Patterns of Human Growth
Second edition

This new, completely revised and updated edition provides a synthesis of the forces that shaped the evolution of the human growth pattern, the biocultural factors that direct its expression, the intrinsic and extrinsic factors that regulate individual development and the biomathematical approaches that are needed to analyze and interpret human growth. After covering the history, philosophy and basic biological principles of human development, the book turns to the evolution of the human life cycle. Later chapters explore the physiological, environmental and cultural reasons for population variation in growth, and the genetic and endocrine factors that regulate individual development, providing a comprehensive explanation for the functional and adaptive significance of human growth patterns. The final chapter integrates all this information into a truly interactive biocultural model of human development. This new edition will continue to be the primary text for students of human growth in the fields of anthropology, psychology and education.

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BARRY BOGIN

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Dedicated to Gabriel Ward Lasker in admiration and friendship and Rachael and Josh Bogin with love.

Contents

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1 *Background to the study of human growth*

People, like all animals, begin life as a single cell, the fertilized ovum. Guided by the interaction of the genetic information provided by each parent and the environmental milieu, this cell divides and grows, differentiates and develops into the embryo, fetus, child, and adult. Though growth and development may occur simultaneously, they are distinct biological processes. **Growth** may be defined as a quantitative increase in size or mass. Measurements of height in centimeters or weight in kilograms indicate how much growth has taken place in a child. Additionally, the growth of a body organ, such as the liver or the brain, may also be described by measuring the number, weight, or size of cells present. **Development** is defined as a progression of changes, either quantitative or qualitative, that lead from an undifferentiated or immature state to a highly organized, specialized, and mature state. **Maturation**, in this definition, is measured by functional capacity, for example, the development of motor skills of a child that result in mature state of bipedal walking. Though broad, this definition allows one to consider the development of organs (e.g., the kidney), systems (e.g., the reproductive system), and the person.

Why grow and develop?

A large mammal, such as a human being, is composed of about 10^{12} cells, which result from approximately 2^{38} mitoses (cell divisions) since the moment of fertilization. During mitosis, cells differentiate into dozens of types of tissues and organs. Why must multicellular organisms of the five kingdoms of life – animals, plants, fungi, protists, and monera – undergo this process of cell multiplication and specialization? The answer is, because all such living things are mortal. Reproduction is necessary to replace those organisms that die, and reproduction requires both growth and development. Some forms of life reproduce asexually, in which one or a few cells are contributed by a parent and those cells eventually grow and develop into a new mature individual. Most species reproduce sexually, requiring a single cell with some biological material from each of two parents. In either case, the initial contribution of cells cannot look or behave in any way like the parent. To be like their parents, '. . . the new organisms will have to suffer changes before they become something approaching replicas of the old' (Newth, 1970 p.1). Newth, an embryologist, adds that the process of growth and development is arduous, often prolonged, and generally hazardous. Sex, growth, development, and death are some of the prices to be paid for multicellularity.

Historical background for the study of human growth

Like the fertilized ovum, the study of human growth and development has undergone an arduous, prolonged, and hazardous history of intellectual development. Arduous and prolonged because it has taken more than three thousand years of study to arrive at our present state of knowledge. Some of the highlights of these three millennia are described in the next paragraphs of this section. The history of growth research is hazardous because misinformation and gaps in our knowledge lead to tragic consequences for human beings. The thalidomide drug disaster of the 1960s and the decline in breast-feeding in 'modern' societies are just two recent examples of these hazards. Thalidomide is a sedative and hypnotic drug that was used to treat some of the discomforts of pregnancy. It was withdrawn from sale after it was found to cause severe birth defects, especially of the limbs. The thalidomide case promoted tougher standards for testing the safety of new drugs and more research on environmental influences of embryonic development.

A decline in breast-feeding during the twentieth century is a typical occurrence in both developed and developing nations. The development of milk-based formulas to feed infants and aggressive promotion of these formulas as 'modern', and sometimes superior to breast milk, led partly to the decline. In the past decade, a body of research has accumulated showing that there are harmful effects for infants who are never breast-fed. These include increased incidence of respiratory and inner ear infections, accumulation of more body fat and later risk of heart disease (Cunningham, 1995; Scariati *et al.*, 1997), and reduced mental development (Dettwyler, 1995) in formula-fed infants. After reaching an all-time low in the early 1970s, the incidence of breast-feeding in the United States has increased as both the medical profession and the public have become aware of the benefits of nursing (Ryan, 1997a).

These examples of hazards in the history of the study of human growth and development provide reason for caution in the future. Another reason to study the history of any discipline is that one learns what topics have been studied, when such inquiry first occurred, and which problems are in need of further study. Historical study is important from a conceptual perspective as well, as it may help explain why scholars and practitioners have been interested in human development. In particular, the history of study of human growth makes clear the relevance of growth research to medicine, epidemiology, and public health. More generally, an understanding of the history of the study of human growth reveals connections between economics, art, law, politics, philosophy, and other fields of knowledge that influence the course of human events.

The following is a review of some of the major historical events in the study of human growth, with special emphasis on those which still have an influence on growth research today. Boyd (1980) and Tanner (1981) provide book-length histories of the study of human growth. Lowery (1986) offers a brief review focused on pediatric medicine. Bogin & Kapell (1997) present a concise history of the study of normal human growth emphasizing topics of anthropological interest. The *History of Physical Anthropology: An Encyclopedia* (Spencer, 1997) and the *Cambridge Encyclopedia of Human Growth and Development* (Ulijaszek *et al.*, 1998) provide many entries relating to the history of human growth research.

Prehistory and early historic period

Small stone sculptures, often called 'Venus figurines', and cave paintings from Europe depict people and animals that may be pregnant. The earliest of these artistic renderings date from about 25 000 years BP (before present). There are also rock paintings from southern Africa and Australia, older than the European cave art, that depict people and other animals of various ages and sexes. The fossil record includes Neanderthal and early modern human skeletons of children, including some with developmental pathology. One Upper Paleolithic skeleton from Italy seems to have been from an adolescent with a type of dwarfism caused by acromesomelic dysplasia (Frayer *et al.*, 1987). This type of dwarfism results in severe deformity and physical impairment, but normal intelligence. The affected individual would have been unable to contribute much labor to a hunting and gathering group. Frayer and colleagues believe that this individual's survival to the teenage years indicates both tolerance and care for impaired infants and children. This may be so, but a detailed understanding of how Paleolithic peoples may have interpreted the meaning of pregnancy, normal and pathological growth, and human development in general are matters for speculation.

The earliest written records about human growth date from Mesopotamia, about 3500 BP. Inscribed myths recount the act of fertilization, the nine months of pregnancy, and both full term and premature birth. Concerns about low birth weight or prematurity, birth defects, and twinning also are recorded. The Sumerians divided postnatal life into several stages that correspond to modern ideas of infancy, childhood, youth, adulthood and old age. There is no direct evidence that Sumerians measured the dimensions of the body. Some of the art works seem to depict accurately size differences between children and adults. Other works of art depict high status people, such as male elders, as disproportionately taller than lower status people, such as women. Several texts also make mention of a positive relationship between health, social status, and stature. Thus, both in Sumerian art and in life there was a relationship between growth and biosocial conditions. That this relationship appears in the earliest writing on human growth is fascinating, for the study of this association is still a very active area of research today (see Chapters 5 and 6).

The ancient Egyptian, Chinese, Hindu, Greek and Mesoamerican civilizations follow many of these Sumerian traditions. Written records and art work show that the earliest interest in the biology of children was primarily a concern with the preservation of life. Greek, Roman and Arab physicians prescribed regimes of physical activity, education, and diet to help assure the health of children. Their advice was more often guided by the needs of their societies for military personnel and by religious dogma about children rather than by empirical observations of the effect of child-rearing practices or child growth, development, and health. Of course there were marked differences between these cultures in specific cultural values, but the universal biological nature of pregnancy, birth, and infancy (this nature is reviewed later in this chapter) meant that all human societies must converge on some basic strategies for the care and feeding of their young.

Some of the early civilizations, such as the Egyptians and the Hindu Indians, showed careful concern for measurement of the body, including children and youths. Egyptians used a grid system to carefully render body proportions correctly. Other cultures, such as the Chinese and Early Jewish Tradition, emphasized more spiritual aspects of human development in their concern for the young. One matter of repeated concern for these ancient societies is the number of stages of life. Numbers vary, but by the time of the Romans ‘seven ages of life’ becomes a frequent blueprint for human development. Today, research into life history theory, which is concerned in part with the number of stages in the life cycle of organisms, is very popular and productive. Human life history theory is a central concern of Chapters 3 and 4 of this book.

The Latin West and the Renaissance

Egyptian, Greek, and Roman artwork, especially three-dimensional sculptures, depict infants and children fairly accurately in terms of body size and proportion (infants have relatively larger heads and shorter arms and legs than children and adults). In some of this art the children are depicted at play. Viewing this art can give a sense that infancy, childhood, youth, and the other 'seven stages of life' were each accorded its own special biology and behavior. Scholarly concern with the stages of life continued following the collapse of the Roman Empire, but there seems to have been a shift in the status accorded to children and youths. Medieval physicians, clerics, and artists began to follow a tradition of treating the child as a miniature adult. In this tradition, the growth and development of infant to adulthood involved only an increase in size and maturity during the growing years.

There is some debate as to how, and why, children of the Medieval Age were perceived and treated. Nevertheless, Kaplan (1984, p. 46) writes that, 'Plague, pestilence, ignorance, extraordinary poverty, drudgery, starvation, perpetual warfare were . . .' some of these reasons why children lost special status. Ariès (1965) reconstructs the social world of that time and concludes that after the age of seven years, children were forced to enter the social world of adults. Ariès believes that this accorded children great freedom, but Kaplan views this as a kind of abandonment. In either case, the social reality was that young people were expected to become adult-like at a fairly young age. In the art works of the time, especially paintings and mosaics, young people are depicted with the same body proportions as adults. The 'Rucellai Madonna', attributed to the Italian artist Duccio (1285?), the 'Madonna of the Trees' by Bellini (1487), and 'Peasant Dance' by Pieter Bruegel the elder (1568?) are all in this stylistic tradition.

A few words of caution need to be interjected at this point. Our current interpretation of the history growth research, and of 'children' and 'childhood' (in fact human development from fetus to young adult), is distorted by our own ethnocentric ideals and beliefs. Ethnocentric notions, of course, clouded the perceptions and behavior of people in the past toward children as well. Sommerville (1982) mentions that the Greeks made note of the *absence* of infanticide among the Egyptians. After invading the Americas, the Spanish were impressed that all Aztec, Maya, and Inca infants were breast-fed, and that nursing, along with other foods, continued until four years of age. Even women of royal status nursed their own babies (Shein, 1992). It seems that in sixteenth century Spain, and elsewhere in Europe, breast-feeding was viewed as 'too natural' and thus not becoming to people. This was especially so for those of high social status who often contracted lower social status women as wet nurses. So, when historians of the past 40 years debate the alleged brutalities against children of past ages, readers should be careful not to commit the ethnocentric fallacy of judging other cultures by one's own standards. What late twentieth century writers note with amusement about the past may be telling us more about our own unconscious assumptions, or wanting behaviors, toward our own children.

It is also important to interpret the art of the past with some caution. A critic of the first edition of this book stated, 'Art is a figurative medium and cannot often be used to make objective assumptions about culture' (Kathryn Stark, personal communication). The same critic wonders if it is correct to state that Picasso (b1881–d1973) paints children 'better' than Bruegel (b1525?–d1569)! Despite the fact that it may not be possible to know exactly how infants, children, and youth were treated, and perceived, during the Medieval period, it is clear that human growth and development were not studied scientifically. During the Renaissance period there was a revival of the classical Greek concept of the dynamics of growth, which is amusing as this concept was never accepted popularly by the Greeks or Romans. The scholar Giordano Bruno (ca. b1550–d1600) wrote, '. . . We have not in youth the same flesh as in childhood, nor in old age the same as in youth; for we suffer transmutation, whereby we receive a perpetual flow of fresh atoms and those we have received are ever leaving us' (Boyd, 1980, p. 176). This is a remarkably modern statement of the constant turnover of cells and the constituents of cells in the human body. Leonardo da Vinci (b1452–d1519) proposed that new studies of human growth and development, from conception onwards, needed to be undertaken. Leonardo initiated his own human dissections, including his study of a seventh-month fetus, the placenta, and stillborn full-term infants (Figure 1.1). In the year 1502, the physician Gabrielo de Zerbis (ca. b1460–d1505) published a description of the anatomical differences between child and adult. Many other medical and scientific publications quickly followed.

Leonardo used his scientific studies of human growth to produce drawings that correctly rendered adult and child body proportions. Building on the work of Vitruvius, a first-century BC Roman architect and writer, Leonardo developed canons, or rules, for drawing human proportions (Tanner, 1994). Albrecht Dürer (b1471–d1528), a German artist, devised a method of geometric transformations that he used to accurately render proportions of the human head and face. With his geometric methods, Dürer could draw not only the canonical types, but any manner of human variation in size or proportion. He applied his method to drawings of men, women, children and infants (Figure 1.2). Including women and children in

Figure 1.1. Fetal positions and structures of the placenta shown in sketches by Leonardo da Vinci. Windsor collection, folio 8r. From *Quaderni d' anatomia*, volume III.

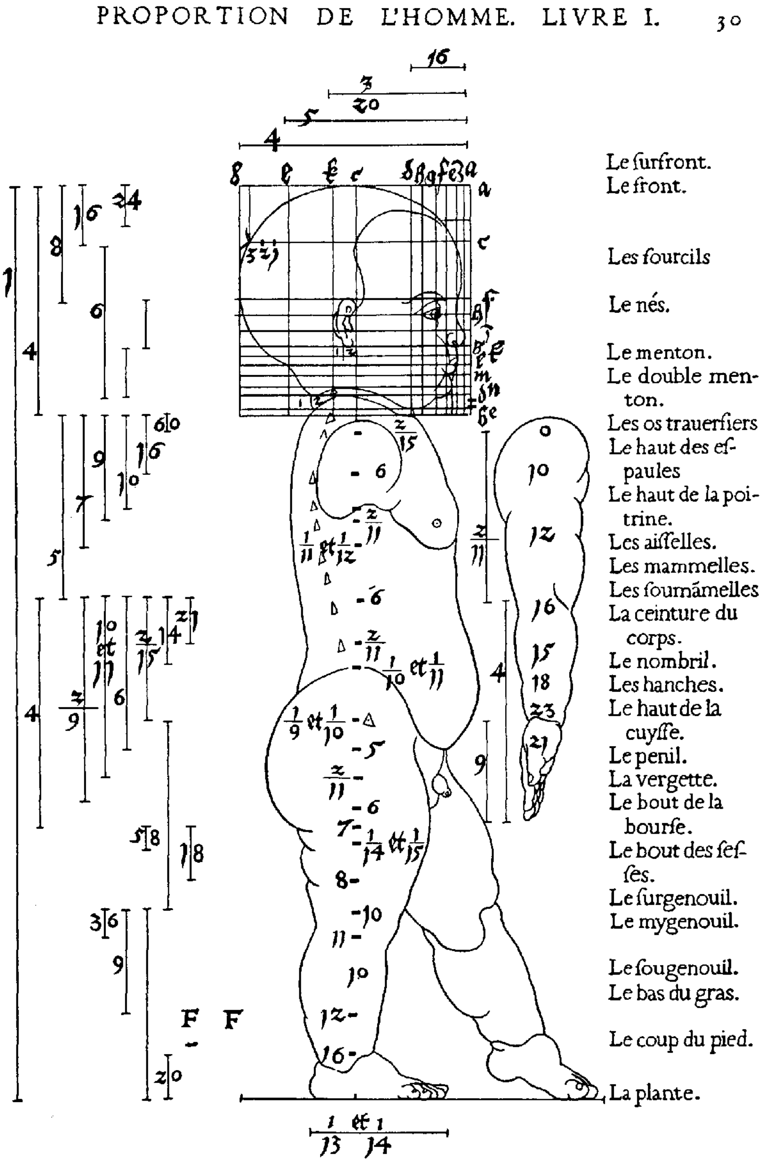

Figure 1.2. Proportions of the infant, diagram by Albrecht Dürer. From the 1557 edition of *Les quarte livres d'Albert Dürer.*

this type of methodological work was an innovation, as most artists followed the teachings of Cennino Cennini (*ca.* b1400) who wrote that women do '. . . not have any set proportion' (Boyd, 1980, p. 202). Children, it seems, were too inconsequential for Cennini to even mention! As a reflection of the art and scholarship of the time, the work of Leonardo and Dürer portended a major change in the concept of children and research into human growth.

After the year 1600, the post-Renaissance painters begin to depict children with normal proportions and also with growth pathologies. The Flemish artist Van Dyck depicts three normal children in the painting 'The Children of Charles I' (1635). The painting 'The Maids of Honor' by Diego Velazquez (1656) depicts a normal child, a woman with achondroplastic dwarfism (normal-sized head and trunk with short arms and legs) and a man with growth-hormone deficiency dwarfism (proportionate reduction in size of all body parts). At the time of these paintings, of course, the biological control of normal and pathological growth was not known. Nor is it clear today how physicians and scientists of that time regarded different types of dwarfism.

Embryonic and fetal development

Ancient, Classical, and Medieval scholars had written a great deal on human growth and development prior to birth. Some of this was undoubtedly based on observation of human and non-human fetuses, but much was also the product of imagination and myth. The actual process of growth and development from fertilized ovum to the birth of a human child is so counterintuitive to our expectations, based on our experience with child growth after birth, that through much of human history scholars and physicians did not know or believe that it occurred. It was not until the year 1651 that the physician William Harvey helped establish that the embryo is not a preformed adult. Harvey showed that during prenatal development there are a series of embryological stages that are distinct in appearance from the form visible just before and after birth. The Greek physician Galen (*ca.* b130–d200 AD) wrote about the appearance of the fetus in the later stages of pregnancy. However, the first accurate drawings of the fetus were made by Leonardo da Vinci, as mentioned above. Other descriptions of fetal anatomy and physiology followed Leonardo's work, notably the studies published by Vesalius in 1555 and Volcher Coiter in 1572. Coiter studied a fetus less than 3 cm in length, indicating that the fetus had developed for about 10 weeks since conception.

During the seventeenth and eighteenth centuries descriptive anatomical

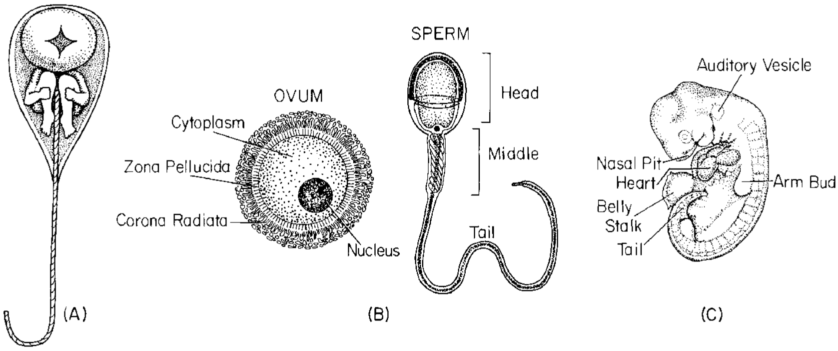

Figure 1.3. (A) Preformationist rendering of a human spermatozoon (Hartsoeker, 1694; from Singer, 1959). (B) Diagram of human ovum and spermatozoon. (C) Diagram of human embryo 32 days after fertilization.

studies continued, with most of the work being done on fetuses in the last trimester of pregnancy (last three months). The fetus of this age is of unmistakable human appearance, so these studies failed to appreciate the physical changes that take place earlier in prenatal life. Some biologists continued to believe in preformation, and a few extended that concept beyond pregnancy to the formation of spermatozoa (Figure 1.3). In 1799 S. T. Sommerring published drawings of the human embryo and fetus from the fourth week post-fertilization to the fifth month, clearly showing that the embryo is not a preformed, or miniature, human being.

The scientific study of the cellular mechanisms of fertilization and embryonic development has its roots in the work of Karl Ernst von Baer (b1792–d1876), published in 1829 (see Baer, 1886). He described the 'germ layers' of the embryo, properly called the endoderm, the mesoderm, and the ectoderm. The endoderm cells give rise to the internal organs, cells from the mesoderm form the skeleton and the muscles, and the skin and the teeth develop from ectoderm cells. The work of von Baer removed the need to invoke mystical 'vital forces' to explain embryological transformations, replacing these with more mechanistic processes. However, it was not until the twentieth century that an understanding was achieved of the highly complex nature of the physical, chemical, and biological processes that occur during prenatal growth.

Longitudinal studies of the eighteenth century

Another post-Renaissance advance was a growing interest in how early life events could influence later development. For instance, by the 1700s physicians pursued the study of birth weight and its relation to child health. Prenatal and neonatal influences on later development remain topics of research interest today. A new research strategy had to be developed to study the relationship between early influences and later growth outcomes. This is the longitudinal method of research. A longitudinal approach requires that the same individuals be examined on at least two occasions, separated by some period of time. Prior to the use of longitudinal methods, the predominate strategy was the cross-sectional approach in which each individual is examined only once. The cross-sectional approach has the advantage that many people can be measured in a short period of time. The disadvantage is that the dynamics of growth, such as changes in rate of growth, cannot be properly studied.

The Count Philibert Guéneau du Montbeillard (b1720–d1785) of France, measured the stature of his son every six months from the boy's birth in 1759 to his eighteenth birthday. George-Louie Leclerc de Buffon (b1707–d1788) included the measurements, and his commentary on them, in a Supplement to his *Histoire Naturelle* in 1777. These data are usually considered to constitute the first longitudinal study of human growth and, due to Buffon's commentary, the most famous study. The growth in height of this boy, both in terms of achieved stature by age and rate of growth at any age, are illustrated in Figure 1.4. The original data were reported in antiquated French units of measurement, but Scammon (1927) converted these to modern metric units. The metric data are drawn here as mathematically smoothed curves (the cubic spline technique was applied to the data given by Scammon by the present author). The smoothing makes the important features of the curve more easily seen.

The curve in the figure labeled A is the boy's total height at each measurement. If growth is viewed as a motion through time, then this graph may be called the **distance curve** of growth. The boy's rate of growth between successive measurements is graphed in part B of the figure, commonly called the **velocity curve** of growth. Buffon had earlier written on the adolescent spurt in growth (the rapid acceleration in growth velocity around the time of sexual maturation) and on the general advancement of maturation of girls compared with boys. With the data on Montbeillard's son, Buffon noted the seasonal variation in rate of growth; the boy grew faster in the summer than in the winter. Buffon also wrote of the daily variation in stature; the boy was taller in the morning after lying at rest during the night than he was in the evening after working and playing during the day. Since Buffon's time, it has become necessary to take these variations in seasonal growth and daily stature into account when designing or analyzing longitudinal growth studies.

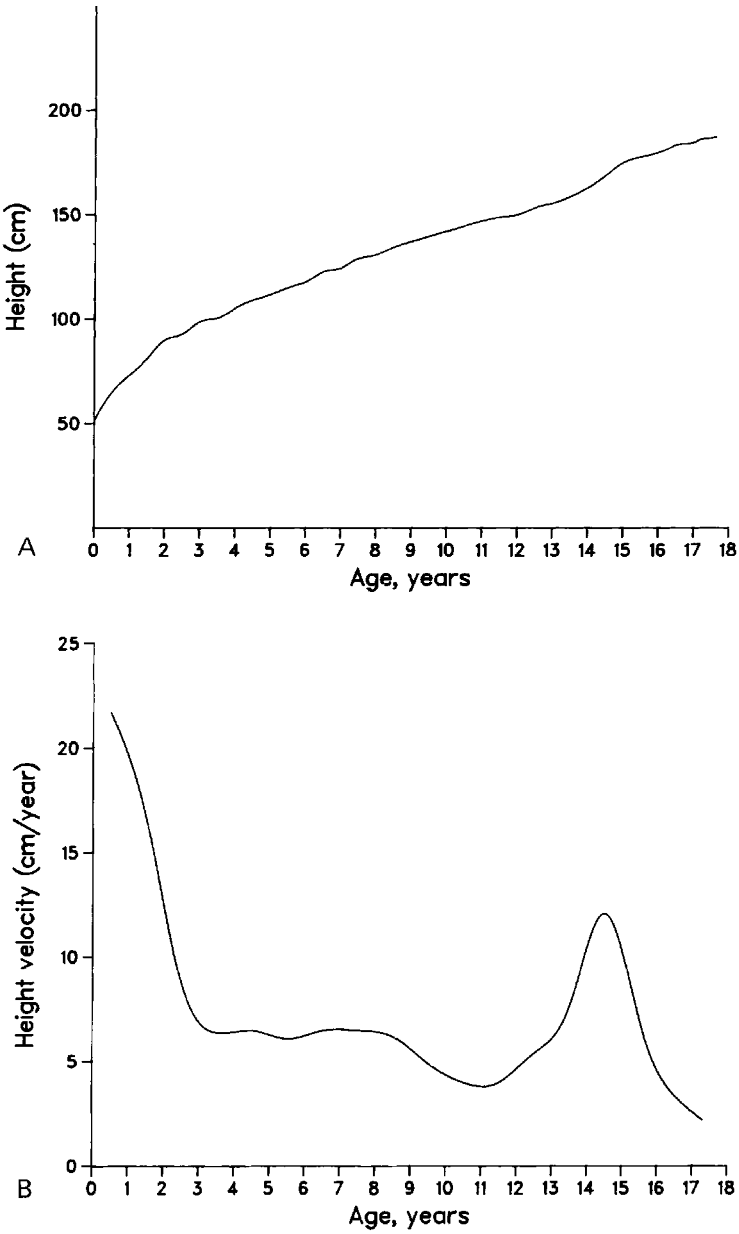

Figure 1.4. Growth in height of the son of the Count Montbeillard during the years 1759–77. (A) Amount of growth achieved during each six months from birth to age 18 years. (B) Rate of growth in height during each six months from birth to age 18 years.

Except for the adolescent growth spurt, Buffon made little mention of changes in growth velocity that are clearly seen in Figure 1.4. Montbeillard's son shows four distinct phases of growth velocity. The approximate duration of each phase, its name, and its tempo are: from birth to three years of age, the **infant phase**, growth decelerates rapidly from its maximum value of 22 cm/year to 6 or 7 cm/year; from three to about seven years of age, the **childhood phase**, growth rate remains fairly constant; after age 7 years until about 11 years, the **juvenile phase**, growth rate decelerates again, at first rather slowly but then much faster; from about 11 to 18 years of age, the **adolescence phase**, there is a classic adolescent growth spurt, with an acceleration period from about 11 to 14.5 years followed by a deceleration period that continues until 18 years and beyond. Note that the acceleration period is less steep, that is the tempo of growth changes less rapidly, than the deceleration period. A more detailed discussion of these phases of postnatal growth is presented in the next chapter.

Another eighteenth century longitudinal study of growth is that of the students of the Carlschule, conducted between the years 1772 and 1794. The pupils of this high school, founded by the Duke of Wurttenburg, included sons of the nobility and of the bourgeoisie. The growth data showed that the former were, on average, taller than the latter during the growing years but both groups achieved approximately equal height at 21 years of age. Thus, the sons of the nobility experienced an advancement of the rate of growth. This study, and the work of Buffon, clarify the important difference between amount of growth achieved at a given time and the rate of growth over time.

Statistical approaches of the nineteenth century

In 1835 Lambert Adolphe Quetelet (b1796–d1874) published the first statistically complete study of the growth in height and weight of children. Quetelet was the first researcher to make use of the concept of the 'normal curve' (commonly called today the normal distribution or 'bell-shaped' curve) to describe the distribution of his growth measurements, and he also emphasized the importance of measuring samples of children, rather than individuals, to assess normal variation in growth. Quetelet's statistical approach was followed in Europe by Luigi Pagliani (b1847–d1932). Pagliani began his studies on the size and fitness of Italian military personnel. He later applied his methods to children, and in 1876 demonstrated that the growth status and vital capacity (the maximum volume of air that can be inspired in one breath) of orphaned and abandoned boys, ages 10 to 19, improved after they were given care at a state-run agricultural colony.

Pagliani also noted that children from the higher social classes were taller, heavier, and had larger vital capacities than poverty-stricken children. Finally, Pagliani followed Buffon in taking longitudinal measurements of the same children. From these Pagliani noted that menarche (the first menstruation of girls) almost always followed the peak of the rapid increase in growth that takes place during puberty. He concluded that reproduction was delayed in young women until growth in size was nearly finished. This, he considered, was a proper relationship, for the nutritional and physiological demands of growth would interfere with similar demands imposed by pregnancy.

Politics, heredity, environment and growth

During the nineteenth century growth research was used for the first time to inform political and legal decisions regarding the treatment of children. The growth of European cities during the eighteenth century led to a flow of rural-to-urban migrants. Urban life dislocated many people from traditional rural family social organization. One result was an increase in the number of infants and children who became wards of the parish or were placed in foundling hospitals. The growth and health of these abandoned infants was extremely poor and many died. The physician William Cadogan (b1711–d1797) published *An Essay Upon Nursing and the Management of Children from Their Birth to Three Years of Age* (1750) that instructed the women working in foundling hospitals and parish orphanages. In a sense, this book was the first practical pediatric guide to baby care. The need for such books has not diminished over time. Indeed, the current best-seller, Benjamin Spock's (b1903–d1998) *Baby and Child Care* (first published in 1946), sold over 30 million copies in its first 30 years in the Untied States (only the Bible sold more copies). By 1998 the book had sold more than 49 million copies worldwide, in 39 languages.

The publication of Cadogan's *Essay* reflected a broad concern for infant health in England, where by 1767 laws were passed regulating the operation of foundling homes. On the Continent new concerns for infant care was sparked by the publication of Jean Jacques Rousseau's (b1712–d1778) book *Emile* in 1762. Rousseau advocated a 'return to nature', including the breast-feeding of infants by their own mother. Artificial feeding devices ranging from cow's horns to clay vessels had been used for centuries, but were becoming more common in cities. Such devices were difficult to clean, and the animal milk or other liquids fed to infants was surely not maintained under hygienic conditions. The inevitable result was intestinal infection for the infant. The higher social classes, especially in large cities such as

Paris, often 'farmed out' their infants to wet-nurses. Since these nurses might have several infants to feed, including her own infant, it is likely that some or all of her charges received too little breast milk, or were fed artificially. Rousseau's book was highly critical of these practices and, '. . . profoundly influenced thinking on child care and education throughout Europe' (Boyd, 1980, p. 270).

Another social force working against the welfare of children was the Industrial Revolution. Between the years 1765 to 1782 James Watt (b1736–d1819) developed a commercially viable steam engine, which forever changed the nature of human labor. The factory system ushered in under steam power reduced the need for human muscle power, and allowed children to be employed for many tasks. One survivor of childhood labor described his life to a British Parliamentary investigation in 1832 (quoted from Sommerville, 1982):

> Have you ever been employed in a factory? – Yes.
> At what age did you first go to work? – Eight.
> Will you state the hours of labour at the period when you first went to the factory, in ordinary time? – From 6 in the morning to 8 at night.
> When trade was brisk what were your hours? – From 5 in the morning to 9 in the evening.
> With what intervals at dinner? – An hour [once per day].
> During those long hours of labour could you be punctual; how did you awake? – I seldom did awake spontaneously; I was more generally awoke, or lifted from bed, sometimes asleep, by my parents.
> Were you always on time? – No.
> What was the consequence if you had been too late? – I was most commonly beaten.
> Severely? – Very severely, I thought.

The testimony continues at some length and describes a life in the factories of fatigue and hunger, punctuated by beatings.

Medical hygienists, or what we call today Public Health professionals, established the decline of health associated with urbanization and industrialization, by measuring the height and weight of people. In France, Louie-René Villermé (b1782–d1863) found in 1829 that military conscripts from mill or factory areas were too short, and suffered too many disabilities to make them fit for military service. Edwin Chadwick (b1800–d1890) published data on growth and health of factory children in his *Report of the Commissioners on the Employment of Children in Factories* (1833). Some of these data are reproduced in Figure 1.5, which compares the average height deficit of the English factory children (as reported by Tanner, 1981) against the international reference data for stature published by the United States

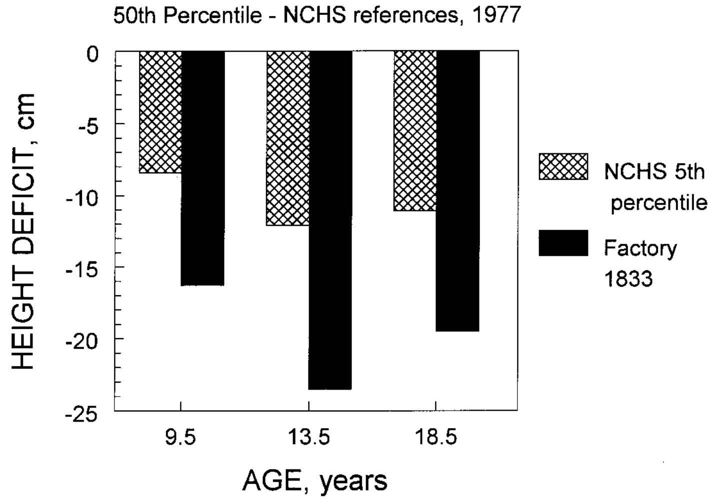

Figure 1.5. Height of English factory children in 1833 compared with the National Center for Health Statistics (NCHS) references. The heights of the factory children are shown as deficits, in cm, to both the 50th percentile and the 5th percentile of the NCHS references.

National Center for Health Statistics (NCHS) (Hamill *et al.*, 1977). In this figure, the '0' line represents the fiftieth percentile height of the reference population. The factory children are 16.3 to 23.5 cm shorter than the NCHS fiftieth percentile, and 7.9 to 11.4 cm below the NCHS fifth percentile. In a group of children an average height below the fifth percentile is an indication of major growth delay and stunting. This magnitude of stunting is usually seen only in children with serious pathology. Even children growing up under conditions of poverty in the least developed nations of the world today have average heights above the fifth percentile of the NCHS references. At 18.5 years of age only the Pygmy populations of central Africa have smaller average heights – about 150 cm for Pygmies versus 158 cm for the factory children.

In response to these findings Friedrich Engels (b1820–d1895) campaigned extensively against the employment of children in English factories. Engels cited evidence of stunted growth, spine and bone deformities, and the physical and sexual abuse of child workers. Some physicians, Engels proclaimed, said that the factory districts would produce 'a race of pigmies' (Sommerville, 1982, p. 146) by a kind of evolutionary decline. Engels may have misunderstood the workings of evolutionary biology, but his social approach to growth stunting was correct. Chadwick's report included

Engels' concerns and that report, along with personal testimonies, led to the passing of the Factories Regulation Act (1833) in England. The Act prohibited the employment of children under the age of nine and stipulated that periods for eating and rest must be provided for older children during the work day. Age was determined by the state of dental maturation as assessed by the eruption of permanent teeth.

The relationship between tooth eruption and chronological age was verified in an extensive survey by Sir Edwin Saunders published in 1837. Saunders assessed the state of permanent molar eruption in English school children at ages 9 and 13 years, and showed that dental eruption was a better indicator of chronological age than height. By this work Saunders helped establish that development of the dentition is less influenced by the environment, while height, and therefore skeletal development, is more affected. In later years an appreciation of these differences would lead to the crucial concept of 'biological versus chronological age' and research leading to the production of atlases of dental and skeletal development (topics discussed in more detail later in this chapter).

Race and growth

In the United States a highly contentious political debate involved the use of growth data. Starting in 1875, Henry Pickering Bowditch (b1840–d1911) gathered measurements of height and weight, taken by school teachers, of 24 500 school children from the Boston, Massachusetts area. In a series of reports published in 1877, 1879 and 1891, Bowditch applied modern statistical methods (following Quetelet) to describe differences in growth associated with sex, nationality, and socioeconomic level between different samples of children. Bowditch was the first person to construct percentile growth charts, which he published in 1885. The NCHS growth charts discussed above are the modern descendants of Bowditch's work. With the first use of these charts Bowditch found that children of the laboring classes were smaller than children from the non-laboring classes. To account for this fact Bowditch preferred an environmental, rather than a genetic, explanation. He said the non-laboring classes were taller because of the '. . . greater average comfort in which [they] live and grow up . . .' (Boyd, 1980, p. 469).

This conclusion ran counter to that of Francis Galton (b1822–d1911). In his book *Natural Inheritance* (1889) Galton demonstrated the heritability of stature and other physical traits. Galton's work led some to believe that heredity was the all-powerful determinant of human form and functional capabilities. Galton's work was used to support the eugenics movement, a pseudo-scientific political movement that claimed to be able to improve the human species by controlled breeding. Eugenicists held that the laboring classes were genetically inferior to the non-laboring classes. One proof of this inferiority was their short stature. Eugenicists also believed that the 'race', or ethnic origin, of American-born children could easily be determined on the basis of physical measurements, and that 'racial' admixture, especially between 'Anglo-Saxons' and people from southern and eastern Europe, would bring about a physical degeneration of Americans.

Previously mentioned in the Introduction to this book was the research of Franz Boas (b1858–d1942), a German-born anthropologist working in the United States. Boas demolished the position of the eugenicists with his studies of migrants to the United States and their children. Boas found that children of recent immigrants grew up to look much like the 'good old Americans' (older generations of immigrants) due to modifications in the process of growth and development as a response to environmental change. Accordingly, Boas concluded that, 'we must speak of plasticity (as opposed to permanence) of types' (1910, p. 53). The term 'types' is a synonym for 'race'. Eugenicists believed that each 'race' could be defined by genetically fixed sizes and shapes of the human body or parts of the body. The plastic changes in growth discovered by Boas applied to both the laboring and non-laboring classes. Boas ascribed this plasticity to the better health care and nutrition received by the children in the United States. Bowditch had earlier found the same effect of migration on growth but in smaller samples of children, for example, that German-Americans were taller on average than Germans in Germany. What both men were able to show was that the American-born offspring of immigrant parents grew up to look more like each other in body size than they looked like their parents.

Thus, Bowditch and Boas proved statistically that the eugenicists claim that ethnicity could be determined by physical measurements was not true. Bowditch concluded that his research disputed the '. . . theory of the gradual physical degeneration of the Anglo-Saxon race in America' (Boyd, 1981, p. 469) as a result of admixture (intermarriage) taking place there. The results of Boas' research agreed with those of Bowditch, but despite their work many eugenicists and politicians called for quotas on the immigration of so-called inferior peoples into the United States. In 1911 Boas presented to the US Congress a report titled, 'Changes in the bodily form of descendants of immigrants', which explained his research and may have helped delay the imposition of limitations on immigration. Nevertheless, the American Congress eventually passed the 'Immigration Restriction Acts' in 1921 and 1924, which specifically targeted southern and eastern Europeans and Asians for migration quotas (Gould, 1981).

Boas and the environmentalists may have lost that political battle, but their work influenced three generations of anthropologists, public health workers, epidemiologists and others. Undernutrition, poor health, illiteracy, and poverty are still rampant today. Documentation of the pernicious effects of these conditions on the physical and mental growth of children continues to be carried out, and, in the tradition of Villermé, Chadwick, Bowditch, and Boas, recommendations for action to alleviate this suffering are made by researchers who have, '. . . a feeling of responsibility for the children's welfare' (Borms, 1984).

Twentieth-century research

Boas' scientific discoveries also include his research into the methodology of growth studies (1892, 1930). One of his enduring contributions is the importance of calculating growth velocities from the measurements of individuals rather than from sample means. As shown in Figure 1.6, the former method gives an accurate estimate of average growth rate, while the latter method mixes data from early, average, and late maturing children and results in a mean velocity curve that underestimates the actual velocity of growth of all children during the adolescent growth spurt. Boas also provided the concept of **tempo of growth** to understand the difference between early and late maturing individuals. The effects of maturational timing are most evident at the time of the adolescent growth spurt, but they are present at all stages of life – even during the prenatal period. Early maturers are always ahead of late maturers in skeletal development and other indicators of biological maturation. Tanner (1990, p. 75) explains that the concept of tempo of growth is a metaphor from classical music, '. . . some children play out their growth *andante*, others *allegro*, a few *lentissimo*.' With both methodological and conceptual advances such as these, and the descriptive knowledge gained since the time of Buffon, the modern era of growth measurement and analysis began.

In the first half of the twentieth century several large-scale longitudinal studies of growth were started in the United States and Europe. In addition to better quantification of amounts and rates of growth of healthy children, these studies made use of new technologies in radiology, physiology, and psychology to characterize the biological maturation of body systems. Equally important, these longitudinal studies represented a new philosophy about human growth and development. Research workers and politicians became interested in the causes of individual differences between people. Perhaps this interest was a consequence of the work of Boas on the environmental determinants of growth and physical development. It may

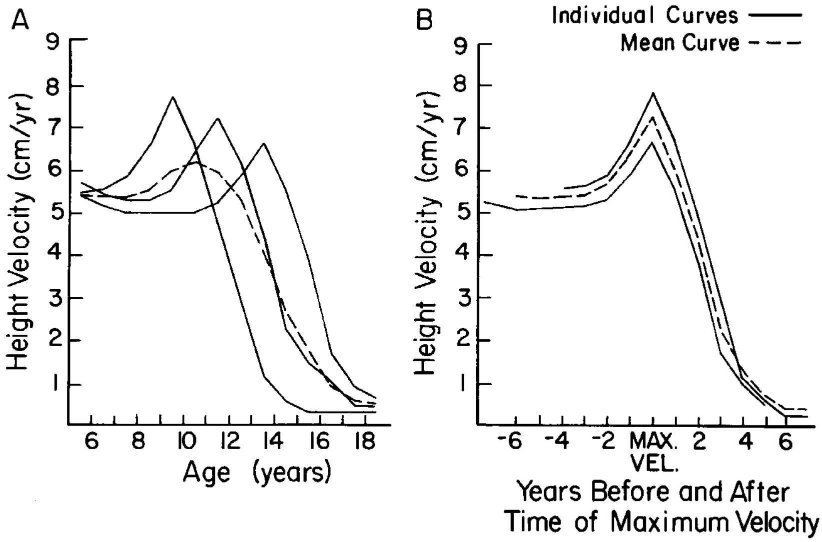

Figure 1.6. (A) Individual velocity curves of growth (solid lines) and the mean velocity curve during the adolescent growth spurt. The mean velocity curve does not represent the true velocity of growth of any individual. (B) The same curves plotted against time before and after peak height velocity (maximum velocity) of each individual. The mean curve accurately represents the average velocity of the group.

also be a reflection of an American cultural ideal, the 'rugged individual' and how to ensure continued production of the same. Lester W. Sontag (b1901–d1991), who directed the Fels Longitudinal Study in Yellow Springs , Ohio from 1929 to 1970, writes, '. . . that modern understanding of the growth, health, behavior, and effectiveness of human beings could only be understood if the nature and significance of individual characteristics of each child's physiological, biochemical, nutritional, educational, and environmental characteristics could be assessed and integrated into a total picture' (1971, p. 988). Sontag summarizes this approach as the study of 'the whole child'.

The American studies

The American longitudinal studies were supported in their early years by private donors. In particular the Rockefeller Foundation and the Laura Spellman Rockefeller Memorial Fund were major sources of financial support. Lawrence K. Frank (b1890–d1968) was an administrator at both funds and helped start and maintain virtually all the major longitudinal studies. Eventually there was also public support for longitudinal research on human growth. The United States National Research Council created the Committee on Child Development in 1923 leading to several White House Conferences on Child Health. Specialized journals such as *Child Development*, started in 1929, and *Growth*, first published in 1937, also appeared. By this time the study of normal growth was of national importance, both for its scientific and political value.

Several large, expensive long-term studies were initiated. These include the Fels Study mentioned above, the University of Iowa Child Welfare Station Study, the Harvard Growth Study, the University of Colorado Child Research Council Study, the Brush Foundation Study of Western Reserve University (Cleveland, Ohio), and several studies at the University of California, Berkeley. Sontag (1971) states that in general these research programs shared several features. First, they were interdisciplinary with physicians, psychologists, anthropologists, and others taking a global approach – they studied 'the whole child'. Second, they were fastidious in terms of the methodology of data collection. Third, they collected data as an end in itself, as they posed no research questions or scientific hypotheses about human growth to be addressed. Fourth, they planned to continue data collection for 15 years or more.

With one exception, all of the American longitudinal studies ended when either funding disappeared, the justification for data collection without purpose could not be sustained, or, most importantly, the philosophy of the 'whole child' research approach was abandoned. The only one of these studies still active today is the Fels Longitudinal Study, which began in 1929. The sample of the Fels study are healthy, well-nourished boys and girls, living in small urban communities and rural areas of southwestern Ohio. Participants in the study are measured longitudinally, ideally once a year or more often, from birth to maturity for height, weight, and a variety of other physical and psychological characteristics. Alex F. Roche (b1921–), became director of the Fels study after Sontag (Roche, 1992). Roche states that the Fels study remained viable because members of its staff were willing to use the data to answer important questions about human growth, development and health. As an example both Sontag and Roche cite the work of Stanley M. Garn (b1922–), a member of the Fels team from 1952 to 1968, on the development of fatness from birth to old age, and the relation of growth in early life to health and disease in adulthood (see Garn, 1958, 1970). These were new directions in research in the 1950s and 1960s, and have become 'normal science' today.

Other notable consequences of the American longitudinal research program is the work of Frank K. Shuttleworth (b1899–d1958) who used the data of the Harvard Growth Study to design new statistical methods to analyze longitudinal data. His first major report on this was published in 1937, and many of his methods are still used standardly today. Howard Meredith (b1903–d1985), long associated with the University of Iowa Growth study, focused much attention on population, geographic, and sex-related differences in growth. He was instrumental in applying many new mathematical techniques to the description of growth curves and did much to sort out some of the genetic and environmental determinants of human growth.

The Brush Foundation and Spelman Fund supported a longitudinal study at Western Reserve University in Cleveland, Ohio. Katherine Simmons (no dates found) and T. Wingate Todd (b1885–d1938) produced reference standards from ages three months to 13 years for height and weight from these data. They also analyzed the correlation between growth in height, weight, and sexual maturation over time. Simmons and Todd came to the important conclusion that weight was not as reliable an indicator of healthy growth as height. This is because weight is the sum of many body tissues, and also includes the amount of fat and water in the body. All of these tissues and components of the body can vary with age, sex, nutritional status, state of health, physical activity, etc., which make weight too imprecise a measure of health.

Todd also used the hand–wrist radiographs collected during the study, and an extensive series of human skeletons he collected, to publish the first major *Atlas of Skeletal Maturation* (Todd, 1937). Todd's method to assess skeletal maturation was based on first selecting a 'representative' radiograph for each age and sex. Todd and others had already found that the rate of skeletal development of girls is advanced over that of boys. For example, from all of the radiographs of eight-year-old girls, Todd found the one that had both an equal degree of development of all the bones in the hand and wrist (and there are 28 such bones, or ossification centers to consider), and also had a degree of development that was average among all the eight-year-old girls (see Figure 2.4 for an illustration of hand-wrist radiographs). This process was repeated separately for eight-year-old boys, and then repeated again at every age. These 'average' radiographs then became the standard against which all other radiographs were judged. Todd's *Atlas* was used for many years and was revised in the 1950s into the form still used today (Greulich & Pyle, 1959).

Interest in the study of body composition may have been stimulated by Simmons and Todd's work. Major studies of body weight and its division, '. . . into "fat" and "lean" components . . .' (Baumgartner, 1997) began in earnest in the 1940s with the work of Albert R. Behnke. In the 1950s Ansel

Keys and Joseph Brozek expanded these studies to separate body composition into components, '. . . of water, protein, minerals, carbohydrates, or glycogen . . .' (ibid).

In 1928 the first of several longitudinal studies, The Berkeley Growth Study, was started at the University of California, Berkeley. Nancy Bayley (b1899–) was director until 1954, and she fully subscribed to the 'whole child' philosophy of these studies. Bayley was trained as a psychologist and one of her most notable contributions is the Bayley Infant Scales of Motor and Mental Development, which she created in 1940. She also received training in anthropometry from Sarah Idel Pyle (b1895–d1987) at Iowa. Bayley not only collected physical growth data (22 different measurements) but also analyzed it in novel ways. There were 61 infants recruited for the study, 31 boys and 30 girls, and 47 were followed to maturity. After three years of age, and then again after ten years and at maturity, Bayley calculated correlation coefficients between the measurements. These correlations indicate the amount of relationship between the measurements. Stated another way, the correlations can be used to estimate the degree of predictability of one measurement from another measurement, say the predictability of weight if stature is known.

Bayley was the first to find that correlations are much lower from birth to six months of age than from six months to one year of age. Correlation between measurements continues to rise until the age of two years (Bayley & Davis, 1935). Thus, it seemed that an infant's individual pattern of growth is a bit disorganized just after birth, but becomes better organized during the first two years of life. This discovery had important practical implications for the prediction of adult size at early ages. In 1952 Bayley and S. R. Pinneau published the first tables for predicting adult height using height and skeletal age measured at earlier ages. These prediction tables are still used by physicians and researchers.

In addition to work on longitudinal patterns of growth in external body size, several studies of the growth of internal organs and chemical composition by Richard E. Scammon (b1883–d1952) and Edith Boyd (b1895–d1977) are of importance. Figure 1.7 reproduces one of Scammon's classic illustrations of growth of the internal organs, and the body as a whole, during postnatal life. By necessity, this work was based on cross-sectional samples of cadavers, but Scammon and Boyd took a longitudinal approach when presenting their data. Their studies of the internal milieu of the human body started with the embryo and continued until old age. With this research the scientific and medical world gained its first accurate understanding that in terms of chemical composition, 'The organic body is not a closed system. It receives and liberates materials constantly' (from

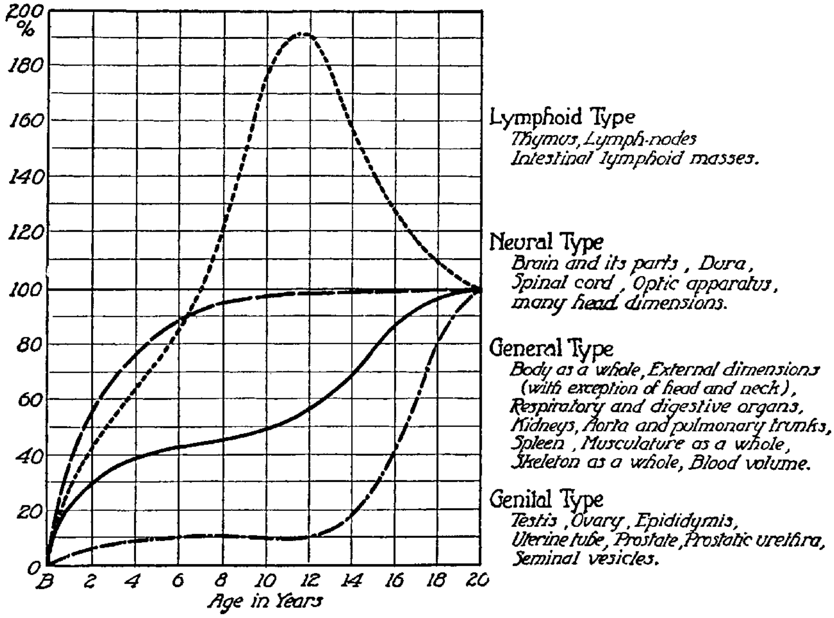

Figure 1.7. Four major types of postnatal growth curves from birth to 20 years, expressed as the percent of the total increment of growth (Scammon, 1930).

Scammon's 'Introduction' to Boyd, 1980). These studies of internal organs showed that the parts of the body do not develop or grow according to one grand pattern, rather there are several different curves of growth for different types of tissues.

The European studies

European longitudinal growth research had a slower start than in the United States and was probably delayed by the World Wars. In the 1920s there were two notable studies with a longitudinal component. The first was the Aberdeen, Scotland study conducted by Alexander Low (b1868–d1950). Low personally measured 21 dimensions of 900 newborn babies in 1923. He then remeasured 65 of the boys and 59 of the girls annually until they were 5 years old. The data were never properly analyzed until Tanner *et al.* (1956) produced a study of correlations between measurements taken at different ages. As part of their analysis, the authors also searched for the original participants of the Aberdeen study and found 42 of the men and 38 of the women. The adults were measured and correlations between the birth to age five year data and the adult data were calculated. Tanner and colleagues generally confirmed similar work by Nancy Bayley (discussed above). However, the Tanner group was the first to try to explain the pattern of increasing correlations from birth onwards. They emphasized that late in pregnancy, the fetus may be 'deflected very considerably' from its growth trajectory. After birth the infant slowly recovers toward that trajectory, 'somewhat after the manner of a growing animal who has passed through a period of not too severe malnutrition' (quoted material from Tanner, 1981, p. 347). A discussion of this perinatal 'malnutrition' effect is presented in the section on birth, and birth size, in Chapter 2.

The second longitudinal study of the 1920s was conducted by Rachel Mary Fleming (no dates known). She recorded the annual measurements of stature and head dimensions on children and youth three to 18 years old in England and Wales. She published the data in 1933 and her analysis included a longitudinal curve of growth in stature, head length and head breadth for each participant in the study – there were more than 100 participants. With this individual approach Fleming noted that some children grew throughout the teenage years, while others came to an early stop. Some children grew steadily during puberty and others experienced a rapid burst of growth followed by an end to growth. Some children were tall until puberty but then ceased growing and remained shorter than average as young adults. Today these patterns of growth are well know and reflect normal individual differences in the 'mode and tempo' (as Boas, 1930 called them) of growth.

Fleming also noted 40 individuals with unusual stature graphs. These children, of different ages, showed a longitudinal pattern of normal growth, a period of growth arrest, and then a resumption of normal growth. None of these children had been identified as growth-delayed during the cross-sectional medical examinations by the school physician. All attended a small village school and lived so far away from the school that they had to bring lunches to school, whereas other children attending the school, but who lived in the village, went home for dinner. The bag lunches were usually bread and jam, while the home dinners, the main meal of the day, were usually a hot lunch of meat and vegetables. The typical evening meals for all the children were bread, jam, and tea. Thus, only on weekends did the bag lunch children receive a full meal at dinner. When the school instituted a lunch program of meat and vegetable stew the stunted children returned to normal growth. The cause of the growth stunting seemed to be a combination of inadequate food intake, plus the energy expended in the commute to school.

Fleming's serendipitous finding of alterations in the pattern of growth associated with a change in school policy was to be repeated by another British researcher, Elsie M. Widdowson (b1906–), in the aftermath of World War II. Widdowson's research, discussed in detail in Chapter 6, found that a negative emotional environment during school mealtimes can suppress physical growth. The point to make here is that much scientific discovery is unexpected and found only when the individual researcher is willing to take the risk of exploring new research territory, trying new strategies and methods, and thinking in new ways about how things work. Rachel Fleming is not well known today, but she exemplified these characteristics of noteworthy research. She played a part in changing social policy, especially the introduction of free school lunch programs for undernourished children and the need to identify such children.

Fleming's work formed a basis for the discovery that children's nutritional requirements are divided between maintenance and repair of the body, work, and growth. When food intake is inadequate to meet all of the requirements, it is usually growth that suffers first. Later in life, growth-stunted children become adults with reduced performance in both physical and mental work capacity. In retrospect this seems obvious, but it took decades of research, tens of millions of dollars, and much intellectual debate to reach this conclusion (see Chapters 5 and 6). With the advantage of her longitudinal data, Fleming also performed statistical analyses to reveal several features of the human adolescent growth spurt; '. . . The results show that the fast-growing period for girls starts sooner, finishes earlier, and is less intensive than for boys. The sexes are equal up to 11 years of age, between 11–14 girls are taller than boys, but from 14 onwards the boys become steadily taller than the girls' (Boyd, 1980, p. 374). These well-known features of human growth at adolescence were new discoveries to late nineteenth and early twentieth century growth researchers. Many were puzzled by the growth spurt, some denied it really existed, and others had their Victorian sensibilities offended by the transitory 'ascendancy' in stature (as Tobias, 1970 refers to it) of girls over boys during adolescence.

During World War II the Oxford Child Health Survey was started by John Ryle (b1899–d1950). A total of 470 infants and children were recruited and measured between the ages of one month to five years of age. The data include anthropometric measurements, illness histories, social changes in the families of the participants, and radiographs of the hand and wrist, knee, and chest. From an historical perspective, the X-ray data are most important. Roy Acheson (b1921–) was a member of the team analyzing the data. To make use of the radiographs Acheson developed a new system to rate skeletal maturation. He was dissatisfied with the Todd method of assessing a bone age from the entire hand–wrist or a group of bones. Acheson wanted a simpler system and found that individual bones of the hand–wrist could be used to determine maturation. Acheson determined the number of identifiable stages of appearance of each bone as it matured. Each stage was given a number, 1, 2, 3, etc. A maturity score for any hand-wrist radiograph was easily calculated by giving each bone its stage number and adding up all of the numbers. A higher numerical total meant a higher skeletal maturity score. The score could be treated just like any other measurement, such as height in centimeters, for statistical analysis. This simplified procedure for skeletal maturity was refined and standardized by Tanner and colleagues (1983b) into a widely used clinical method.

Soon after World War II, longitudinal research in Europe began in earnest. The British Harpenden study started in 1949 and continued until 1971 (Tanner, 1981). Other longitudinal studies were started in Paris, Zurich, Stockholm, London, Brussels. These studies were coordinated by the International Children's Center (ICC) in France. There was an ICC sponsored study in the United States as well, the Louisville (Kentucky) Study. This was, and is, a longitudinal study of twins (results are discussed in Chapter 7). All of the ICC studies followed a standardized procedure for anthropometric measurement and data recording. This was a major advance as earlier studies often used methods of measurement and recording that made comparisons between data sets difficult. The focus of these ICC studies, and the Harpenden Study as well, was medical, and the research personnel were mostly pediatricians and endocrinologists. James M. Tanner (b1920–), a member of the ICC board, states that in contrast to the 'whole child' approach of the American studies, the European longitudinal research was concerned more with growth pathologies. Important medical discoveries were made by these studies, but there were also advances in understanding the basic biology of human growth. It is commonplace in biology that we come to understand how a normal system operates by studying what happens when things go wrong. Tanner advanced the cause of growth research in Europe by promoting many of these studies and by publishing several major works. His book *Growth at Adolescence* (1955 and 1962) summarized the state of knowledge of normal and pathological growth derived from all of the research of the first half of the twentieth century. Tanner and colleagues, especially his long-time research partner Reginald Whitehouse (b1911–d1987), also published some of the most widely used modern references for growth in height and weight, the stages of sexual maturation, and for skeletal maturation (Tanner & Whitehouse, 1975; Tanner *et al.*, 1983b).

Longitudinal studies in the developing world

The ICC also sponsored longitudinal studies in Africa; the Dakar and Kampala Studies. By the early 1960s some results of these studies were published, and the findings were puzzling. In some respects African infants and children were advanced over Europeans, such as in skeletal development. In other measures, such as height, weight, and fatness, Africans were smaller than Europeans. Moreover, the differences between populations increased with age. Some researchers were content to ascribe these growth differences to genetics, but other scholars looked more to the ecology for human growth of Africa and its history. Poverty is the word often chosen to best describe the human ecology of Africa. The history of Colonialism was cited by some workers to explain the origins of much of this poverty. There was little hope for extensive longitudinal research in Africa to settle the question of 'genes versus environment'. By the 1960s, Europe was losing its colonies in Africa and there was little popular sentiment in Europe, or North America, to invest the resources needed to conduct research.

In Central America research was underway to examine the environmental and genetic determinants of human growth. Robert MacVean (b1917–), an American who settled in Guatemala after World War II, helped to establish the American School of Guatemala as a laboratory school (one that conducts research and training in addition to teaching) in 1948. A longitudinal study of child, juvenile, and adolescent development was chosen as the basic research project of the laboratory school program. Data collection started in 1953 and until 1963 was limited to all of the students at the American School, an expensive private school. Beginning in 1963 other schools, representing middle and low socioeconomic status (SES) families in Guatemala City, were added to the study. All of the students attending each school were measured once each year for height, weight, and hand grip strength, and eruption of the permanent teeth; a hand–wrist X-ray was taken. Several tests of cognitive development and school performance (e.g., IQ and reading tests) were also administered. As the measurements were taken from the entire school population of each year, this was not a pure longitudinal study. Children might have left or entered the school at any time, although many of the students did continue through the elementary grades and on to complete secondary school. This study, now called 'The Longitudinal Study of the Growth and Development of the Guatemalan School Child', became one of the first large-scale mixed-longitudinal investigations of human growth.

Actually, the mixed-longitudinal study is considered a very powerful statistical design for growth research. In this design, subjects of different starting ages are measured for several years. The overlap in age means that data covering much, or all, of the growing years may be collected in just a few years rather than two decades. In addition, each age group serves as a check against other age groups to ascertain if the data collected are representative, that is, that the particular individuals of any age group are typical in terms of the measurements taken. In a pure longitudinal study, peculiarities of the sample of children, such as a disease or social stigma, may invalidate application of any findings to the population at large.

Masses of data were collected, but little analysis was conducted until Francis E. Johnston (b1931–), an American anthropologist, became a consultant to the study in the late 1960s. From 1974 to 1976 the present author (Barry Bogin, b1950–), one of Johnston's students, did his doctoral dissertation research in Guatemala and became a consultant to the longitudinal study as well. I suggested adding measures of body composition (triceps and subscapular skinfolds and arm circumference) to better estimate nutritional status, and these have been taken on all participants since 1976. I also suggested adding a school with a **Maya** population. Maya are the majority ethnic group of Guatemala. Maya ethnicity is characterized by language (there are more than 20 Maya languages in Guatemala), traditional clothing styles, religious practices, and rules for cultural behavior (such as kinship and family organization). In many ways the present-day Maya of Guatemala are the cultural descendants of the Classic Period Maya who constructed the ceremonial centers of pre-contact Mesoamerica (places such as Tikal and Palenque). Prior to 1976, the schools participating in the longitudinal study were comprised primarily of **Ladinos** (attending all of the schools) or Europeans/North Americans (attending the American School). Ladinos are the second largest ethnic group in Guatemala. In a sociocultural sense, Ladinos are descendants of the Spanish conquistadors who ruled Guatemala for the past 400 years. In 1979 a Maya school, comprised mostly of children from very low SES families, was added to the study.

The important results of this study are not discussed here, but are incorporated into many discussions of human growth and development throughout this book. From an historical perspective it is important to state now that the American School study, and its enlarged successor, was the first major research program of its type in any developing nation. Moreover, the study is still operating today, making it one of the longest-lived projects of its type, a resource of unparalleled data which remains to be fully exploited.

Guatemala was also the site of the second major longitudinal study of human development in the developing world. This was the research program of the Institute of Nutrition of Central America and Panama (INCAP), and is sometimes called the 'Four Village Study' because participants were recruited from two small (about 500 person) and two larger villages (about 900 persons) in rural Guatemala (Martorell *et al.*, 1975). Except for population size, the large and small villages were fairly homogeneous in terms of ethnicity (all people were Ladinos) and other social and economic factors. This was a study of growth and development from birth to age seven years. Participants were recruited when their mothers were pregnant, at their birth, or soon thereafter. This was also an experimental study. The participants in one large and one small village received a dietary supplement called *atole*, the local term for a gruel usually made with corn meal. The participants in the other villages received a low calorie *fresco*, the name for a cool refreshing drink. When the study started in 1969, the *atole* supplement contained protein, carbohydrates, vitamins and minerals. The *fresco* contained only carbohydrates, water, and artificial flavor. From 1971 to 1977, when the study ended, it was decided to increase the vitamin and mineral content of the *atole* and add equal amounts of these vitamins and minerals to the *fresco*, so that the analysis could be confined to the energy containing nutrients, the protein and carbohydrates.

The major research question of the INCAP study was to what extent a nutritional supplement, especially of protein, could enhance the physical and mental development of children. The infants and children living in the four villages suffered from both kwashiorkor, an acute type of undernutrition that can kill, and chronic mild-to-moderate undernutrition, not severe enough to kill a person directly. In the 1960s it was hypothesized that chronic mild-to-moderate malnutrition could retard growth and development and reduce the body's ability to fight off diseases, which could kill. There were also hypotheses that poor, rural people of less-developed countries like Guatemala had 'adapted' in some way to a limited food supply, and would not benefit from additional food. However, the INCAP study proved that lack of adequate nutrition is a major factor retarding the physical growth and mental development of Guatemalan children. The infants and children supplemented with *atole* grew significantly taller and heavier than the children receiving the *fresco*. The *atole*-supplemented children also performed better on cognitive tests and were more likely to enter school. By extension, these results could also apply to children living in poverty in Africa, Asia, and the developed nations of Europe, North America, Australia, and Japan. To test this, several studies were started, especially in Asian countries, that followed in the steps of the INCAP project (specific findings of the INCAP study and the others will be presented in later chapters).

Other basic research related to growth

During the twentieth century, research into genetics of growth became possible. The rediscovery of Mendelian principles in the year 1900 and the characterization of the DNA molecule (deoxyribonucleic acid) in 1952, are two of the major historical events influencing growth research. An early emphasis on 'racial genetics', *à la* Galton, gave way to modern population genetics by the early 1950s. Methods to study the influence of genes at the individual and family level were also developed, including studies of monozygotic and dizygotic twins and studies of family pedigrees (see Chapter 7 for details). By the 1960s research on the effect of chromosomal variations and abnormalities had appeared. To date, the only evidence that specific genes exist for growth in size, body proportions, body composition, and rate of maturation is derived from studies of sex chromosomes. Garn & Rohmann (1962) proposed that genes on the X chromosome control some aspects of the development of skeletal and dental tissue. J. German and colleagues (1973) proposed that genes on the Y chromosome stimulate the growth of skeletal tissue to produce the greater average stature, arm length, and biacromial breadth (shoulder width) of men versus women. The specific sequences of DNA responsible for these effects are still not known.

An important corollary of these genetic studies was the discovery of new ways in which the environment can produce effects on growth that seem to be hereditary. In 1964, both in Poland (Malinowski & Wolanski, 1985) and the United States (Bloom, 1964) researchers found that the heritability of some phenotypic characteristics (such as stature) is higher in groups of parents and children living under low socioeconomic status (SES) conditions, but that the heritability is lower when children live under more favorable SES conditions than did their parents. Benjamin S. Bloom (b1913–) formalized this observation into what he called the 'powerful environment hypothesis'. By this Bloom meant that when succeeding generations of people grow up under the same, or similar, environment of extreme deprivation or privilege, each generation will develop similar physical and cognitive characteristics. A high correlation between parent and offspring in any measurable trait is often taken as evidence of a genetic effect. When living under powerful environments, however, the traits of both generations may be altered in similar ways without any genetic contribution. Polish researchers were able to show that when the negative influence of the environment is ameliorated the correlation between generations declines, sometimes effectively to the point where there is no correlation (reviewed by Wolanski, 1967). In many ways the powerful environment hypothesis complimented and extended the work of Boas and other anti-eugenics researchers.

Technological developments

The technical basis for all of the research on growth lies in the precision of the instruments used to measure lengths, weights, circumferences, and other dimensions and the accuracy and reliability of the methods of measurement. Growth research technology and methods, beginning with the invention of the anthropometer (a device to measure stature) by Johann S. Elsholtz (b1623–d1688) in 1654, are reviewed by Noel Cameron (1984). Cameron also reviews the development of skinfold calipers, radiography, photogammetry, and data analysis. These devices are mentioned here briefly, and then discussed in greater detail later in this chapter and other chapters where relevant.

The anthropometer was developed to measure lengths of the body, especially stature. Eventually, it was modified to measure lengths of body segments (arms, legs, etc.) and then was used to measure body breadths, such as the **biacromial** ('shoulder') and **bicristal** ('hip') breadths. Skinfold caliper measurements, first used by Ludwig W. Kotelman (b1839–d1908) in Germany in 1879, have become the most widely used method to evaluate subcutaneous fat, and its relation to growth, body composition, health, and behavior. Modern anthropometers and calipers are designed to produce both accurate and reliable measurements, which are needed especially in longitudinal research where the same individual is measured repeatedly.

The discovery of X-rays in 1895 was soon followed by applications to document skeletal and dental development. Several works depicting normal skeletal development appeared starting in 1904 and culminating in Todd's 1937 *Atlas of Skeletal Maturation* (discussed above). Todd's atlas was revised by William Walter Greulich (b1901–d1987) and Sarah Idel Pyle (b1895–d1987) and published in 1950 as the *Radiographic Atlas of Skeletal Development of the Hand and Wrist*, which is still widely used for basic and clinical research (Greulich & Pyle, 1959). Longitudinally collected radiographs from the Oxford Child Health Survey (see above, Acheson, 1954), the Fels Study, and the Harpenden Study were used to create newer methods for the assessment of skeletal maturation (Roche *et al.*, 1975a; Tanner *et al.*, 1983b). These newer methods are more precise in the prediction of adult stature, which are a concern of parents, pediatricians, the military, and the ballet – ballerinas should not be too short or too tall.

Photogammetry is a method of growth evaluation based upon '. . . photographs of a subject posed in a particular position to facilitate either visual appraisal of the body . . . or detailed measurement of body parts . . .' (Cameron, 1984, p.142). One of the primary areas of use of photogammetry is **somatotyping**, which as developed by William H. Sheldon (b1898–d1977) relates human morphology to physical and psychological behavior (Sheldon, 1940). Progress in imaging, such as PET scans (positron emission tomography) and MRI scanning (magnetic resonance imaging) allow for the non-invasive examination of internal soft tissue and for the examination of internal structures of fossil human ancestors without damaging the specimen. There are also devices under development that will scan the human body and automatically derive many standard anthropometric measurements (Jones, 1995). These devices, along with advances in data collection strategies, statistical processing, and computerization have, and will continue to, revolutionize growth research.

Endocrines and growth control

In the early 1960s, Tanner stated, 'There exists at present no entirely convincing and coherent theory of endocrinology of adolescence . . .' (1962, p. 176). It may be added that an understanding of the endocrine regulation of growth at all other stages of life, prenatal and postnatal, was equally poor. In 1974 Melvin Grumbach and colleagues published *Control of the Onset of Puberty*, which contains several 'coherent and convincing' theories of the endocrinology of growth. Today, models and theories of hormonal control exist for all other stages of growth (Box 1.1 describes the meaning and use of models in the study of growth). The rapid pace of research in this field is due both to technological advances in the assay of hormonal factors and advances in understanding how hormones exert their influences on human growth and development. The history of human growth hormone (hGH) and the insulin-like growth factors (IGFs) are examples. The existence of hGH was demonstrated in 1944, and the first IGF in 1957. The process by which these hormones work was largely speculative until several lines of research were combined into the 'duel-effector' model (Green *et al.*, 1985 – Chapter 7 details this model). Anthropological interest has been stimulated by the discovery of human population differences in the presence of these hormones. For example, African pygmy populations seem to be deficient in one of the IGFs (Merimee *et al.*, 1981), or its receptor (Baumann *et al.*, 1989).

There are at least six hypothalamic hormones, eight pituitary hormones, a dozen or more hormones secreted from other endocrine glands (e.g., thyroid, adrenal, ovary and testis) and a host of growth factors produced throughout the body that regulate human growth. Each of these has a

Box 1.1. Models in biology: description and explanation

Models are representations that display the pattern, mode of structure, or formation of an object, a process, or an organism. A model may also serve as a standard for comparison, between hypotheses that test human understanding of how some physical or biological phenomenon operates and the actual nature of that phenomenon. For example, models are often employed to study aspects of human growth, such as the adolescent growth spurt, and aspects of maturation, such as the onset of puberty. No model can represent a complete understanding of the regulation of human growth and maturation, for that would require inclusion of all of the many genetic, endocrine, and environmental factors, and their interactions, that influence the developmental process. However, models are easier to construct, to understand, and to test than total reality, since the models usually represent only a small portion of total amount of this detail.

Two types of models are used by growth researchers. The first type describes a result. For instance, a series of longitudinal measurements of the height of a child may be compared to a mathematical formula that fits a curve to the growth data. The mathematical parameters of the curve are chosen to model the actual increases in height of the child over time. The fit of the curve may be quite precise, that is, the model describes growth very well. However, this type of model does not explain why increases in height occur or when changes in the rate of growth in height are likely to take place.

A second type of model attempt to describe a result as well as explain some of the determinants of the observations. An example is D'arcy Thompson's model for the growth of the Nautilus, presented in Figure I.3. The equiangular spiral, the mathematical function that describes the growth of the *Nautilus* shell, implies that the proliferation of shell material occurs at a constant rate; proportional to the amount of tissue already produced. Thus, volumetric growth rate constantly accelerates, producing ever-larger chambers in the shell. Unlike a purely descriptive representation, D'arcy Thompson's model predicts, with great precision, the size and volume of the next chamber to develop.

A predictive model of growth has both mathematical and biological meaning, and is preferred to descriptive models. Applied to human growth, such a model might attempt to describe and predict growth in height from birth to maturity. For instance, if it is assumed that a genetic program aims the growth of a child toward an 'ideal' size, as might be the case with strong genetic selection for size, then the rate of growth should be proportional to the difference between present size and ideal size. Departures from the predicted rate of growth, such as the mid-growth spurt during childhood and the adolescent growth spurt, may be explained by additional hypotheses about the regulation of the growth. In this way a model building process is encouraged, which leads to the testing of hypotheses against observations of growth and maturation and the eventual formulation of a theory of human development.

history of discovery and understanding similar to hGH and the IGFs (reviewed in Chapter 7). Initially, most of the information on hormone regulation was derived from studies of children with endocrine pathologies. Newer, non-invasive assay methods (e.g., detecting hormones in saliva rather than blood or tissue) now permit the study of large samples of normal children. This should lead to a more comprehensive understanding of endocrinology and growth in the next decade or so.

Growth theory

The public health work of the nineteenth century and the large-scale longitudinal studies of the twentieth century provided a wealth of growth data. Advances in fields such as molecular biology, endocrinology, nutrition, and the social sciences allowed scientists and physicians alike to turn the study of human growth into a research and medical specialty. However, all of these data and technical advances were primarily descriptive in nature. They told us how children grew and how their growth was affected by heredity and the environment, but they could not tell us why. To understand the 'why' of growth and development a theoretical approach was needed. For example, the cell theory of Matthias Jakob Schleiden (b1804–d1881) and Theodor Schwann (b1810–d1882), proposed in 1838, made it possible to understand the earlier work of von Baer, who had described the different germ layers of the developing embryo. These layers were distinct types of cells that gave rise to the different tissues and organs of the body. With the publication of Charles Darwin's (b1809–d1882) *Origin of Species* in 1859 biological research became a modern theoretical science. The scientific method of experimentation and hypothesis testing was increasingly applied to biological questions, including the control of growth and development.

One example is the work of Ernst Haeckel (b1834–d1919), who proposed the theory of recapitulation during embryological development – that is, the development of the individual organism follows the evolutionary history of life (see Haeckel, 1874). In contrast, von Baer in his 1827 study *De Ovi Mammalium at Hominis*, emphasized that during development embryos from different classes of animals move away from common forms, thus there is no recapitulation. This dispute stimulated experimentation and refinements to both hypotheses. Eventually, recapitulation was discredited, but Haeckel's work gave rise to interest in growth theory.

Many other scientists contributed to growth theory during the late nineteenth and early twentieth centuries, but the work of one person stands out more than any other. D'Arcy Wentworth Thompson's (b1860–d1948) book, *On Growth and Form* (1917, 1942, 1992), is a *tour de force* combining the classical approaches of natural philosophy and geometry with modern biology and mathematics to understand the growth, form, and evolution of plants and animals. Thompson visualized growth as a movement through time. Scientists from Buffon to Boas had studied the velocity of growth; Thompson made it clear that growth velocities in stature or weight were only special cases of a more general biological process. The development of flower parts in plants or the evolution of antler size in mammals were also examples of growth as a movement through time. Thompson developed the concept and methodology of using **transformational grids** to quantify the process of growth during the lifetime of an individual or during the evolutionary history of a species (see Figure I.2). Until the advent of high-speed computers, which are needed to carry out the mathematical procedure of the method, the transformational method was difficult and slow to apply and, hence, little used by other biologists (Bookstein, 1978). Even so, *On Growth and Form* provided an intellectual validity to growth and development research and stimulated succeeding generations of growth researchers to think about growth in new ways (e.g., see Huxley, 1932; Tanner, 1963; Thom, 1983; Bogin, 1980, 1991).

Conclusion

This highlights some advances in the study of human growth. By the 1940s many of the basic principles of physical growth and development were known. Since then, researchers have been making progress, often slowly, in unraveling the underlying biology of physical growth. One fact is clear – all normal, healthy, and well nourished children follow the same basic pattern of growth from birth to maturity. Research also shows that a common pattern of human development and growth occurs during the prenatal period as well. The next chapter describes these major features of human growth and development from conception to death.