The Developing Human

Second Edition

Clinically Oriented Embryology

KEITH L. MOORE

ILLUSTRATED BY GLEN REID

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To my beautiful and brilliant wife
MARION
and our five children,
WARREN, PAMELA, KAREN, LAUREL, and JOYCE

Preface to the Second Edition

Although this book was planned as a text for first-year embryology courses in the health sciences, additional information was included in small print for reference in later years. Much to my delight, the book has been widely adopted and translated into several foreign languages; in addition, many physicians and surgeons have found the book helpful. I have been assured by many students and colleagues that the method of approach used has widened the understanding of embryology in many parts of the world. For this reason, the format of the book remains the same.

In addition to the numerous changes required for updating the text, many illustrations have been modified or replaced by new ones. Colors have been applied to more drawings, especially those illustrating early stages of development. My students find the use of colors especially helpful in understanding the formation and differentiation of the germ layers. The *Timetables of Human Prenatal Development* and the descriptions of early human development have been revised in accordance with the meticulous studies on the Carnegie Embryology Collection by Dr. Ronan O'Rahilly (Carnegie Institution of Washington Publication 631, 1973) and Dr. Raymond Gasser (*Atlas of Human Embryos*. Hagerstown, Harper & Row, Publishers, 1975).

Because few first-year students appear to check the references, three or four books or articles have been selected for each chapter in this edition as suggestions for additional reading, in the hope that they will read at least these. The updating of the text is reflected in the many additions to the bibliography as well as in the use of the new international nomenclature, Nomina Embryologica [1974].

I am grateful to Drs. D. Cox and M. Ray, Department of Anatomy and Pediatrics (Genetics), and to Dr. T. V. N. Persaud, Professor of Anatomy at the University of Manitoba, for helping me to revise Chapter 8, "Causes of Congenital Malformations." Their expert advice and provision of new illustrations is most warmly appreciated.

During the preparation of the first edition, and to some extent with this edition, I have received generous assistance from several other colleagues at the University of Manitoba—notably, Dr. I. Maclaren Thompson, Professor Emeritus of Anatomy; Dr. Harry Medovy, Professor of Pediatrics; Dr. Ashley Coopland, Associate Professor of Obstetrics and Gynecology; and Miss Jean Hay, Associate Professor of Anatomy. To these friends I renew my thanks.

I am pleased to express my thanks again to Mr. Glen Reid; his exceptional artistic ability has contributed much to the success of this book. My secretaries, especially Mrs. Barbara Clune and Mrs. Rosemary Fletcher, and many students and colleagues at the University of Manitoba and other universities who have taken the time to make suggestions for improvements in the text or in the illustrations deserve my warmest appreciation.

As I write this preface, I am planning a move to the University of Toronto. Like Professors J. C. B. Grant and William Boyd, who left Manitoba for Toronto many years ago, I shall always be grateful to the University of Manitoba for the opportunities and encouragement afforded me.

Finally, I should like to say to students around the world, "I sincerely hope that your reading of this book will not only help you with your studies but will also stimulate your permanent interest in a fascinating subject, much of which is still poorly understood."

KEITH L. MOORE

Toronto, Ontario, Canada

Preface to the First Edition

With increasing encroachment upon the time available for anatomy, the formal study of embryology has been severely curtailed. This curtailment is regrettable in view of the increasing importance of this subject in modern medicine. Most existing textbooks are too detailed for short courses and do not arouse the beginning student's interest in this fascinating field.

This book began as a set of illustrated notes for a *core* course in medical embryology* which was intended to give students a base from which to develop. Unexpectedly, these notes were also enthusiastically received by other health science students, by practicing physicians, and by clinical colleagues in disciplines where embryology is applied. The author was urged to develop the notes into a textbook of *clinically oriented embryology*.

The purpose of this book is to present a synopsis of human development and related information. Although each chapter gives a relatively concise account of developmental processes, it is followed by numerous references for students wishing further information. Each chapter, except the first, is followed by a summary of the main events. An attempt has been made to "bridge the gap" between embryology and adult anatomy, histology, pathology, obstetrics, pediatrics and surgery. Congenital malformations of each system are described, with emphasis on the common ones, and an entire chapter has been devoted to a discussion of the *causes of congenital malformations*.

The book is freely illustrated because much of the difficulty encountered by students beginning to study embryology results from their inability to visualize developmental processes and time sequences. Most illustrations are diagrammatic, some in color, and show *progressive stages of development,* conveying ideas and processes as blackboard sketches do during lectures. Numerous photographs are also included, similar to those used in case presentations at clinical seminars.

Text material has been used mainly to: (a) emphasize important points, (b) discuss opposing views, and (c) summarize concepts and processes. Basic or *core material is set in regular type,* whereas less important information is shown in small type, or added as footnotes. The terminology is mainly based on the *Nomina Em-*

*Core is defined as "that material which lies in the mainstream of the continuing learning process and is necessary for the understanding of the next step in the progression."

bryologica adopted by the Ninth International Congress of Anatomists held at Leningrad in August, 1970. In some cases where there seems to be a need for reconsideration of terms in the interest of clarity and consistency, the old terminology has been used or given in parentheses. Because of common clinical usage, certain synonyms and eponyms are given in footnotes.

While writing this book, an attempt was made to keep in mind what the naturalist John Ray said in the seventeenth century: "*He that useth many words for the explaining of any subject, doth like the cuttle-fish hide himself . . . in his own ink*"; and the often-quoted Chinese proverb, "*A little picture is worth a million words.*"

KEITH L. MOORE

Winnipeg, Canada

Contents

CHAPTER 1

INTRODUCTION

Developmental Terms and Concepts

Development is a continuous process that begins when an *oocyte* (ovum) is fertilized by a *spermatozoon* (sperm) and ends at death. It is a process of growth and differentiation which transforms the *zygote*, a single cell, into a multicellular adult human being. Most developmental changes occur during the embryonic and fetal periods, but important changes also occur during infancy, childhood, adolescence, and adulthood.

DEVELOPMENTAL PERIODS

Although it is customary to divide development into *prenatal* and *postnatal* periods, it is important to realize that birth is merely a dramatic event during development resulting in a distinct change in environment. Development does not stop at birth; important developmental changes, in addition to growth, occur after birth, e.g., development of the teeth and the female breasts. Most developmental changes are completed by the age of 25.

PRENATAL PERIOD

The important changes occurring before birth are illustrated in the *Timetables of Human Prenatal Development* (Figs. 1–1 and 1–2), which are mainly based on the Carnegie Institution's Developmental Stages in Human Embryos (Streeter, 1942, O'Rahilly, 1973, and Gasser, 1975). Note that the most striking advances in development occur during the first eight weeks. The following list explains commonly used terms.

Oocyte. This term is used to refer to the ovum or female germ cell. Although it should not be used after fertilization has occurred, the term *ovum* is loosely applied up to the late blastocyst stage. This usage is not recommended and is not used in this book.

The term "egg" is also used to refer to the oocyte, but O'Rahilly (1973) stated, "the term egg is best reserved for a nutritive object frequently seen on the breakfast table."

Zygote. This cell results from fertilization of an oocyte by a sperm and is *the beginning of a human being.*

Cleavage. Mitotic division of the zygote results in the formation of daughter cells called *blastomeres.* At each succeeding division, the blastomeres become smaller and smaller.

Morula. When 16 or so blastomeres have formed, the *solid ball of cells* is called a morula. It was so named because it resembles a mulberry (from the Latin word *morus,* meaning "mulberry").

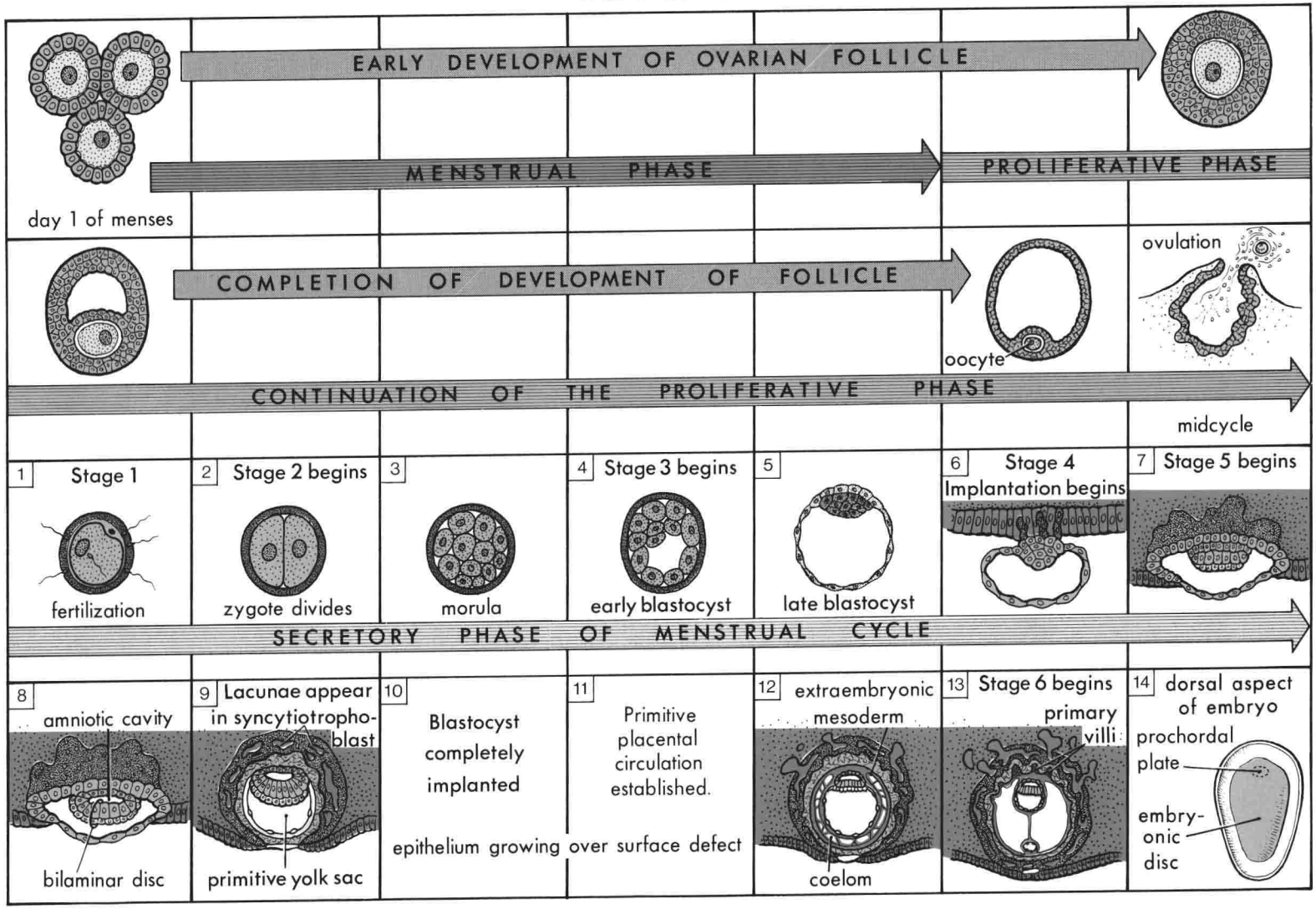
Blastocyst. After the morula reaches the uterus, fluid passes into it, forming a cavity; this converts the morula into a blastocyst.

Embryo. Embryo-forming cells, grouped as *the inner cell mass* (or *embryoblast*), are recognizable in the morula stage, but the term embryo is usually not used until the second week, when the bilaminar *embryonic disc* forms. The *embryonic period* extends until the end of the eighth week, by which time the beginnings of all major structures are present.

Fetus. After the embryonic period, the developing human is called a fetus. During the *fetal period* (ninth week to birth), many

Text continued on page 6.

TIMETABLE OF HUMAN PRENATAL DEVELOPMENT
1 to 6 weeks



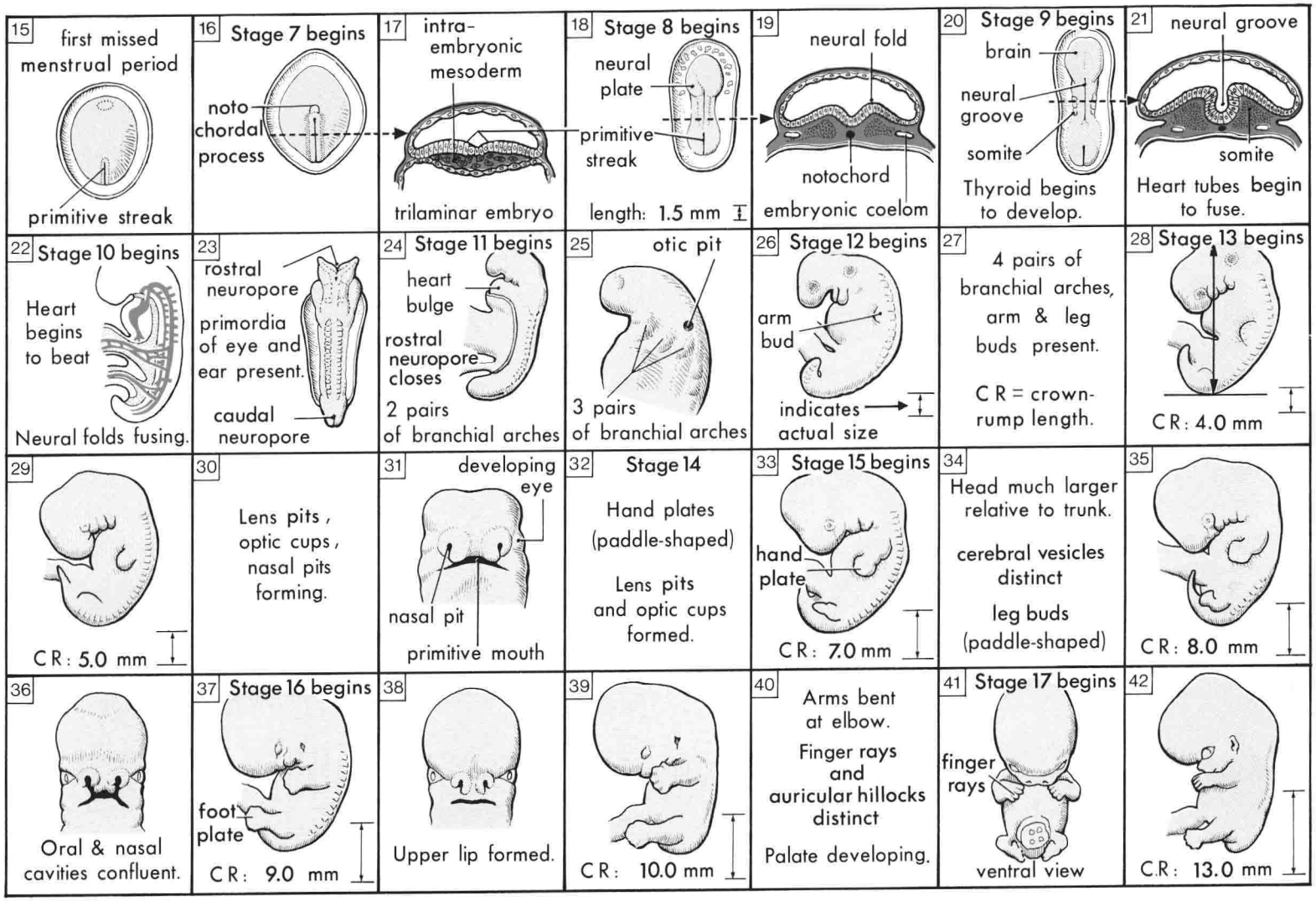
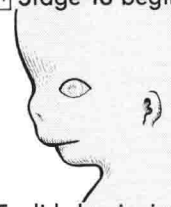
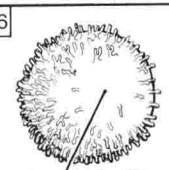
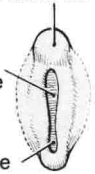
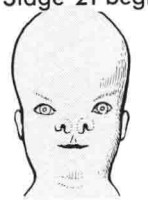
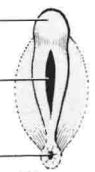
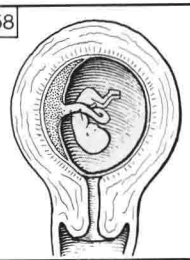
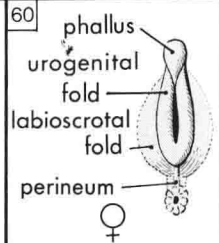
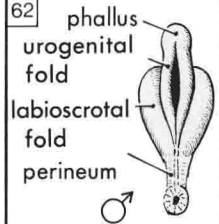
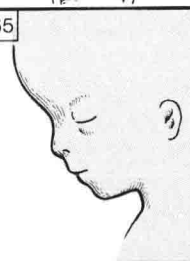
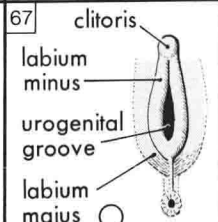
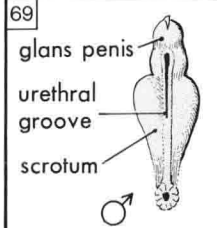


Figure 1–1 Development of a follicle containing an oocyte, ovulation, and phases of the menstrual cycle are illustrated. *Development begins at fertilization,* about 14 days after the onset of the last menstruation. Cleavage of the zygote in the uterine tube, implantation of the blastocyst, and early development of the embryo are also shown. The main features of the developmental stages in human embryos are illustrated.

TIMETABLE OF HUMAN PRENATAL DEVELOPMENT
7 to 38 weeks

AGE (weeks)							
7	43  CR: 16.0 mm.	44 Stage 18 begins  Eyelids beginning	45 Tip of nose distinct Toe rays appear Ossification may begin  CR: 17.0 mm	46  Loss of villi Smooth chorion forms.	47 genital tubercle  urogenital membrane anal membrane ♀ or ♂	48 Stage 19 begins Trunk elongating and straightening	49  CR: 18 mm
8	50 Upper limbs longer & bent at elbows Fingers distinct	51 Anal membrane perforated Urogenital membrane degenerating. Testes and ovaries distinguishable.	52 Stage 21 begins 	53 Stage 21 External genitalia still in sexless state but have begun to differentiate.	54 Stage 22 begins  genital tubercle urethral groove anus ♀ or ♂	55 Beginnings of all essential external & and internal structures are present.	56 Stage 23  CR: 30 mm
9	57 beginning of fetal period	58 	59 Genitalia show some ♀ characteristics but still easily confused with ♂.	60  phallus urogenital fold labioscrotal fold perineum ♀	61 Genitalia show fusion of urethral folds. Urethral groove extends into phallus.	62  phallus urogenital fold labioscrotal fold perineum ♂	63  CR: 50 mm
10	64 Face has human profile. Note growth of chin compared to day 44.	65 	66  Face has human appearance.	67  clitoris labium minus urogenital groove labium majus ♀	68 Genitalia have ♀ or ♂ characteristics but still not fully formed.	69  glans penis urethral groove scrotum ♂	70  CR: 61 mm

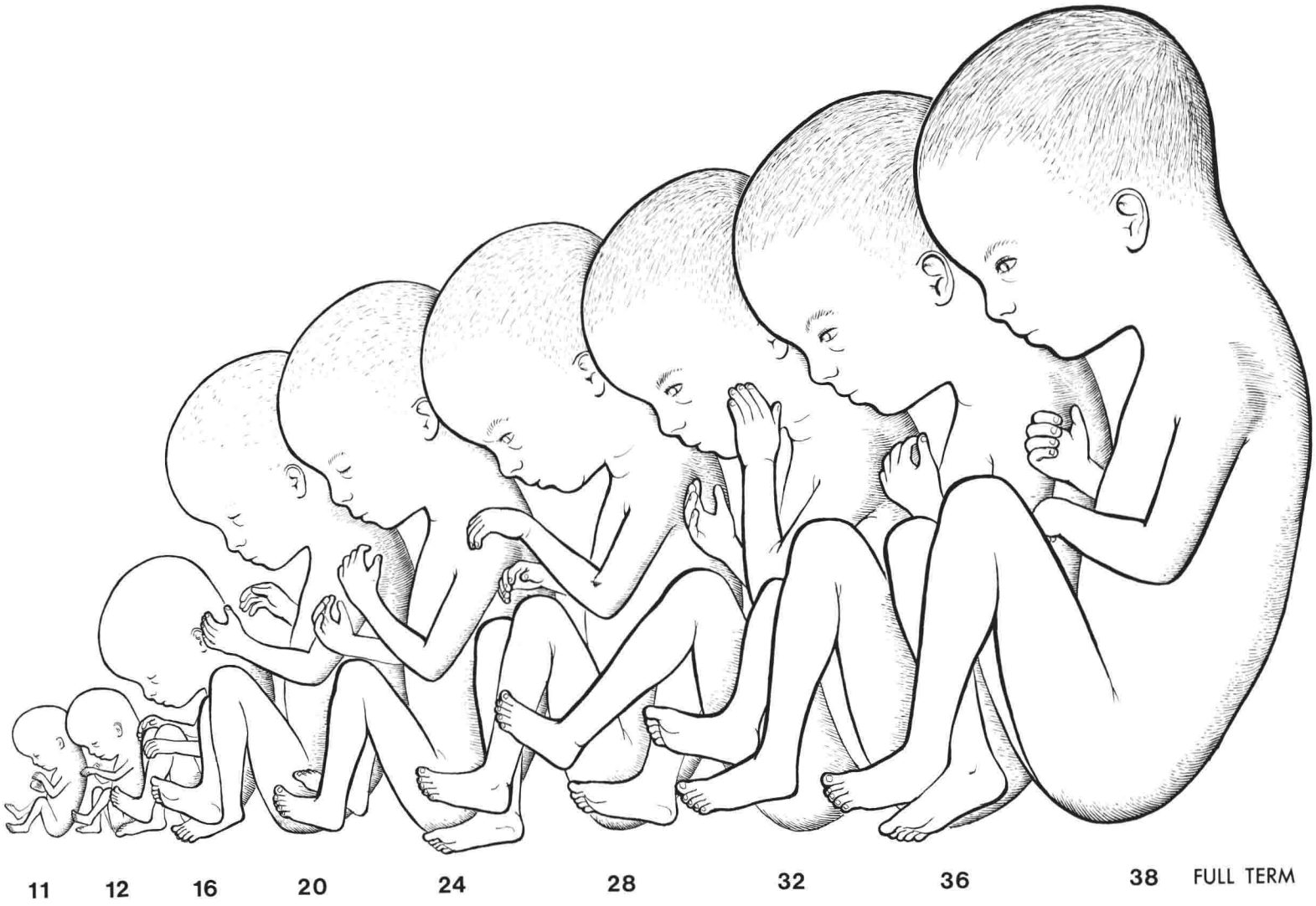


Figure 1–2 The embryonic period ends at the end of the eighth week; by this time, the beginnings of all essential structures are present. The fetal period, extending from the ninth week until birth, is characterized by growth and elaboration of structures. Sex is clearly distinguishable by 12 weeks. The above 11- to 38-week fetuses are about half actual size. For more information, see Chapter 6.