (GUATE), and the NCHS reference data. The NCHS references were developed by the United States National Center for Health Statistics, and represent the growth of healthy, well-nourished children. Data for boys and girls within all samples are combined. Note that there is virtually no change in the mean size of the Guatemala-living Maya. This indicates that the generally poor environmental conditions for growth remained unchanged for that decade. The Maya in the USA are significantly larger than Maya in Guatemala.

Guatemala. In the USA there are also social services that are unavailable in rural Guatemala, including health care, food supplementation programs, schools, job training programs. All of these differences improve the biological and social environment for human growth. The most important differences, however, are safe drinking water and the conditions that go with less political repression. The public supply of safe drinking water in the

USA eliminates the constant exposure to bacteria, parasites, agricultural pesticides, and fertilizers that contaminate drinking water in rural Guatemala. The relative political freedom for Maya in the USA allows parents to pursue their goals for the healthy growth and development of their children. In 1977, Robert LeVine, an anthropologist of the family and of children, proposed a universal evolutionary hierarchy of human parental goals. The primary goal is to encourage the survival and the health of a child. Secondary goals relate to developing the child into a self-supporting adult and instilling cultural beliefs and behavioral norms. Economic and political conditions in Guatemala make it difficult for parents to achieve these goals for their children. The political economy of the United States offers real possibilities for success, and Maya parents seize upon these, just as other immigrants have done before them.

As Boas argued for nearly 50 years, the study of human growth provides a mirror of the human condition. Reflected in the patterns of growth of human populations are the 'material and moral conditions of that society' (Tanner, 1986, p. 3). The forces holding back growth in Guatemala are severe indeed, and the growth differences between Maya of Guatemala and the United States may be used as a measure to assess the magnitude of change in political and socioeconomic conditions.

Growth and evolution

The pattern of human growth serves as another type of mirror; one that reflects the biocultural evolution of our species. **Biological evolution** is the continuous process of genetic adaptation of organisms to their environments. **Natural selection** determines the direction of evolutionary change and operates by **differential mortality** between individual organisms prior to reproductive maturation and by **differential fertility** of mature organisms. Thus, genetic adaptations that enhance the survival of individuals to reproductive age, and that increase the production of similarly successful offspring, will increase in frequency in the population over time.

Human biocultural evolution produced the pattern of growth and development that converts a single fertilized cell, with its complement of **deoxyribonucleic acid (DNA)** into a multicellular organism composed of hundreds of different tissues, organs, behavioral capabilities, and emotions. That process is no less wondrous when it occurs in an earthworm than in a whale or a human being. Indeed, many growth processes that occur in people are identical to those in other species and attest to a common evolutionary origin. The discovery of PAX-6, a 'master-control gene' for growth and development of the eye (Halder *et al*., 1995) common to species as diverse as marine worms, squid, fruit flies, mice, and people, is powerful evidence for the common evolutionary origin of the eye. Other organs, and the genetic mechanisms that control their growth and development, also are shared among diverse species (Chapter 7 discusses the genetics of growth). Nevertheless, some events in the human life cycle may be unique, such as a distinct childhood growth stage and menopause (discussed in Chapters 2, 3, and 4), and these attest to ongoing evolution of our species.

Dobzhansky (1973) said that, 'nothing in biology makes sense except in the light of evolution'. Human growth, which follows a unique pattern among the mammals and, even, the primates, is no exception to Dobzhansky's admonition. A consideration of the chimpanzee and the human, two closely related (genetically) extant primates, shows the value of taking an evolutionary perspective on growth. Huxley (1863) demonstrated many anatomical similarities between chimpanzees and humans. King & Wilson (1975) showed that such anatomical similarities are due to a near identity of the structural DNA of the two species. One interpretation of King & Wilson's findings is that the differences in size and shape between chimpanzee and human are due to the regulation of gene expression, rather than the possession of unique genotypes. Of course, humans are not descended from the chimpanzee, but both species did have a common ancestor some five, or more, million years ago. During evolutionary time, mutations and selective forces were at work on the descendants of this ancestor shaping their genetic constitution and its expression in their phenotypes.

The anatomical differences between human and chimpanzee that result from alterations in gene regulation are achieved, in part, through alterations in growth rates. D'Arcy Thompson showed in 1917 that the differences in form between the adults of various species may be accounted for by differences in growth rates from an initially identical – one might better say 'similar' – form. Thompson's transformational grids (Figure I.2) of the growth of the chimpanzee and human skull from birth to maturity, show how both may be derived from a common neonatal form. Different patterns of growth of the cranial bones, maxilla, and mandible are all that are required to produce the adult differences in skull shape. Of course, the differences in skull growth are related to size and shape of the brain, and size of the dentition (both species have the same number and types of teeth). In a similar manner, the differences in the post-cranial anatomy between chimpanzee and human being result from unequal rates of growth for common skeletal and muscular elements.

Despite the anatomical and biochemical evidence for the evolutionary

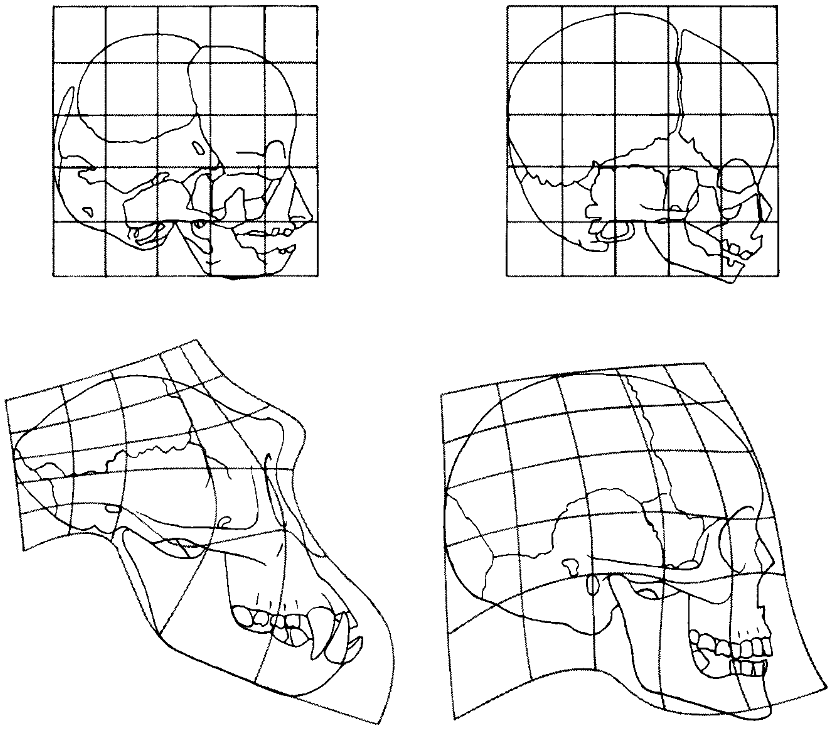

Figure I.2. Transformation grids for the chimpanzee (left) and human (right) skull during growth. Fetal skull proportions are shown above for each species. The relative amount of distortion of the grid lines overlying the adult skull proportions indicate the amount of growth of different parts of the skull (inspired by the transformational grid method of D'Arcy Thompson, 1942, and redrawn from Lewin, 1993).

origins of the human growth pattern, most works on human growth give little consideration to this topic. A paragraph or two is all that may be found in the current physiological and medical texts devoted to human growth. Recent textbooks in biological anthropology, however, do give space and emphasis to the evolution of the human pattern of growth (e.g., Relethford, 1997; Boaz & Almquist, 1997). In this book, two chapters are devoted to an account of the evolution of the human pattern of growth. Moreover, the theme of evolution runs throughout this book because it is the evolutionary perspective which makes sense of the rest.

Growth theory

This is also a book about a theoretical approach to the study of human growth. The literature in the general area of animal growth is rich in both hypothesis testing and theory (e.g., Thompson, 1917; Huxley, 1932; Brody, 1945; Weiss & Kavanau, 1957; Bertalanffy, 1960; Goss, 1964, 1978; Bonner, 1965; Snow, 1986). By contrast, prior to 1980 only a few workers had published hypotheses about the course and regulation of human growth (e.g., Bolk, 1926; Tanner, 1963; Frisch & Revelle, 1970; Grumbach *et al.*, 1974; Gould, 1977; Bogin, 1980). An example of some important contributions to growth theory, and some of its impact on later research, is given in Box I.1.

Box I.1. Models of the regulation of human growth

A conceptual model of growth

In 1963, James Tanner proposed a conceptual model for the biological regulation of human growth. Basic elements of the model are represented in Figure BI.1. A major feature of this model is that growth is target seeking and self-stabilizing. The curve labeled 'Time Tally 1' represents a hypothetical mechanism that provides a 'target size' for body growth, and also, keeps track of biological time during infancy and childhood. Biological time is measured in units of maturation, with the clock started at conception and stopped when some functionally mature state is reached. The curve labeled 'Inhibitor' represents the concentration in the body of a hypothetical substance, perhaps a by-product of cell division or protein synthesis, that acts upon the time tally to regulate growth rate. The amount of mismatch, 'M', between the two curves determines the rate of growth at each chronological age.

Tanner's model accounts for the deceleration of growth velocity during infancy and childhood and explains the phenomenon of catch-up growth (Prader *et al.*, 1963) following serious illness or starvation. During the normal postnatal growth of an infant, the amount of mismatch between the size the infant might attain and its actual size is large, and growth rate is rapid. As the child grows in size the amount of mismatch decreases and the concentration of inhibitor increases. As a result, the rate of growth slows. Under non-normal conditions, for instance starvation, the

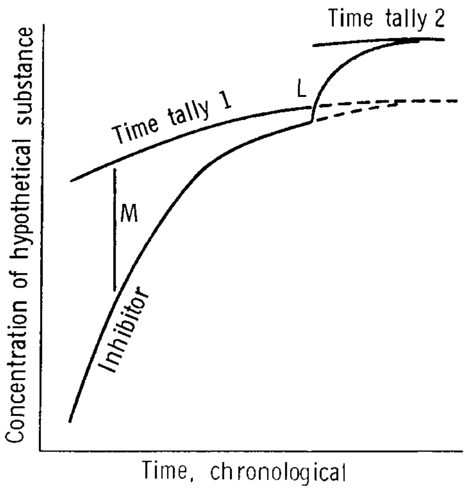

Figure BI.1. Tanner's conceptual model for the regulation of human growth. Rate of growth is determined by the amount of mismatch (M) between the concentration of a hypothetical inhibitor substance and a time tally. Time Tally 1 controls growth during childhood. Time Tally 2 controls growth during adolescence. At point L, the switch between time tallies occurs, and the adolescent growth spurt is initiated (Tanner, 1963).

rate of growth slows or stops during the period of insult. The concentration of inhibitor remains constant during this time as well. The time tally continues to register the mismatch between actual size and target size. When the insult to the child is removed, in this case upon refeeding, there is a rapid increase in growth rate to restore the balance between the time tally, the expected amount of mismatch, and the concentration of inhibitor. When this balance is restored the rate of growth assumes the normal velocity for that child, as if the insult had not occurred.

To account for the abrupt change in the velocity of growth that occurs at adolescence, Tanner suggests the existence of a second time tally. 'Time Tally 2' (Figure BI.1) operates in the same manner as time tally 1, but both the mechanism controlling the new tally and its inhibiting substance are assumed to be distinct from the old one. Tanner believes that the switch to the new tally occurs when a minimum velocity of growth, or minimum mismatch, on the old tally is reached. This is labeled point 'L' in Figure BI.1. After the switch occurs, a new larger mismatch is established and a rapid increase in growth rate results. This is the adolescent growth spurt. As the mismatch is reduced, and the concentration of inhibitor is increased, the rate of growth slows once more. Variation in the timing of the adolescent spurt between individuals is explained by changing the point at which the switch between tallies takes place.