THIEME

Atlas of Anatomy

General Anatomy and Musculoskeletal System

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Foreword

Our enthusiasm for the THIEME Atlas of Anatomy began when each of us, independently, saw preliminary material from this Atlas. Both of us were immediately captivated by the new approach, the conceptual organization, and by the stunning quality and detail of the images of the Atlas. We were delighted when the editors at Thieme offered us the opportunity to cooperate with them in making this outstanding resource available to our students and colleagues in North America.

As consulting editors we were asked to review, for accuracy, the English edition of the THIEME Atlas of Anatomy. Our work involved a conversion of nomenclature to terms in common usage and some organizational changes to reflect pedagogical approaches in anatomy programs in North America. This task was eased greatly by the clear organization of the original text. In all of this, we have tried diligently to remain faithful to the intentions and insights of the original authors.

We would like to thank the team at Thieme Medical Publishers who worked with us. Heartfelt thanks go first to Cathrin E. Schulz, M.D., Senior Editor, for her assistance and constant encouragement and availability.

We would also like to extend our thanks to Stefanie Langner, Production Manager, and Annie Hollins, Assistant Editor, for checking and correcting our work and preparing this volume with care and speed.

Lawrence M. Ross,
Edward D. Lamperti

Preface

As it started planning this Atlas, the publisher sought out the opinions and needs of students and lecturers in both the United States and Europe. The goal was to find out what the "ideal" atlas of anatomy should be—ideal for students wanting to learn from the atlas, master the extensive amounts of information while on a busy class schedule, and, in the process, acquire sound, up-to-date knowledge. The result of this work is this Atlas. The THIEME Atlas of Anatomy, unlike most other atlases, is a comprehensive educational tool that combines illustrations with explanatory text and summarizing tables, introducing clinical applications throughout, and presenting anatomical concepts in a step-by-step sequence that allows for the integration of both system-by-system and topographical views.

Since the THIEME Atlas of Anatomy is based on a fresh approach to the underlying subject matter itself, it was necessary to create for it an entirely new set of illustrations—a task that took eight years. Our goal was to provide illustrations that would compellingly demonstrate anatomical relations and concepts, revealing the underlying simplicity of the logic and order of human anatomy without sacrificing detail or aesthetics.

With the THIEME Atlas of Anatomy, it was our intention to create an atlas that would guide students in their initial study of anatomy, stimulate their enthusiasm for this intriguing and vitally important subject, and provide a reliable reference for experienced students and professionals alike.

"If you want to attain the possible, you must attempt the impossible" (Rabindranath Tagore).

Michael Schünke, Erik Schulte, Udo Schumacher,
Markus Voll, and Karl Wesker

Acknowledgments

First we wish to thank our families. This atlas is dedicated to them.

We also thank Prof. Reinhard Gossrau, M.D., for his critical comments and suggestions. We are grateful to several colleagues who rendered valuable help in proofreading: Mrs. Gabriele Schünke, Jakob Fay, M.D., Ms. Claudia Dücker, Ms. Simin Rassouli, Ms. Heinke Teichmann, and Ms. Sylvia Zilles. We are also grateful to Dr. Julia Jürns-Kuhnke for helping with the figure labels.

We extend special thanks to Stephanie Gay and Bert Sender, who composed the layouts. Their ability to arrange the text and illustrations on facing pages for maximum clarity has contributed greatly to the quality of the Atlas.

We particularly acknowledge the efforts of those who handled this project on the publishing side:

Jürgen Lüthje, M.D., Ph.D., executive editor at Thieme Medical Publishers, has "made the impossible possible." He not only reconciled the wishes of the authors and artists with the demands of reality but also managed to keep a team of five people working together for years on a project whose goal was known to us from the beginning but whose full dimensions we came to appreciate only over time. He is deserving of our most sincere and heartfelt thanks.

Sabine Bartl, developmental editor, became a touchstone for the authors in the best sense of the word. She was able to determine whether a beginning student, and thus one who is not (yet) a professional, could clearly appreciate the logic of the presentation. The authors are indebted to her.

We are grateful to Antje Bühl, who was there from the beginning as project assistant, working "behind the scenes" on numerous tasks such as repeated proofreading and helping to arrange the figure labels.

We owe a great dept of thanks to Martin Spencker, Managing Director of Educational Publications at Thieme, especially to his ability to make quick and unconventional decisions when dealing with problems and uncertainties. His openness to all the concerns of the authors and artists established conditions for a cooperative partnership.

Without exception, our collaboration with the entire staff at Thieme Medical Publishers was consistently pleasant and cordial. Unfortunately we do not have room to list everyone who helped in the publication of this atlas, and we must limit our acknowledgments to a few colleagues who made a particularly notable contribution: Rainer Zepf and Martin Waletzko for support in all technical matters; Susanne Tochtermann-Wenzel and Manfred Lehnert, representing all those who were involved in the production of the book; Almut Leopold for the Index; Marie-Luise Kürschner and her team for creating the cover design; to Birgit Carlsen and Anne Döbler, representing all those who handled marketing, sales, and promotion.

The Authors

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4 Neurovascular Systems: Forms and Relations

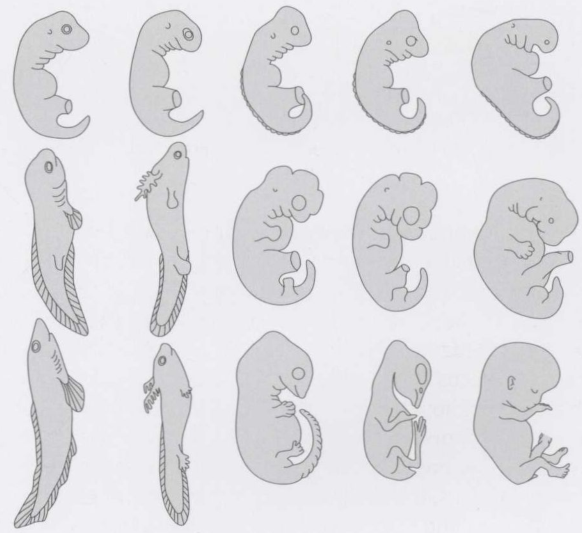
General Anatomy

1.1 Human Phylogeny

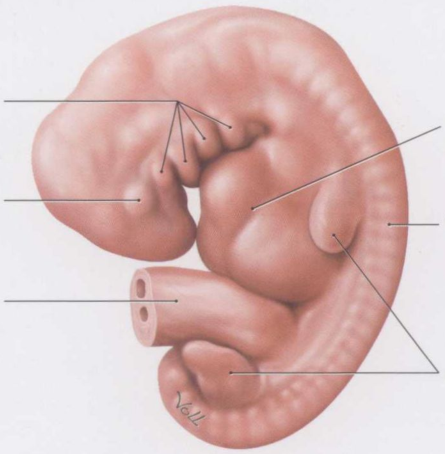
A Brief overview of human phylogenetic development
To better understand the evolution of the human body, it is helpful to trace its phylogenetic development. Humans and their closest relatives belong to the **phylum Chordata**, which includes approximately 50,000 species. It consists of two subphyla:

- Invertebrata: the tunicates (Tunicata) and chordates without a true skull (Acraniata or Cephalochordata)
- Vertebrata: the vertebrates (animals that have a vertebral column)

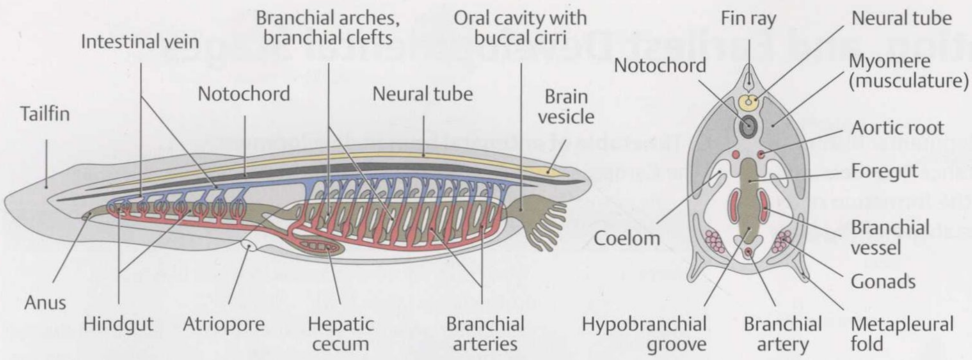
Although some members of the chordate phylum differ markedly from one another in appearance, they are distinguished from all other animals by characteristic morphological structures that are present at some time during the life of the animal, if only during embryonic development (see **G**). Invertebrate chordates, such as the cephalochordates and their best-known species, the lancelet (*Branchiostoma lanceolatum*) are considered the *model of a primitive vertebrate* by virtue of their organization. They provide clues to the basic structure of the vertebrate body and thus are important in understanding the general organization of vertebrate organisms (see **D**).
All the **members of present-day vertebrate classes** (jawless fish, cartilaginous fish, bony fish, amphibians, reptiles, birds, and mammals) have a number of characteristic features in common (see **H**), including a row of vertebrae arranged in a *vertebral column*, which gives the subphylum its name (*Vertebrata*). The evolution of an *amniotic egg*, i. e., the development of the embryo within a fixed shell inside a fluid-filled amniotic cavity, was a critical evolutionary breakthrough that helped the vertebrates to survive on land. This reproductive adaptation enabled the terrestrial vertebrates (reptiles, birds, and mammals) to live out their life cycles entirely on land and sever the final ties with their marine origin. When we compare the embryos of different vertebrate classes, we observe a number of morphological and functional similarities, including the formation of branchial arches (see **B**).
Mammals comprise **three major groups:** monotremes (egg-laying mammals), marsupials (mammals with pouches), and placentals (mammals with a placenta). The placental mammals, which include humans, have a number of characteristic features (see **I**), including a tendency to invest much greater energy in the care and rearing of their young. Placental mammals complete their embryonic development inside the uterus and are connected to the mother by a placenta. Humans belong to the mammalian order of **primates**, whose earliest members were presumably small tree-dwelling mammals. Together with lemurs, monkeys, and the higher apes, human beings have features that originate from the early adaptation to an arboreal way of life. For example, primates have movable shoulder joints that enable them to climb in a hanging position while swinging from branch to branch. They have dexterous hands for grasping branches and manipulating food, and they have binocular, broadly overlapping visual fields for excellent depth perception.



B Different stages in the early embryonic development of vertebrates
The early developmental stages (top row) of fish, amphibians, reptiles, birds, and mammals (as represented by humans) present a series of striking similarities that suggest a common evolutionary origin. One particularly noteworthy common feature is the set of branchial or pharyngeal arches in the embryonic regions that will develop into head and neck. Although it was once thought that the developing embryo of a specific vertebrate would sequentially display features from organisms representing every previous step in its evolution ("ontogeny recapitulates phylogeny", the "biogenetic law" of Ernst Haeckel (1834–1919)), subsequent work has shown that the vertebrates share common embryonic components that have been adapted to produce sometimes similar (fins and limbs) and sometimes radically different (gills vs. neck cartilages) adult structures.

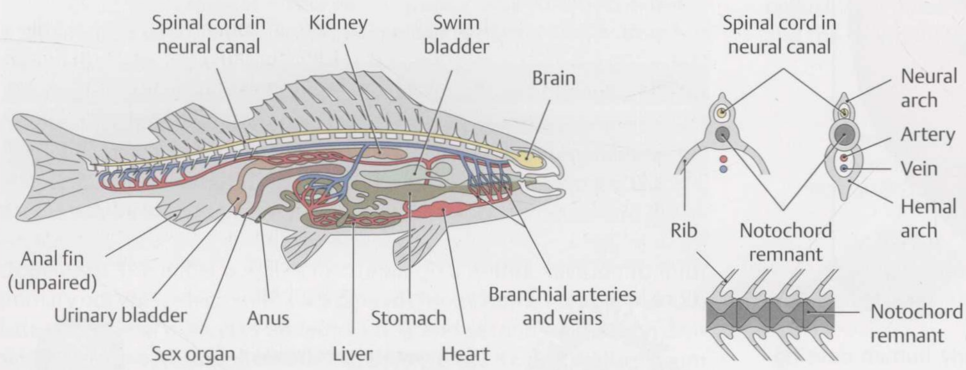


C Formation of the branchial or pharyngeal arches in a five-week-old human embryo
Left lateral view. The branchial or pharyngeal arches of the vertebrate embryo have a *metameric* arrangement (similar to the somites, the primitive segments of the embryonic mesoderm); this means that they are organized into a series of segments that have the same basic structure. Among their other functions, they provide the raw material for the species-specific development of the visceral skeleton (maxilla and mandible, middle ear, hyoid bone, larynx), the associated facial muscles, and the pharyngeal gut (see p. 11).



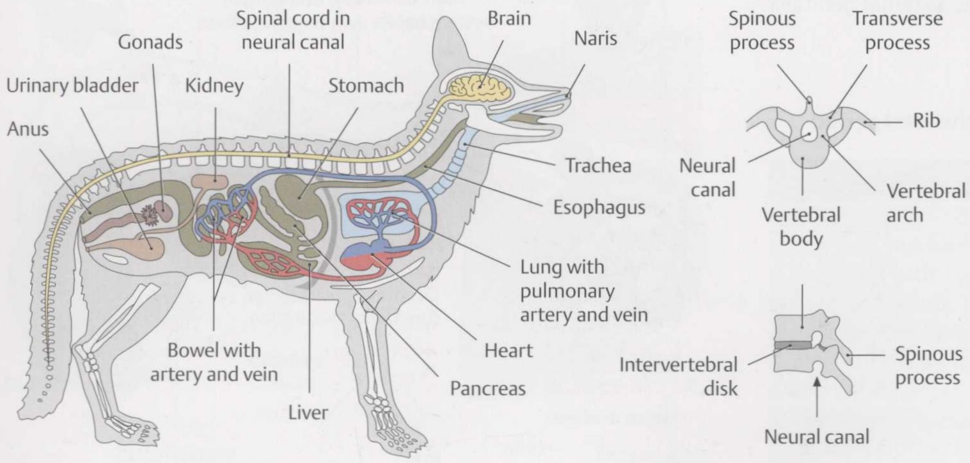
D Basic chordate anatomy, illustrated for the lancelet *(Branchiostoma lanceolatum)*

The vertebrates (including humans) are a subphylum of the chordates (Chordata), of which the lancelet is a typical representative. Its anatomy displays relatively simple terms of structures common to all vertebrates. The characteristic features of chordates include the development of an axial skeleton called the *notochord*. The human body still has remnants of the notochord, such as the nucleus pulposus of the intervertebral disks. The notochord is present in humans only during embryonic life, however, and is not a fully developed structure. Its remnants may give rise to developmental tumors called *chordomas*. Chordates have a *tubular nervous system* lying dorsal to the notochord. The body and particularly the muscles are composed of multiple segments called *myomeres*. In humans, this myomeric pattern of organization is most clearly apparent in the trunk. Another distinguishing feature of chordates is the presence of a closed circulatory system.



E Basic vertebrate anatomy, exemplified by the bony fish

The vertebrates are the *subphylum of chordates* from which humans evolved. With the evolution of fish, the notochord was transformed into a vertebral column (spinal column). The segmentally arranged bony vertebrae of the spinal column encircle remnants of the notochord and have largely taken its place. Dorsal and ventral arches arise from the vertebral bodies. The dorsal arches (vertebral or neural arches) in their entirety make up the neural canal, while the ventral arches (hemal arches) form a caudal "hemal canal" that transmits the major blood vessels. The ventral arches in the trunk region are the origins of the ribs.



F Basic vertebrate anatomy, the dog

G Characteristic features of chordates

- Development of an axial skeleton (notochord)
- Dorsal neural tube
- Segmental arrangement of the body, particularly the muscles
- Foregut pierced by slits (branchial gut)
- Closed circulatory system
- Postanal tail

H Characteristic features of vertebrates

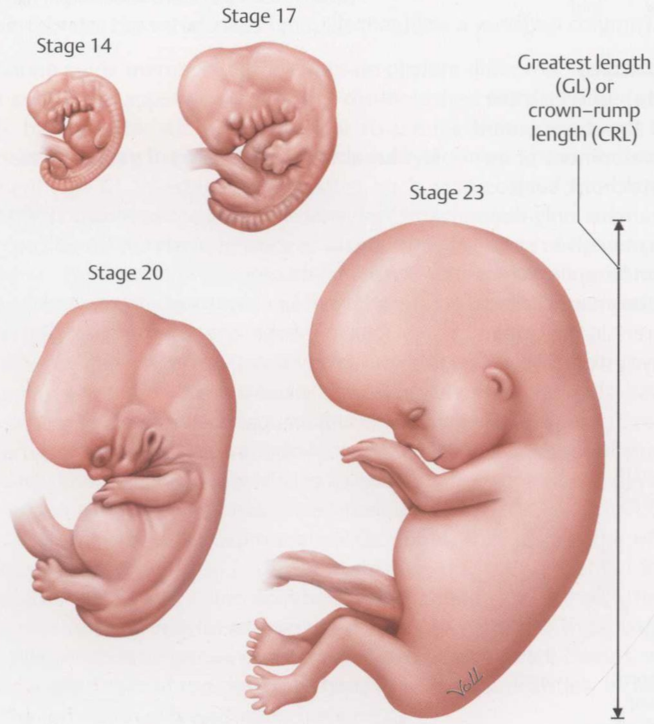
- Nerve cells, sensory organs, and oral apparatus concentrated in the head (cephalization)
- Multipart brain with a pituitary gland
- Replacement of the notochord by the vertebral column
- Generally, two pairs of limbs
- Development of branchial arches
- Presence of neural crest cells
- Closed circulatory system with a ventral, chambered heart
- Labyrinthine organ with semicircular canals
- Stratified epidermis
- Liver and pancreas always present
- Complex endocrine organs such as the thyroid and pituitary
- Complex immune system
- Sexes almost always separate

I Characteristic features of mammals

- Highly glandular skin covered with true hair (terminal hair)
- Females always have mammary glands for nursing offspring, which are usually born live (viviparous)
- Well-developed cerebrum
- Well-developed cutaneous muscles
- Diaphragm is the major respiratory muscle and separates the thoracic and abdominal cavities
- Heterogenous and specialized teeth
- Four-chambered heart with a (left-sided) aortic arch
- Constant body temperature (homeothermy)

1.2 Human Ontogeny: Overview, Fertilization, and Earliest Developmental Stages

Besides gross and microscopic anatomy, the developmental history of the individual organism (ontogeny) is of key importance in understanding the human body. Ontogeny is concerned with the formation of tissues (*histogenesis*), organs (*organogenesis*), and the shape of the body (*morphogenesis*).



A Five- to eight-week-old human embryos

Streeter (1942) and O'Rahilly (1987) classified early human development and the embryonic period into 23 stages based on specimens from the Carnegie Collection. The Carnegie stages are defined by morphological characteristics that can be closely correlated with specific age (postovulatory days or weeks) and size (measured as the greatest length, excluding lower limb (GL), or crown-rump length (CRL) (see **C**).

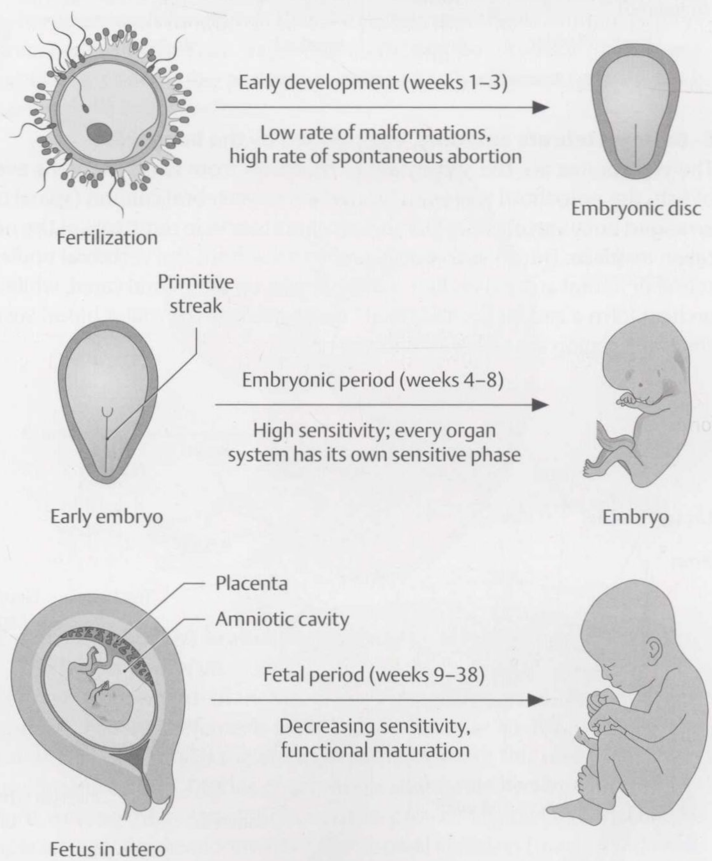
Stage 14: Fifth week, GL 5–7mm, future cerebral hemispheres become identifiable
Stage 17: Sixth week, GL 11–14 mm, digital rays become visible.
Stage 20: Seventh week, GL 18–22 mm, upper arms bent at the elbow, hands in a pronated position.
Stage 23: Eighth week, GL 27–31 mm, eyelids fuse, external genitalia begin differentiation.

B Longitudinal growth and weight gain during the fetal period

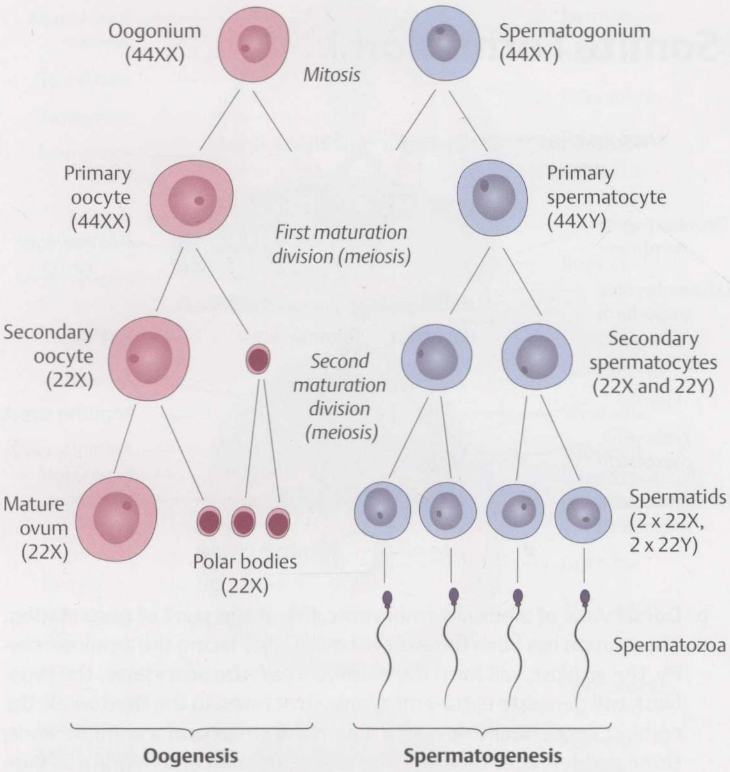
Age (weeks)	Crown–rump length, CRL (cm)	Weight (g)
9–12	5–8	10–45
13–16	9–14	60–200
17–20	15–19	250–450
21–24	20–23	500–820
25–28	24–27	900–1300
29–32	28–30	1400–2100
33–36	31–34	2200–2900
37–38	35–36	3000–3400

C Timetable of antenatal human development
(The Carnegie stages are shown in parentheses.)

Weeks 1–3:	**Early development**
Week 1:	Tubal migration, segmentation, and blastocyst formation (stages 1–3)
Week 2:	Implantation and bilaminar embryonic disk, yolk sac (stages 4–5)
Week 3:	Trilaminar embryonic disk, start of neurulation (stages 6–9)
Weeks 4–8:	**Embryonic period**
Week 4:	Folding of the embryo, neurulation concluded, axial organs, basic body shape (stages 10–13)
Weeks 5–8:	Organogenesis (formation of all essential external and internal organs, elongated limb buds) (stages 14–23)
Weeks 9–38:	**Fetal period**
Weeks 9–38:	Organ growth and functional maturation (sex-specific differentiation of the external genitalia)
Length of gestation	
• p. o. = postovulatory age	266 days = 38 weeks
• p. m. = postmenstrual age	280 days = 40 weeks
Size	
• GL = greatest length, excluding lower limb	simplest, most consistent ultrasound measure
• CRL = crown-rump length	similar to GL in embryonic period, used in most descriptions of the fetal period



D Stages sensitive to teratogenic influences (after Sadler)

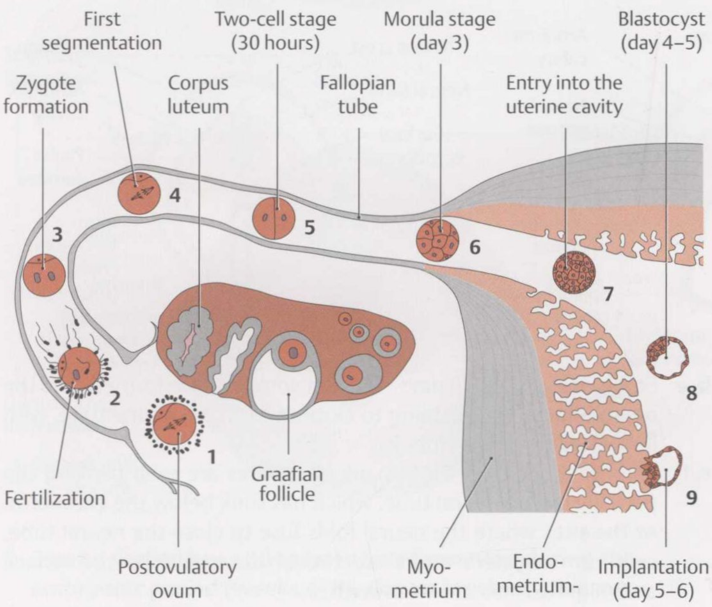


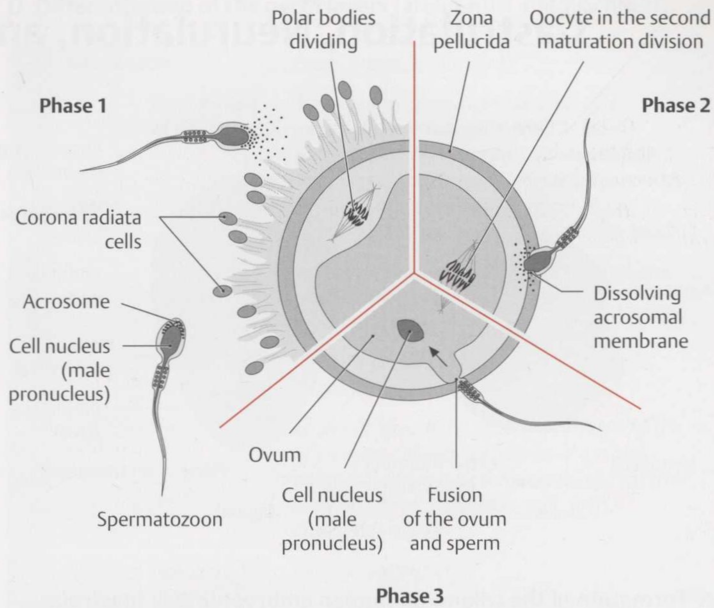
E Formation of the ovum and sperm (after Sadler)

During the formation of the gametes (sex cells), two successive cell divisions occur (the first and second meiotic maturation divisions). This results in cells having a chromosome set that is reduced by one-half (haploid). When fertilization occurs, a diploid (full) chromosome set is restored. During meiosis, extensive chromosal rearrangement occurs, thus recombining the internal genetic information into new and different subsets.

Oogenesis: The initial oogonia first undergo a mitotic division to form primary oocytes, which still have a diploid chromosome number (44 XX). Later the primary oocytes undergo a first and second maturation division by meiosis, resulting in four haploid cells (22 X): one mature ovum and three polar bodies.

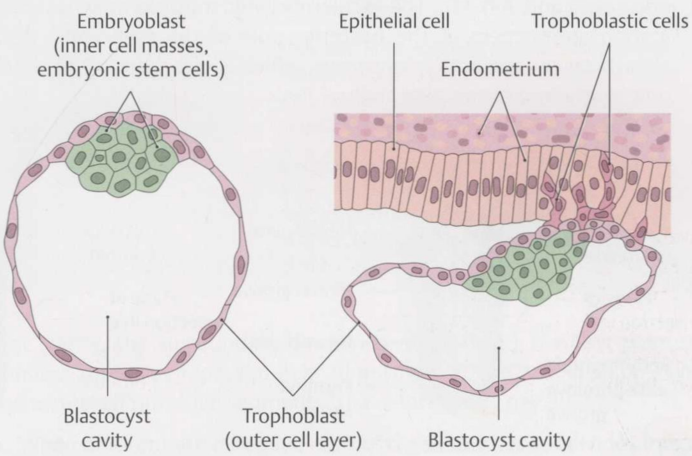
Spermatogenesis: Diploid spermatogonia undergo mitosis to form primary spermatocytes (44 XY). These cells then divide meiotically to form four haploid spermatids, two of which have an X chromosome (22 X) and two a Y chromosome (22 Y). The spermatids develop into motile spermatozoa (spermatohistogenesis).





F Schematic representation of the fertilization process (after Sadler)

In *phase 1*, the spermatozoon penetrates the corona radiata cells. In *phase 2*, the acrosome dissolves, releasing enzymes that digest the zona pellucida. In *phase 3*, the cell membranes of the ovum and sperm fuse, and the spermatozoon enters the egg.

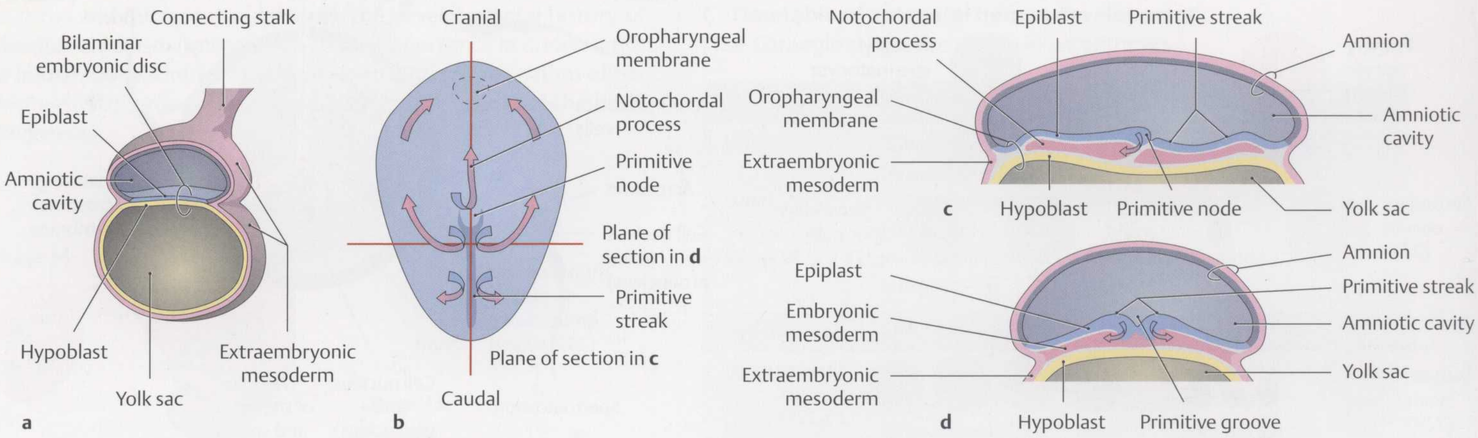


G Implantation of the blastocyst in the uterine mucosa on postovulatory day 5–6 (after Sadler)

H Developmental processes during the first week of development (after Sadler)

1. Ovum immediately after ovulation
2. Fertilized within approximately 12 hours
3. Male and female pronucleus with subsequent zygote formation
4. First segmentation
5. Two-cell stage
6. Morula stage
7. Entry into the uterine cavity
8. Blastocyst
9. Early implantation

1.3 Human Ontogeny: Gastrulation, Neurulation, and Somite Formation



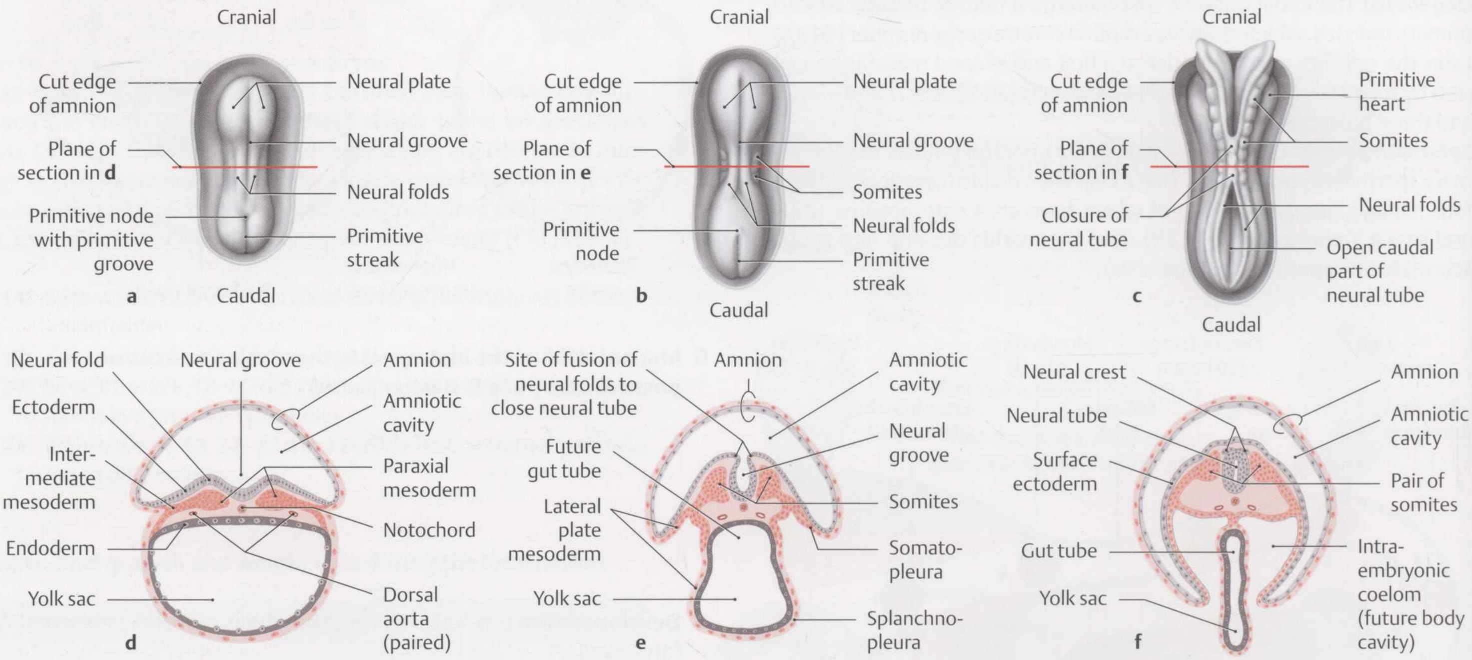
A Formation of the trilaminar human embryonic disk (gastrulation) at the start of the third postovulatory week (after Sadler)
As a result of gastrulation, the cell layers become differentiated into an *ectoderm*, *endoderm*, and *mesoderm*, from which all structures of the human body are derived (e.g., the endoderm gives rise to the central nervous system and the sensory organs). Gastrulation also establishes the primary axes of the body (ventral–dorsal, cranial–caudal, and left–right).

a Sagittal section through a conceptus at 2 postovulatory weeks. The embryonic disk is *still bilaminar* and is stretched between the amniotic cavity and yolk sac. The extraembryonic mesoderm, whose formation commences at the posterior pole of the embryonic disk, already covers the entire conceptus, which is attached to the chorionic cavity by a connecting stalk.

b Dorsal view of a human embryonic disk at the start of gastrulation. The amnion has been removed. The cell layer facing the amniotic cavity, the *epiblast*, will form the embryo itself; the other layer, the *hypoblast*, will generate extra-embryonic structures. In the third week, the epiblast sequentially develops a *primitive streak* and a *primitive node*; some epiblast cells dive into the streak, detach, and migrate as indicated by the arrows to generate the embryonic endoderm and mesoderm; a mass of cells expands cranially from the node to the *oropharyngeal membrane* to form the *notochordal process*. The remaining epiblast cells become the ectoderm, part of which will give rise to the *neuroectoderm* in the next development phase, *neurulation*.

c Sagittal section: embryonic disk along the notochordal process.

d Cross section: embryonic disk at the level of the primitive groove (arrows in **c** and **d**: direction of gastrulation movements by the mesoderm).



B Neurulation during early human development (after Sadler)

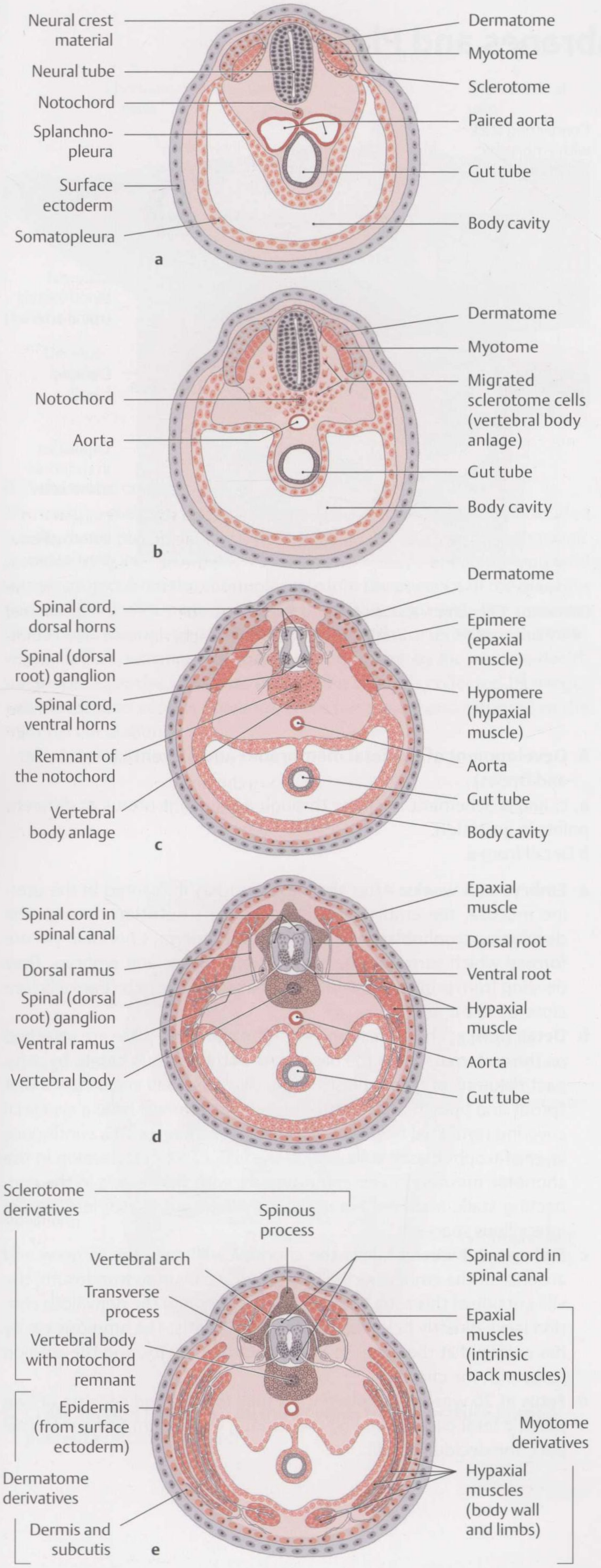
a–c Dorsal view after removal of the amnion.

d–f Schematic cross sections of the corresponding stages at the planes of section marked in **a–c**. Age in postovulatory days. During neurulation, the neuroectoderm differentiates from the surface ectoderm due to inductive influences from the notochord.

a, d Embryonic disk at 19 days. The neural tube is developing in the area of the neural plate.

b, e Embryonic disk at 20 days. The first somites have formed, and the neural groove is beginning to close to form the neural tube, with initial folding of the embryo.

c, f Embryo at 22 days. Eight pairs of somites are seen flanking the partially closed neural tube, which has sunk below the ectoderm. At the sites where the neural folds fuse to close the neural tube, cells form a bilateral neural crest which detaches from the surface and migrates into the mesoderm.



C Somite derivatives and spinal nerve formation during the embryonic period (weeks 4–8), shown in schematic cross sections (after Drews)

D Differentiation of the germ layers (after Christ and Wachtler)

Ectoderm	Neural tube		Brain, retina, spinal cord
	Neural crest	Neural crest of the head	Sensory and parasympathetic ganglia, intramural nervous system of the bowel, parafollicular cells, smooth muscle, pigment cells, carotid body, bone, cartilage, connective tissue, dentin and cementum of the teeth, dermis and subcutaneous tissue of the head
		Neural crest of the trunk	Sensory and autonomic ganglia, peripheral glia, adrenal medulla, pigment cells, intramural plexuses
	Surface ecto-derm	Ectodermal placodes	Anterior pituitary, cranial sensory ganglia, olfactory epithelium, inner ear, lens
			Enamel organ of the teeth, epithelium of the oral cavity, salivary glands, nasal cavities, paranasal sinuses, lacrimal passages, external auditory canal, epidermis, hair, nails, cutaneous glands
Mesoderm	Axial	Notochord, prechordal mesoderm	Extraocular muscles
	Paraxial		Spinal column, ribs, skeletal muscle, connective tissue, dermis and subcutis of the back and part of the head, smooth muscle, blood vessels
	Intermediate		Kidneys, gonads, renal and genital excretory ducts
	Lateral plate meso-derm	Visceral (splancho-pleura)	Heart, blood vessels, smooth muscle, bowel wall, blood, adrenal cortex, visceral serosa
		Parietal (somato-pleura)	Sternum, limbs without muscles, dermis and subcutaneous tissue of the anterolateral body wall, smooth muscle, connective tissue, parietal serosa
Endoderm			Epithelium of the bowel, respiratory tract, digestive glands, pharyngeal glands, eustachian tube, tympanic cavity, urinary bladder, thymus, parathyroid glands, thyroid gland

(For clarity, the surrounding amnion is not shown.) The first pairs of somites appear at approximately 20 postovulatory days. All 34 or 35 of the somites ("primitive segments") have formed by day 30.

a When differentiation begins, each of these somites subdivides into a dermatome, myotome, and sclerotome (i.e., a cutaneous, muscular, and vertebral segment).

b At the end of 4 weeks, the sclerotome cells migrate toward the notochord and form the anlage of the spinal column.

c The neural tube—the precursor of the spinal cord and brain—differentiates to form a rudimentary spinal cord with dorsal and ventral horns. Cells within the ventral horn differentiate into motor neurons that sprout axons which form the *ventral root*. The neural crest has multiple derivatives, including sensory neurons which form dorsal root (spinal) ganglia, which send central processes into the spinal cord via the *dorsal root*. The myotomes become segregated into a dorsal part (epimere = epaxial muscles) and a ventral part (hypomere = hypaxial muscles).

d Each pair of dorsal and ventral roots unites to form a spinal nerve, which then divides into two main branches (a dorsal ramus and a ventral ramus). The epaxial muscles are supplied by the dorsal ramus, the hypaxial muscles by the ventral ramus.

e Cross section at the level of the future abdominal muscles. The epaxial muscles become the intrinsic back muscles, while the hypaxial muscles develop into structures that include the lateral abdominal muscles (external and internal oblique, transversus abdominis) and the anterior abdominal muscles (rectus abdominis).