GROWTH AND DEVELOPMENT OF CHILDREN

EIGHTH EDITION

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Preface

Children are our most enduring and vulnerable legacy. For nations as well as for individual families, they represent the link between past and future, between experience and promise. The nurturing of future generations is a basic, and most important, human activity.
—From the preamble of the Constitution of the American Academy of Pediatrics

Study of the characteristics of normal growth and development of children has become a large and important part of the practice and teaching of pediatrics and of research in all fields related to child health. Included in such studies are not only physical measurements but also observation of all of the dynamic physiologic and psychologic changes taking place from conception to maturity. In preparing the present volume the author, as in previous editions, was faced with the problem of determining a logical limit to the material to be presented. The book was designed to be of practical size for greatest usefulness and yet to be inclusive enough to be of value to a broad range of workers involved in the care of children. Helpful criticisms from those who have read previous editions were carefully considered in preparing the present one. It is hoped this has resulted in few important omissions and improved clarity of the text.

Many more articles were examined than appear as references at the end of each chapter. The selection of the references was made to include, wherever possible, those of a review nature and recent origin and from sources generally available so that they may be used to augment material given in the text.

I must acknowledge my very sincere appreciation to Dr. Hilda Knobloch and Dr. Ralph Gibson who made important contributions to chapter 6 in previous editions, and much of their material remains as originally presented.

Major changes or additions since the seventh edition include new material on maternal-fetal endocrinology, physiology of the low birth weight infant, the controversy concerning maternal-infant bonding, development of the central nervous system in the fetus and infant, and environmental

influences affecting that development. Many additions and a few deletions as well as attempts to improve the presentation of material have been made throughout the book.

Year Book Medical Publishers has continued to be most cooperative and supportive in the preparation of this edition. Finally, it is the author's sincere hope that this and previous editions have made at least a modest contribution to the improvement of child health in all of its aspects.

GEORGE H. LOWREY, M.D.

Contents

1 / History and Introduction

Know then thyself, presume God to scan,
The proper study of mankind is man.
—Alexander Pope

Historical Background

The earliest records concerning the science of child health were primarily concerned with the preservation of life and therefore describe in some detail the proper methods of infant rearing and the diseases common to each age. From the time of ancient Egypt through the classical Greek and Roman periods, there was obvious interest and there were many descriptions of the various stages of human development. Both Hippocrates (ca., 460 to 370 B.C.) and Aristotle (384 to 322 B.C.) wrote rather elaborate accounts of the age changes in form and function. An interesting excerpt from Aristotle's *Historia Animalium* describes adolescent changes: "When twice seven years old, in most of the cases, the male begins to engender seed, and at the same time hair appears on the pubis. . . . About the same time, the voice begins to alter, getting harsher and more uneven, neither shrill as formerly nor deep as afterward, nor yet of any even tone, but like an instrument whose strings are frayed and out of tune, and it is called, by way of by-word, the bleat of the billy goat."[37] Unfortunately, there is very little in the way of quantitative information available, e.g., height, weight, or other measurements. Nutrition, education, and discipline were discussed in some detail, but little of this literature could be considered based on any kind of sound observation. Superstition and religious dogma played a major part in the rules laid down for bringing up children. Often the old texts would give an account of the preparation for birth, care of the newborn, nursing, and the introduction of other foods and then deal with specific diseases. Standards for normal growth and development did not exist. It was a situation in which the only measurement of good health was survival.

The first publication to treat the differences between the anatomy of the

infant, child, and adult was by Gabriele Zerbi, a professor at Padua, in 1502.[1] Leonardo da Vinci (1452 to 1519), the greatest artist and scientist of the Italian Renaissance, made drawings of the fetus in utero that were the first to be accurate.[37] The Flemish physician and anatomist Andreas Vesalius (1514 to 1564), while at the University of Padua, published results of his dissections of the fetus correcting many errors, particularly of the circulation, that had been handed down from Galen's time (c.a. 130 to 200 A.D.). Considerable knowledge of the normal and abnormal is apparent from the art of this period. Albrecht Durer (1471 to 1528) and Titian (1477 to 1576) depicted infants and children in proper anatomical proportions. Durer's careful analysis of infant proportions was strikingly accurate. Several of the paintings by Diego Velazquez (1599 to 1660) are beautiful examples of normal children as well as several types of dwarfism, including achondroplasia. *The Anatomy Lesson of Doctor Frederick Ruysch* by Jan van Meck, painted in 1683, displays the famous anatomist dissecting a newborn baby with the cord and placenta attached. In another corner of this masterpiece is the articulated skeleton of an infant. Ruysch (1638 to 1731) is best remembered for his studies of the vascular system, including the relationship of the fetal and maternal vessels in the placenta. He was a professor at the University of Leiden.

In 1651 William Harvey, better known for his work on the circulation, published his *Exercitationes de Generatione Animalium*, which, although not entirely accurate, helped to dispel the concept that the human embryo was completely preformed from the time of conception and helped to launch embryology as a science. François Mauriceau[2] was the first to give accurate descriptions and illustrations of the proportions of the fetus and newborn. His book, which included some information concerning the physical measurements of infants, was printed in 1694. Although Mauriceau was the greatest French obstetrician of his time, his observations were not free from error. The average weight of the newborn was given as between 14 and 15 lb (based on our present standards). This error was perpetuated in many translations and was not properly challenged until the German J. C. Roederer read a paper in 1753 before the Royal Society of Göttingen. This work may be considered the first to record normal birth weight and length accurately.[2]

Albrecht von Haller (1708–1777), the great Swiss physiologist, had published a similarly correct indication of birth weight a year prior to Roederer, but his observation was an isolated one and his method of arriving at the figure was not given. In England Joseph Clarke had the distinction of being the first to report correct figures for weight at birth and also normal head circumferences at this age. His paper was presented at a scientific meeting in 1786 and was based, for the first time, on what we would consider to be adequate data.[3]

The oldest, and still one of the best, longitudinal studies of the growth of a child was that by Count Philibert Gueneau de Montbeillard, which was completed in 1777 but was published by his friend, Buffon, in 1837. This was a curve of the body length of his son from birth to 18 years, recorded every six months. This study is often quoted as a classic accomplishment, and justifiably so.[4] Buffon was the first to postulate the seasonal changes in growth, based on the figures that were then available to him. He also reported on the smallest adult dwarf so far recorded, a man 36 years of age who was only 16 in. (39 cm) tall.

John Hunter (1728 to 1793) was a very colorful figure in the history of English medicine, and his fame is based upon his discoveries relative to surgical procedures and investigations of infections. However, his interests were broad and included records of measurements of the human body. His museum in London contained a number of skeletons of dwarfs and giants. The most renowned was that of the Irish giant O'Brien. The story of Hunter's acquisition of the body against O'Brien's last wishes and carefully laid plans makes fascinating, though macabre, reading. An apt pupil of Hunter was Samuel von Soemmerring (1775 to 1830) from Poland. He first described in detail the condition of achondroplasia with measurements and drawings, which were published in an atlas of congenital anomalies in 1791.

Certainly we owe the credit for the first complete study of the physical growth of children to the Belgian astronomer and statistician Lambert Adolphe Jacques Quetelet (1796 to 1874). He was director of the Royal Observatory in Brussels for many years and contributed a large number of articles on many scientific subjects during his life. Possibly because of his failure to find satisfactory material on growth in his search of the literature up to that time, he carried out extensive studies of heights and weights of male and female subjects of all ages. These findings were published in 1835.[6] His figures of body dimensions have been used for comparative purposes in growth studies until recent times. The term *anthropometry* was also originated by Quetelet.

A very complete statistical study of the growth of children from the Boston, Massachusetts area was made by H. P. Bowditch[7] in 1875. Bowditch was the grandson of Nathaniel who was a famous mathematician and navigator. His graduation from Harvard Medical School in 1868 was delayed for four years because of his participation in the Civil War as a member of the Massachusetts Cavalry. After a brief period of study in Europe, he returned to Harvard to become a member of the faculty and established the first physiology laboratory for students in the United States. Later, as dean of the school, he became an influential leader in medical education. Bowditch's observations on growth were made on several thousand individuals classified according to age. In a number of subsequent publications, he presented numerous tables and analyses pertaining to height and

weight, nationality, economic backgrounds, and the patterns followed by each sex. We can be thankful that a man of his caliber carried out these studies because he set a sterling example for those who followed him in similar endeavors. His published material served as the usual guide for comparison in most of the standard pediatric texts until well into the 20th century.

William Camerer[25] in Germany collected important data relating to various aspects of metabolism and energy requirements for growth from birth to adult size. These studies were published over a period from 1880 to 1896. Camerer's material included physical measurements for infants and children younger than those included by Bowditch. Together, the work of these two constituted the standards used for measuring physical growth for nearly half a century.

In 1921 and 1922, respectively, R. M. Woodbury and B. T. Baldwin[8] published new charts depicting the growth of children in the United States from birth through adolescence. The former's material consisted of a widespread population of children under six, while the latter's consisted of the entire age range, but of a more homogeneous socioeconomic group. A large number of growth charts have been published in this country and abroad in the past 50 years. A few of these are described in some detail in chapter 4.

The great increase in interest in physical growth and development that was taking place at this period was evident from the appearance between 1900 and 1925 of nearly 3,000 published titles on the subject.[1] Krogman[9] collected over 2,000 references published between 1914 and 1940. The bulk of work following World War I began to shift from Europe to the United States and has continued so until very recent times. Part of this undoubtedly was a result of the aftermath of the war, but much of it resulted from the change in the character of the approach to children's health and the rapid growth of American medicine. More and more emphasis was being placed on a sound knowledge of the subject in the fields of pediatrics, preventive medicine, and education. The very essence of preventive medicine in children has as its goal normal growth and development.

Purely anatomical studies of the infant and child began in the 14th and 15th centuries. Modern anatomy in this field was largely confined to the European literature, mainly German, until after World War I. Among such works may be mentioned Henke's *Anatomie des Kindesalters* (1873), Ribemont's *Recherches sur l'anatomie topographique de fétus* (1878), Symington's *The Topographic Anatomy of the Child* (1887), and Stratz's *Der Körper des Kindes* (1904). R. E. Scammon's summary of anatomy in Abt's *Pediatrics* is a rich and valuable compilation printed in 1923.

A number of research centers for the study of growth and development

were established as early as the 1920s, including the Iowa Child Welfare Research Station, the Brush Foundation at Western Reserve University, the Yale Clinic of Child Development, the Child Health Division of the Harvard School of Public Health, the Child Research Council of the University of Colorado, and the Fels Research Institute for the Study of Human Development, Antioch College. One of the important reasons for the creation of such centers was the longitudinal study of the child. Although cross-sectional studies have value, more detailed knowledge can be obtained by following individual children throughout part or all of their growing period. In 1923 the National Research Council sponsored a Committee on Child Development to foster and coordinate the rapidly growing research in this field. The White House Conference of 1930, and the resulting publications, may still be considered one of the finest sources for material on growth and development of children.[13] Although all of the pediatric journals carry articles on the subject, special publications now came into existence. *Growth: A Journal for Studies of Development and Increase* appeared in 1937 and *Child Development* a few years prior to that.

In 1895 the discovery of x-rays and their properties by Roentgen offered a means of studying the growth of the bony structure of the body in the living. Since then great advance has been made in standardization of techniques of roentgenology and in the appraisal of bone growth. Preston Hickey of Detroit in 1904 reported on his studies of the skeletal maturation of the fetus, infant, child, and adolescent. Pryor (1905)[10] and Thomas Rotch (1907)[5] were the first to show the usefulness of this method in estimating maturation by the examination of the number of bones and their size and shape in the hand. Rotch, who was the first professor of pediatrics at Harvard University, also made other researchers on the "physiologic" age of children. Although T. Wingate Todd published his well-known *Atlas of Skeletal Maturation* in 1937 as a result of his studies carried on at the Brush Foundation, similar but less complete outlines were available previously, based on the work of Baldwin and his co-workers (1928), P. C. Hodges (1933), and C. D. Flory (1936). It is interesting to note that at the same time Pryor and Rotch were discussing physiologic age in terms of skeletal development, an educator, C. W. Crampton,[11] was discussing the same subject in terms of body development, especially the appearance of secondary sexual characteristics. The latter author is credited with being the initiator of the term *physiologic age* (1908).

The first paper to describe the roentgenologic appearance of the fetus was printed the year following the discovery of the x-ray and was written by E. P. Davis of New York. Escherich of Graz, Austria, presented the initial lengthy report on x-ray examination in infants and young children and discussed its potentials as a diagnostic tool (1898).[12] Reyher's mono-

graph of 1908 was the first review of the literature in German, and Rotch's *The Roentgen Rays in Pediatrics* appeared two years later in the United States. Subsequently a number of fine texts have been published, of which Caffey's *Pediatric X-Ray Diagnosis* is outstanding (first edition, 1945).[12]

The concept of types of structure of the body and their possible relationship to specific growth patterns, personality, and predisposition to disease is an ancient one. Hippocrates[23] described the tall thin type as *habitus phthisicus* with an increased incidence of tuberculosis; the short obese person was designated *habitus apoplecticus* with susceptibility to vascular accidents. Shakespeare alludes to the personality of different types in *Julius Caesar:*

> Let me have men about me that are fat
> Sleek-headed men, and such as sleep o'nights.
> Yond Cassius has a lean and hungry look;
> He thinks too much: such men are dangerous.

Leo Rostan of France in 1828[14] proposed that people be classified in terms of body build under one of four categories: *digestif* (short and obese), *musculaire* (solid and muscular), *respiratoire* (combination of *musculaire* and *cerebral*), and *cerebral* (tall and thin). Nearly one hundred years later, Ernst Kretschmer.[15] in Germany described three body types and related them to personality traits and mental diseases. The round-faced, well-nourished person was called *pyknic* and characterized as an extrovert. Manic-depressive psychosis was more commonly found in this group according to Kretschmer. *Asthenic* was the term applied to the tall and thin person who was introverted and the type in which the schizoid person was identified. Between these two in temperament and physique was the *athletic* type. Although little credence is given today to the association of somatotype with specific personalities or diseases, its rough clinical evaluation may have some value in predicting growth patterns.

A few comments may be given to the history of growth studies of special age groups. Although a number of treatises had been written on fetal growth prior to Von Baer's important work of 1829 describing the germ layers and their formation in the embryo, these earlier works broke no new ground not explored by Mauriceau in the late 17th century. It was not until after the formulation of the cell theory by Schleiden and Schwann (1839) that the significance of Von Baer's work was appreciated. A classic summary of anatomy of human embryos *(Anatomie menschlicher Embryonen)* was brought out by His of Germany in 1880. After the turn of the century Dafner of Germany and Mall in the United States supplied accurate figures on the age, growth, and external form of the human embryo.[26] From here

to the premature infant would seem but a short step. However, growth and development of these "problem children" resisted concentrated attention until late in the 19th century, when Camerer brought attention to them in his studies, already mentioned. Ylppö[17] of Finland published in 1919 the first comprehensive report of the physical growth of the premature infant through childhood with many tables of measurements. Hess et al.[18] of Chicago wrote about their experiences with a group of premature babies followed for several years; this was in 1934. Although recent work has thrown some doubt upon certain conclusions of these men, their studies are of more than historical interest.

Charles-Michel Billard, who died at the age of 32, published in Paris in 1828 the first monograph on the newborn infant, which began with a careful consideration of the expected height and weight and color of skin, attitudes, and pulse rate. This text, *Traité des maladies des enfants nouveaunés et à la mamelle*, long remained the standard and was translated into several languages. Another milestone in pediatric literature was August von Reuss's *Krankheiten des Neugebornen*, printed in Vienna in 1914. Like Billard's book, it was primarily concerned with disease but outlined normal growth and development and the meager knowledge then available of physiology of the neonatal period. Unique in this field was the first edition of Clement A. Smith's *The Physiology of the Newborn Infant*, which immediately became a classic upon publication in 1945.

Intensive study of the growth and development of the adolescent is of relatively recent origin. Wilhelm Kotelmann (1839 to 1908) studied the physical development of students in private and public schools in Hamburg and noted the individual differences in the adolescence growth spurt and that children of the upper socioeconomic class at all ages were superior in mean height and weight to those of the public schools. His observations were first published in 1879.[42] Karl Vierordt (1818 to 1884)[19] of Tubingen along with Bowditch made important contributions at about the same time in the late 1870s. They divided periods of growth according to age and to other aspects of maturation recognizing the adolescent spurt and also that girls enter this period sooner than boys. Franz Boas (1858 to 1942),[43] born and educated in Germany, came to the United States where he served on the faculty of Clark University and later Columbia University as well as holding important positions as an editor and museum curator. He wrote extensively on growth throughout his life. He recognized the individuality of the adolescent growth spurt and stressed the importance of the longitudinal studies to show that individuality. The two volumes on adolescence by Stanley Hall (1846 to 1924),[22] published in 1904, were especially complete for their time recognizing the secular trend in growth and the effects that socioeconomic factors had upon it and menarchial age. In 1923 the

Scandinavian Carl Schiotz (1877 to 1938)[46] published his findings based on Oslo children indicating the effects of social class on body dimensions and secular changes in height, weight, and age at menarche in comparison with previous populations. In the United States, Shuttleworth[44] and Stuart[45] and, in England, Tanner[16] have made particularly large contributions on the subject of the adolescent.

Physiologic and biochemical differences among infants, children, and adults were relatively recent subjects of interest. It should be recalled that physiology passed beyond metaphysics and speculation as recently as the first half of the 19th century. This change was due mainly to the efforts of the Frenchmen François Magendie (1783 to 1855) and Claude Bernard (1813 to 1878). Both insisted upon proof of facts by the experimental technique. Special study of the body functions of the pediatric age group became well established in Germany in the last half of the 19th century. At first this was primarily concentrated upon nutrition and related aspects of physiology. In 1878 Friedrich Ahlfeld emphasized the relationship of an infant's weight to adequate nutrition. At the same time, Joseph Forster studied the respiratory gases in the newborn and showed that they produced more carbon dioxide per unit of weight than the adult. Shortly after this, Camerer introduced the scientific investigation of infantile metabolism with special reference to energy requirements. Max Rubner and Otto Heubner in 1898 published *Die natürliche Ernährung eines Saüglings*, which is often considered the starting point of all modern work on infant metabolism. Rubner also was among the first to relate rate of energy metabolism to surface area. Heubner later became the director of the Pediatric Clinic in Berlin and was given the first full professorship in Germany in 1894. Adalberg Czerny of Prague made many contributions in regard to infant feeding and was among those first interested in the products of intermediate metabolism. He also anticipated the modern behaviorists in his teachings on child rearing. In 1913 he assumed the chair of pediatrics in Berlin, following Heubner. In his time Czerny was undoubtedly the European leader in pediatrics, and his influence was felt throughout the world.[20]

In the United States John Murlin, Fritz Talbot, and Francis Benedict made particularly significant contributions to the understanding of energy metabolism in the early years of the present century. It is beyond the scope of this review to mention all of the important work in this and related biochemical fields, and new developments of today are changing previously held concepts at a rapid rate. It would be an unpardonable omission, however, not to acknowledge the work in chemistry of John Howland (1873 to 1926) of Johns Hopkins University and William McKim Marriott (1885 to 1936) of Washington University in St. Louis. These two men were directly

responsible for emphasizing the importance of laboratory methods in studying clinical problems, a concept that is largely taken for granted now.

The behavior and psychologic development of the child was first approached on an educational basis. The general attitude until quite recent times was that children were inferior objects and did not warrant any special study. Education was important only because it aided the child in assuming the tasks of the adult and becoming a dependable parent. Johann Amos Comenius (1592 to 1670), a Moravian bishop, published several works on education and first emphasized the individuality of children and that education should be directed according to ability rather than to a desire to mold into a socially acceptable pattern. The philosophical implications of Jean Jacques Rousseau (1712 to 1778) have carried considerable weight upon ideas of children's behavior and methods of teaching. He extolled natural methods as opposed to the disciplinary ones practiced in teaching at that time: "Nature never deceives us; it is always we who deceive ourselves." He wrote that the child has ways of observing, thinking, and feeling that are peculiar to him or her. In Germany Friedrich Froebel (1782 to 1852), the father of the kindergarten, preached much the same concept in his attempt to reform contemporary education, basing his ideas upon careful observations of children in the school and the home.

Although records were incomplete, it is estimated that only one of every two children born in America 200 years ago would live to reach the age of 21 years. Infectious diseases were the major reason for this mortality, of which diarrhea and enteritis were the leading causes.[30] As recently as 1910, 30% of all infant deaths were caused by diarrhea and enteritis. Most mothers breast-fed their infants but this was often supplemented with milk or water from contaminated sources. Wet-nursing was common since women did not hesitate to suckle each other's children. The superstition that the milk might be responsible for passing on the characteristics of the woman supplying it was so strong that it imposed considerable limitations to a practice that might have saved more lives. The time of weaning was one of worry since many ills had their onset then.[31]

Substitutes for breast milk included the milk from cows, goats or asses, and occasionally other animals. These animals often were easier to obtain and cheaper than human wet nurses. One of the first texts on child care, published in this country in 1825, called attention to the value of various animal milks in infant feeding.[32] Some authorities in America and Europe considered the use of a specific animal's milk, added to the diet, as having remedial qualities. Well into the present century, a major portion of time in pediatric training was devoted to the preparation of infant formulas.

Reduced infant morbidity and mortality from contaminated formulas was the result of a number of important developments beginning at the end of