# THIEME

Latin Nomenclature

# Atlas of Anatomy

## Volume 1
## General Anatomy and Musculoskeletal System


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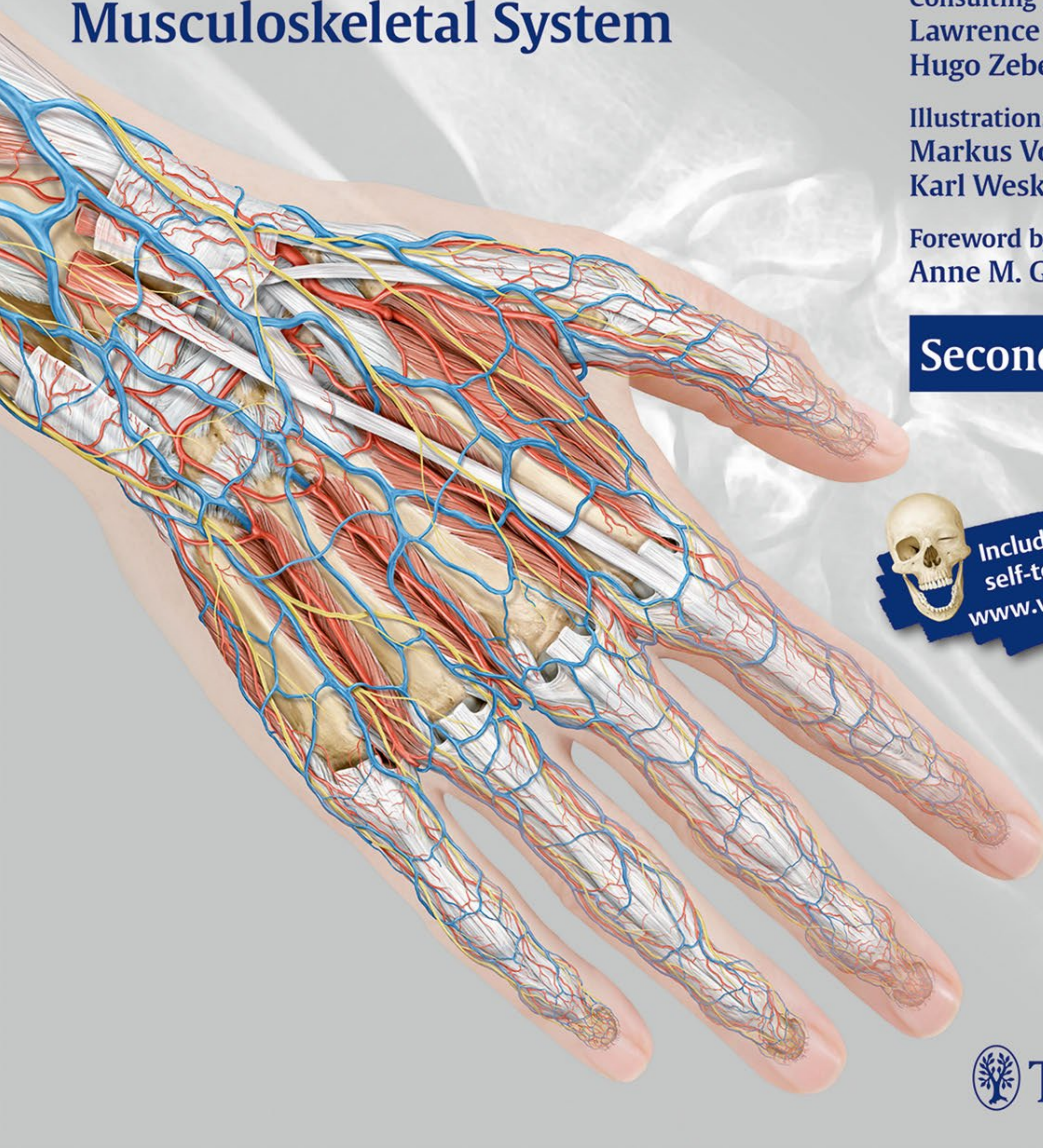
Anne M. Gilroy


Second Edition

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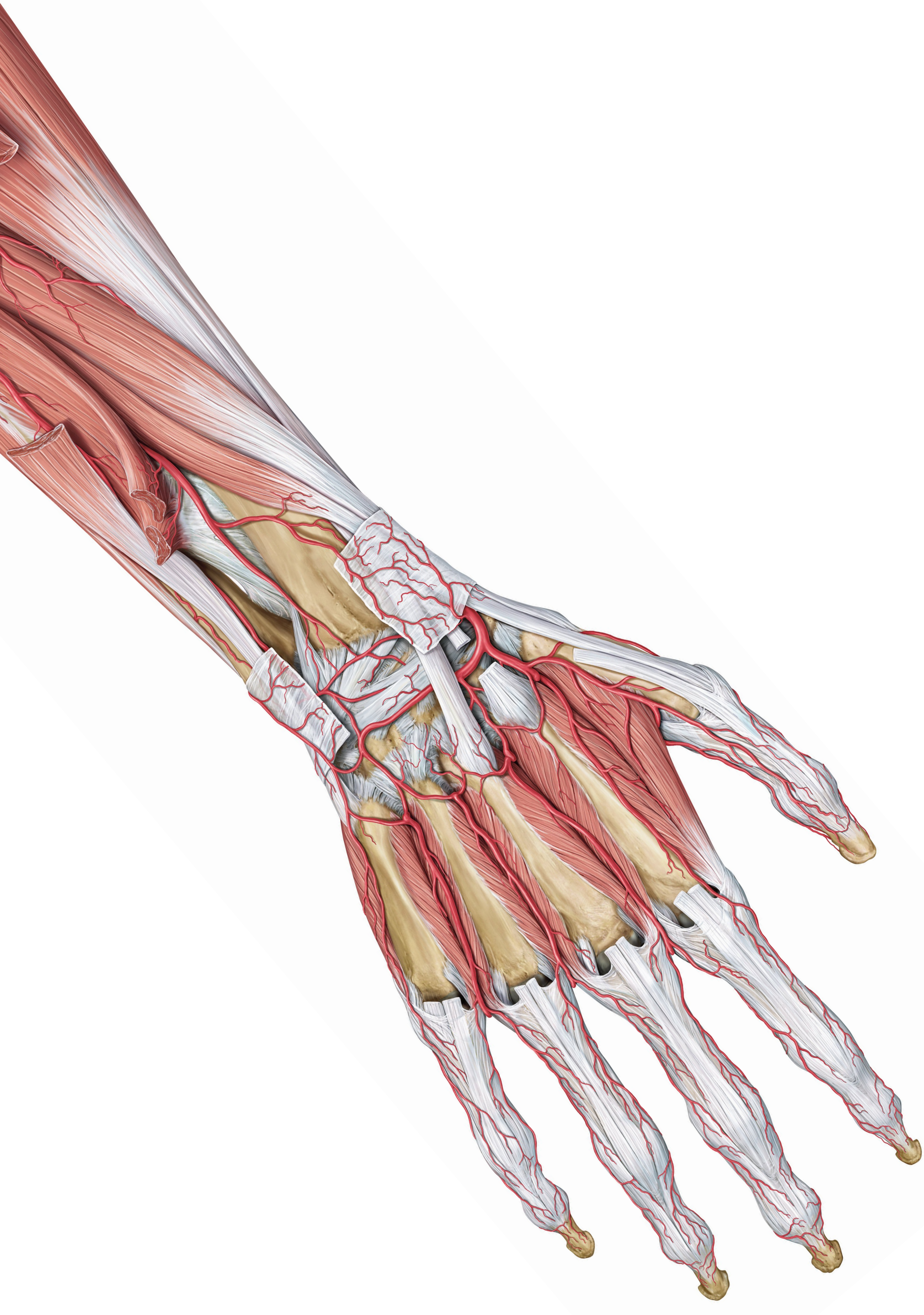

Volume 1

General Anatomy and Musculoskeletal System

# THIEME Atlas of Anatomy

## 2nd Edition

Latin Nomenclature

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# Foreword

Each of the authors of the single volume Thieme Atlas of Anatomy was impressed with the extraordinary detail, accuracy, and beauty of the illustrations that were created for the Thieme three volume series of anatomy atlases. We felt these images were one of the most significant additions to anatomic education in the past 50 years. The effective pedagogical approach of this series, with two-page learning units that combined the outstanding illustrations and captions that emphasized the functional and clinical significance of structures, coupled with the numerous tables sum-marizing key information, was unique. We also felt that the overall organization of each region, with structures presented first systemically - musculoskeletal, vascular, and nervous – and then topographically, supported classroom learning and active dissection in the laboratory.

This series combines the best of a clinically oriented text and an atlas. Its detail and pedagogical presentation make it a complete support for classroom and laboratory instruction and a reference for life in all the medical, dental and allied health fields. Each of the volumes - General Anatomy and Musculoskeletal System, Neck and Internal Organs, and Head and Neuroanatomy - can also be used as a stand-alone text/atlas for an in-depth study of systems often involved in the allied health/medical specialty fields.
We were delighted when Thieme asked us to work with them to create a single-volume atlas from this groundbreaking series, and we owe a great debt to the authors and illustrators of this series in as much as their materials and vision formed the general framework for the single volume Thieme Atlas of Anatomy.

We thank the authors and illustrators for this very special contribution to the teaching of anatomy and recommend it for thorough mastery of anatomy and its clinically functional importance in all fields of health care-related specialties.

Lawrence M. Ross, Brian R. MacPherson, and Anne M. Gilroy

# Preface to the Second Edition

Six years have passed since the first edition of the Thieme Atlas of Anatomy: General Anatomy and Musculoskeletal System was published. It has passed its first test and met the needs of students and practitioners everywhere, as evidenced by the many letters and e-mails we have received. We thank you for your praise and constructive criticism, which helps us keep improving this atlas.

Clinical knowledge presented in conjunction with anatomy is increasingly important earlier and earlier in the study of medicine. This has been further strengthened in this edition with the inclusion of about 30 new two-page spreads across the book devoted to

- osteoarthritis of the hip joint,
- compression syndromes of peripheral nerves,
- conduction anesthesia of peripheral nerves,
- shoulder arthroscopy and degenerative changes of the shoulder joint,
- functions of individual muscles and the symptoms associated with shortening or weakening of these muscles, and
- diagnostic imaging of the large joints, such as the shoulder, elbow, and wrist, and the hip, knee, and ankle.

In addition, we have added spreads on important foundational information on the common imaging planes for plain film, MRI, and CT scans, the structure of skeletal muscle fibers, the structure and chemical composition of hyaline cartilage, and the regeneration of peripheral nerves.

We have also checked, corrected, and updated all the information in this atlas.

With these improvements, this atlas is even better suited to students of medicine in what the World Health Organization (WHO) is again calling the "Decade of Bones and Joints" (first 2000 to 2010 and now 2010 to 2020) to draw attention to the continuing prominence and dramatic rise of diseases of the musculoskeletal system with the rise in average life expectancy worldwide. Today over half the chronic diseases of those over 60 involve the bones (e.g., osteoporosis) and joints (e.g., osteoarthritis), with tremendous economic consequences. One of the main reasons WHO is publicizing this is so that the world's universities appropriately prepare physicians, physical therapists, and other health care workers to address the growing global burden of these diseases due to the aging population.

This atlas emphasizes the correlations between physiologic changes in the course of life, the frequency of certain pathologic phenomena, and effective diagnostics while teaching the anatomy, better preparing students to treat patients with musculoskeletal diseases when they meet them in the clinic or in practice. When an elderly person suffers a fracture, it is not sufficient to just address the fracture. The doctor must learn why the fracture happened and address the underlying cause. Does, for example, the patient have osteoporosis, or is he or she so inflexible that any unexpected need to move leads to a fall? Interdisciplinary cooperation is needed to address these causes and provide appropriate preventive and rehabilitative care. The older we get, the more important it is for us to keep the musculoskeletal system in motion to curb degenerative disease and prevent injury.

This atlas, we hope, continues to meet your needs in the classroom and clinic, helps you attain a more nuanced understanding of the anatomy of the musculoskeletal system, and brings the fascination of anatomy in motion home to you.

Our special thanks to Prof. Dr. Cristoph Viebahn, Georg-August University, Göttingen, and Prof. Dr. Thilo Wedel, Christian-Albrechts University, Kiel, for their commitment to and constructive help on the new edition.

Michael Schuenke, Erik Schulte, Udo Schumacher,
Markus Voll, and Karl Wesker
Kiel, Mainz, Hamburg, Munich, and Berlin

# Preface to the First Edition

When Thieme started planning this atlas, they sought the opinions of students and instructors in both the United States and Europe on what constituted an “ideal” atlas of anatomy—ideal to learn from, to master extensive amounts of information while on a busy class schedule, and, in the process, to acquire sound, up-to-date knowledge. The result of our work in response to what Thieme learned is this atlas. The Thieme Atlas of Anatomy, unlike most other atlases, is a comprehensive educational tool that combines illustrations with explanatory text and summary tables, introducing clinical applications throughout, and presenting anatomic concepts in a step-by-step sequence that includes system-by-system and topographical views.

Since the Thieme Atlas of Anatomy is based on a fresh approach to the underlying subject matter, it was necessary to create an entirely new set of illustrations for it—a task that took eight years. Our goal was to provide illustrations that would compellingly demonstrate anatomic relations and concepts, revealing the underlying simplicity 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 Schuenke, Erik Schulte, Udo Schumacher,
Markus Voll, and Karl Wesker

# A Note on the Use of Latin Terminology

To introduce the Latin nomenclature into an English-language textbook is a delicate task, particularly because many Latin loanwords have passed into general use. Some loanwords are so common that fluency of the text would be disturbed if they were to be translated back into Latin. These Latin loanwords have typically undergone several adaptations before becoming part of the English language. A term such as sympathetic trunk (lat. truncus sympaticus) has undergone morphological adaptation (through the loss of masculine suffix -us), orthographical adaptation (through the substitution of a "Germanic" k for a Latin c), and phonological adaptation (th and e instead of t and i). In addition, the word order has been reversed. The Latin term sympaticus is in fact borrowed from the late Greek word sympathetikos (from sympathes "having a fellow feeling, affected by like feelings"), thereby illustrating that words move between languages when cultures meet. Other anatomical terms are so colloquial (e.g. hand), that a Latin word (e.g. manus) would be inappropriate to use at all occasions. Clearly, the text would become unreadable if a strict translation of all English terms into Latin were imposed.

As a result, Latin has been used as long as it does not disrupt the flow of the text and whenever possible in figures and tables. In some cases, dual terminology has been used, with either the English or Latin word in parentheses. As much as possible, the terminology of Terminolgia Anatomica (1998) has been followed.

Hugo Zeberg

# 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 prepared 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 only came to appreciate 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 debt 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 the 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 Liesa Arendt, Birgit Carlsen, and Anne Döbler, representing all those who handled marketing, sales, and promotion.

The Authors

As consulting editor I was asked to review, for accuracy and appropriateness, the English translation of the Thieme Atlas of Anatomy: General Anatomy and Musculoskeletal System, second edition. My work involved a review and edit of the translation, conversion of nomenclature to terms in common usage in English, and some small changes in presentation to reflect accepted approaches to certain anatomic structures in North American anatomy programs. This task was eased greatly by the clear organization of the original text. In all of this, I have tried diligently to remain faithful to the intentions and insights of the authors and illustrators, whom I wish to thank for this outstanding revision.

I would also like to thank the team at Thieme Medical Publishers who worked with me. First, I wish to thank translators Terry Telger and Judith Tomat for their work with the new and altered text and Anne Vinnicombe, editorial director for Educational Products, and editorial assistants, Shira Kaye and Huvie Weinreich, for their work with the translator and for checking and correcting my work and preparing this volume with care and speed.

Finally, heartfelt thanks go to Cathrin E. Schulz, M.D., editorial consultant, for her invitation to work on the first edition of this series and her assistance and constant encouragement at that time.

Lawrence M. Ross

It has been a great honor to act as a consulting editor, with responsibility for the Latin nomenclature, for Thieme Atlas of Anatomy: General Anatomy and Musculoskeletal System, Second Edition. There were several people from whom I received a great deal of assistance and guidance, and must express my gratitude towards. Regarding the discussion of nomenclature, I would wish to thank my mentor Prof. Peter Århem, Ph.D., my father Lennart Zeberg, M.D., and Prof. Jonas Broman, Ph.D. In addition, I would also like to express my gratitude to Prof. Björn Meister, M.D., Ph.D., for putting forward my name for this task.

Moreover, I am deeply grateful to the staff at Thieme Medical Publishers that I have been in close contact with, in particular, the editorial director Anne Sydor, Ph.D., managing editor Judith Tomat, editorial assistant Huvie Weinreich, and marketing agent David Towle.

I would also like to acknowledge the Federative International Programme for Anatomical Terminology (FIPAT) for their work towards a standard nomenclature in the field of anatomy.

Hugo Zeberg

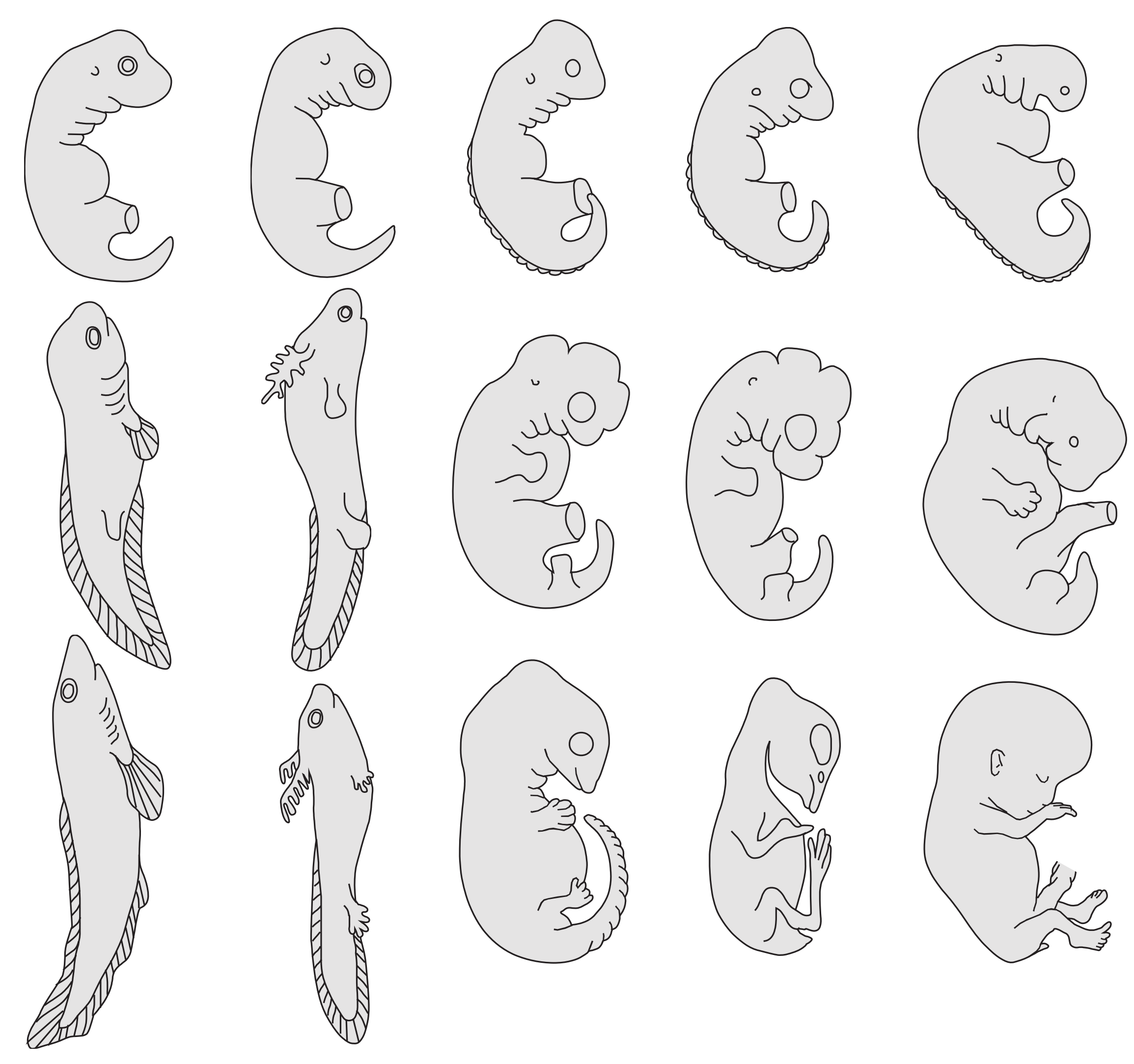
# General Anatomy

# 1.1 Human Phylogeny

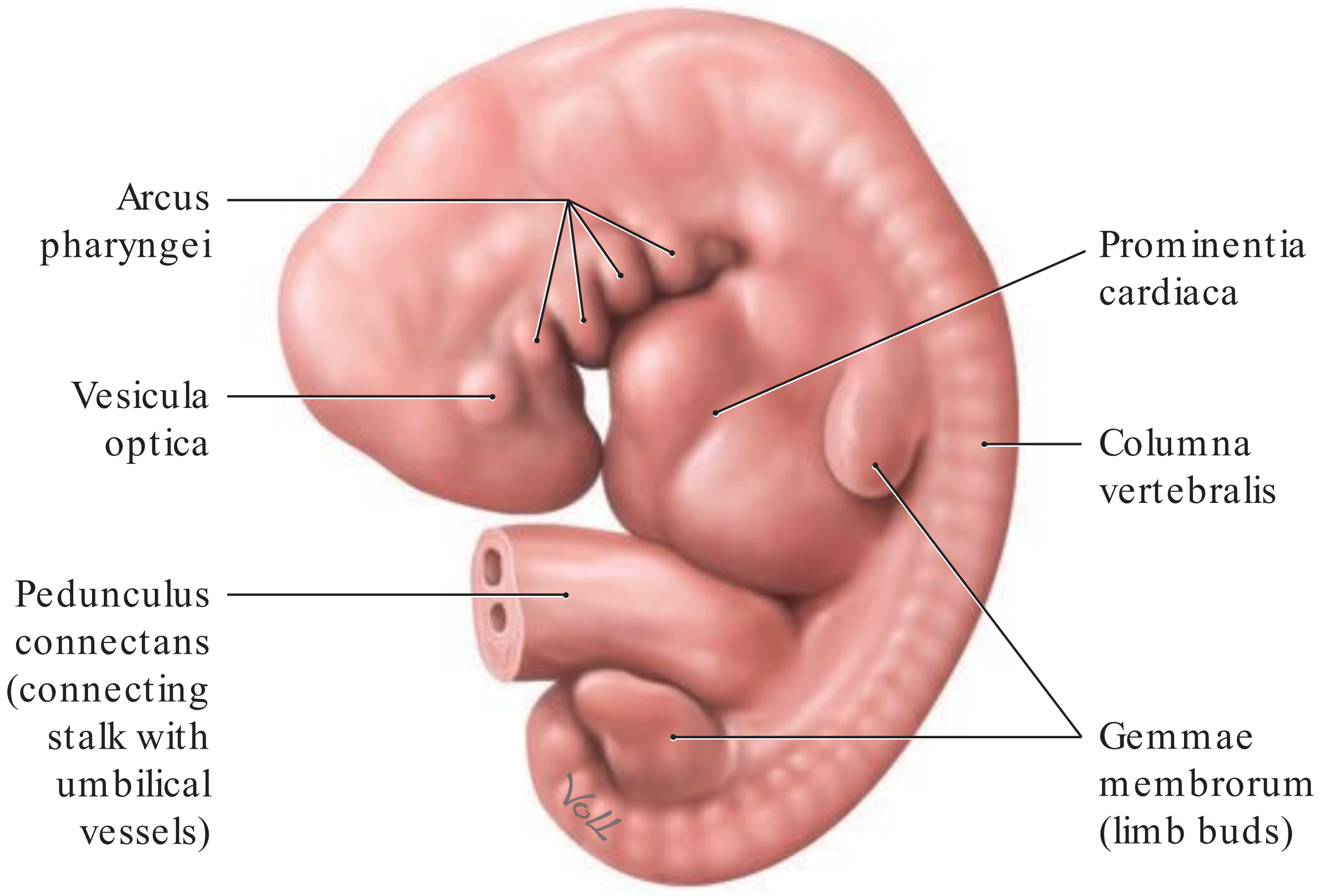
**A Brief overview of human phylogenetic development**
To better understand the evolution of the human body, it is helpful to trace its phylogenetic development. Humans and their closest relatives belong to the **phylum Chordata**, which includes approximately 50,000 species. It consists of two subphyla:

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

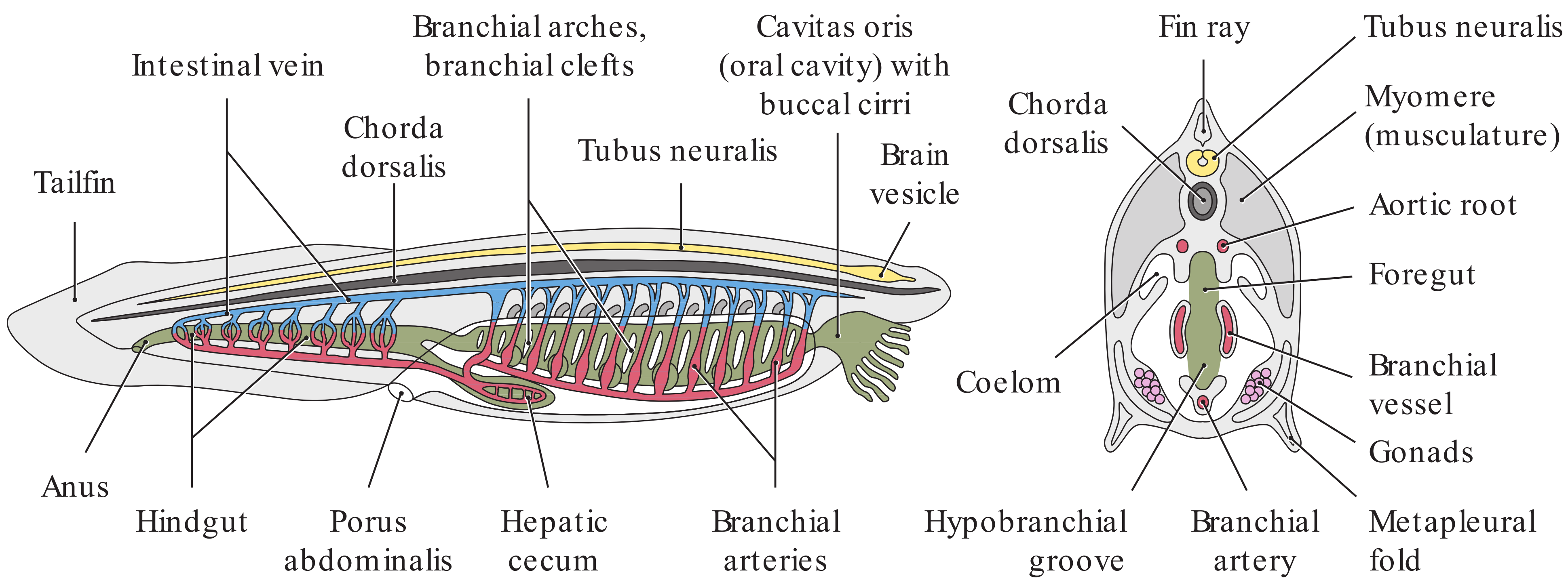
Although some members of the chordate phylum differ markedly from one another in appearance, they are distinguished from all other animals by characteristic morphological structures that are present at some time during the life of the animal, if only during embryonic development (see **G**). Invertebrate 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 (columna vertebralis), 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:** Monotremata (egg-laying mammals), Marsupialia (mammals with pouches), and Placentalia (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 the 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.

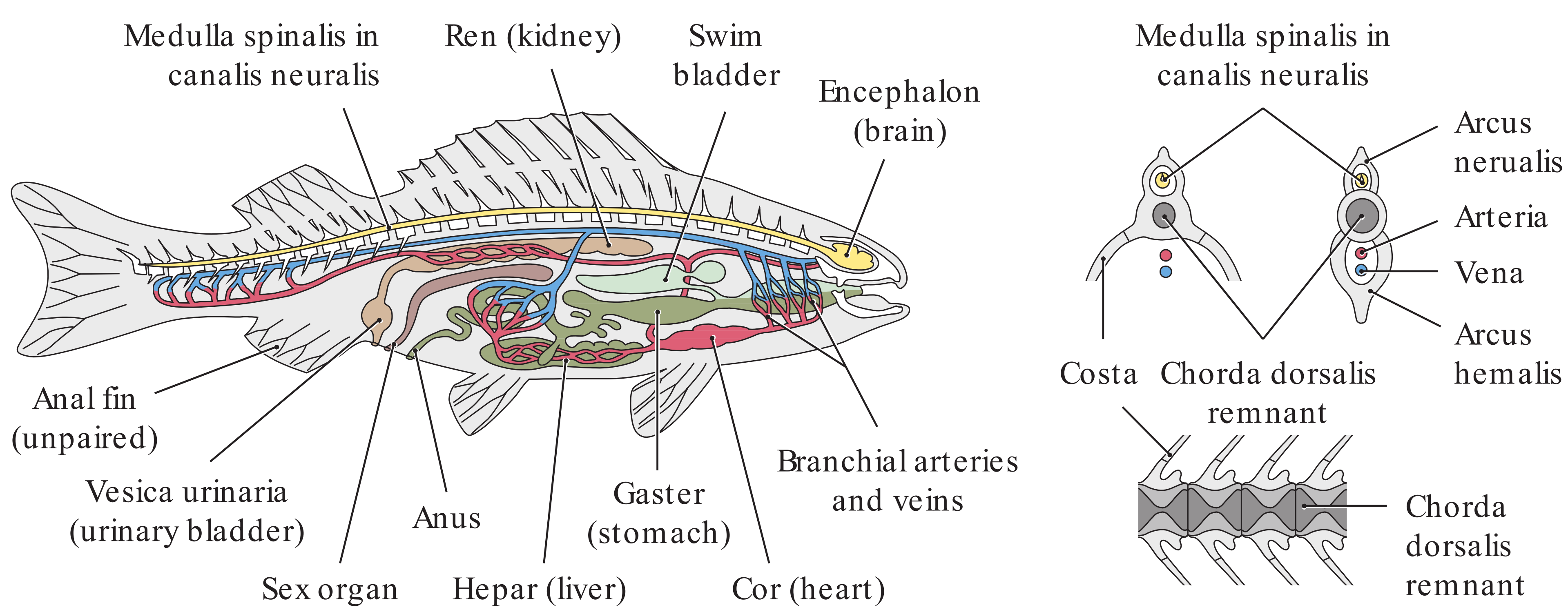



**C Formation of the branchial or pharyngeal arches in a 5-week-old human embryo**
Left lateral view. The branchial or pharyngeal arches (arcus pharyngei) of the vertebrate embryo have a metameric arrangement (similar to the somites, the primitive segments of the embryonic mesoderm); this means that 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, mandibula, auris media (middle ear ), os hyoideum, and larynx), the associated facial muscles, and the pharyngeal gut (see p. 11).



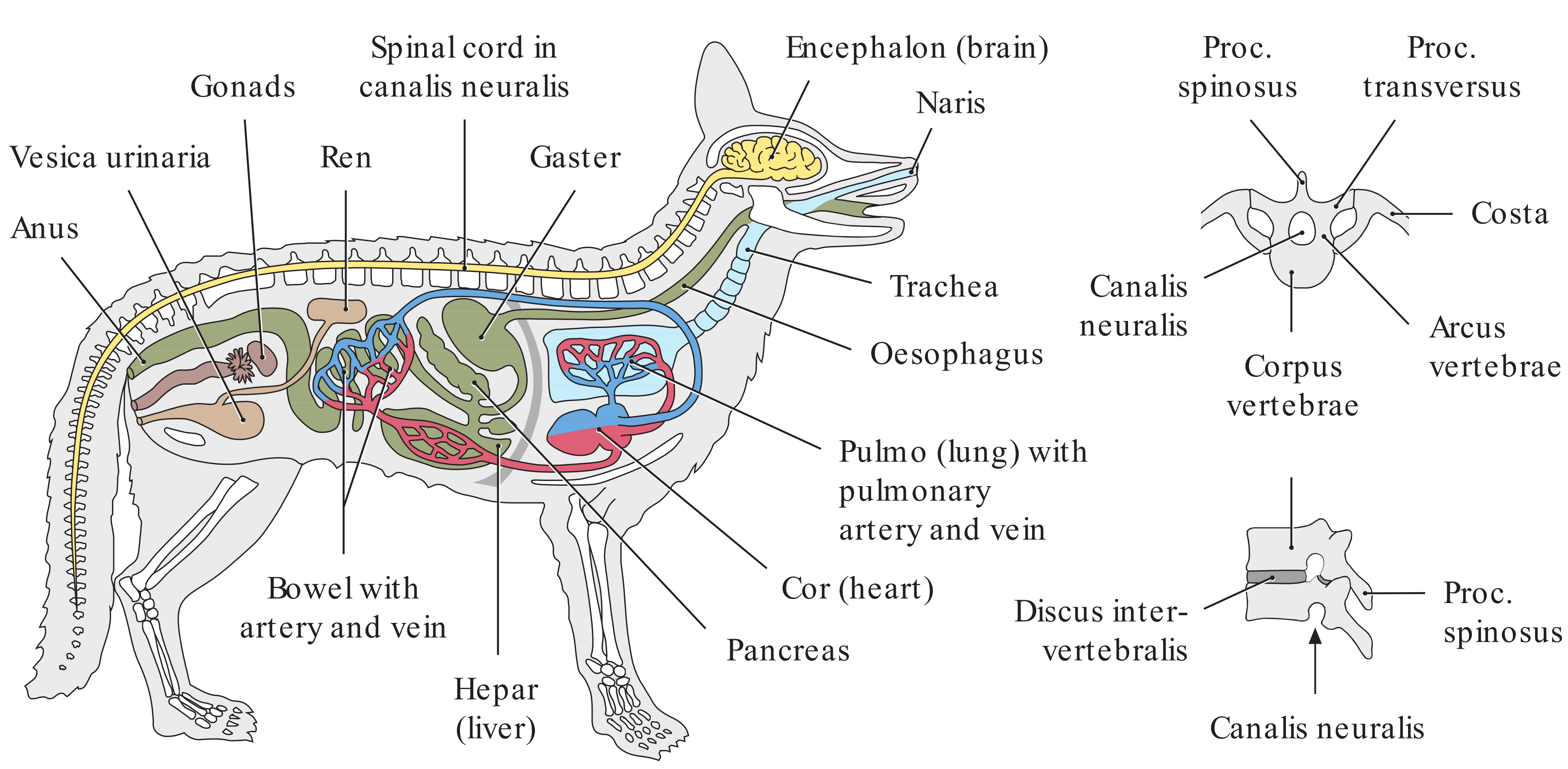

**D Basic chordate anatomy, illustrated by the lancelet** (Branchiostoma lanceolatum)

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 chorda dorsalis. The human body still has remnants of the chorda dorsalis, such as the nucleus pulposus of the intervertebral disks. The chorda dorsalis 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 chorda dorsalis. The body, particularly the muscles, is 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, illustrated by the bony fish**

The vertebrates are the subphylum of chordates from which humans evolved. With the evolution of fish, the chorda dorsalis was transformed into a vertebral column (spinal column). The segmentally arranged bony vertebrae of the spinal column encircle remnants of the chorda dorsalis 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 canalis neuralis, while the ventral arches (hemal arches, arcus hemalis) 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, illustrated by the dog**

**G Characteristic features of chordates**

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

**H Characteristic features of vertebrates**

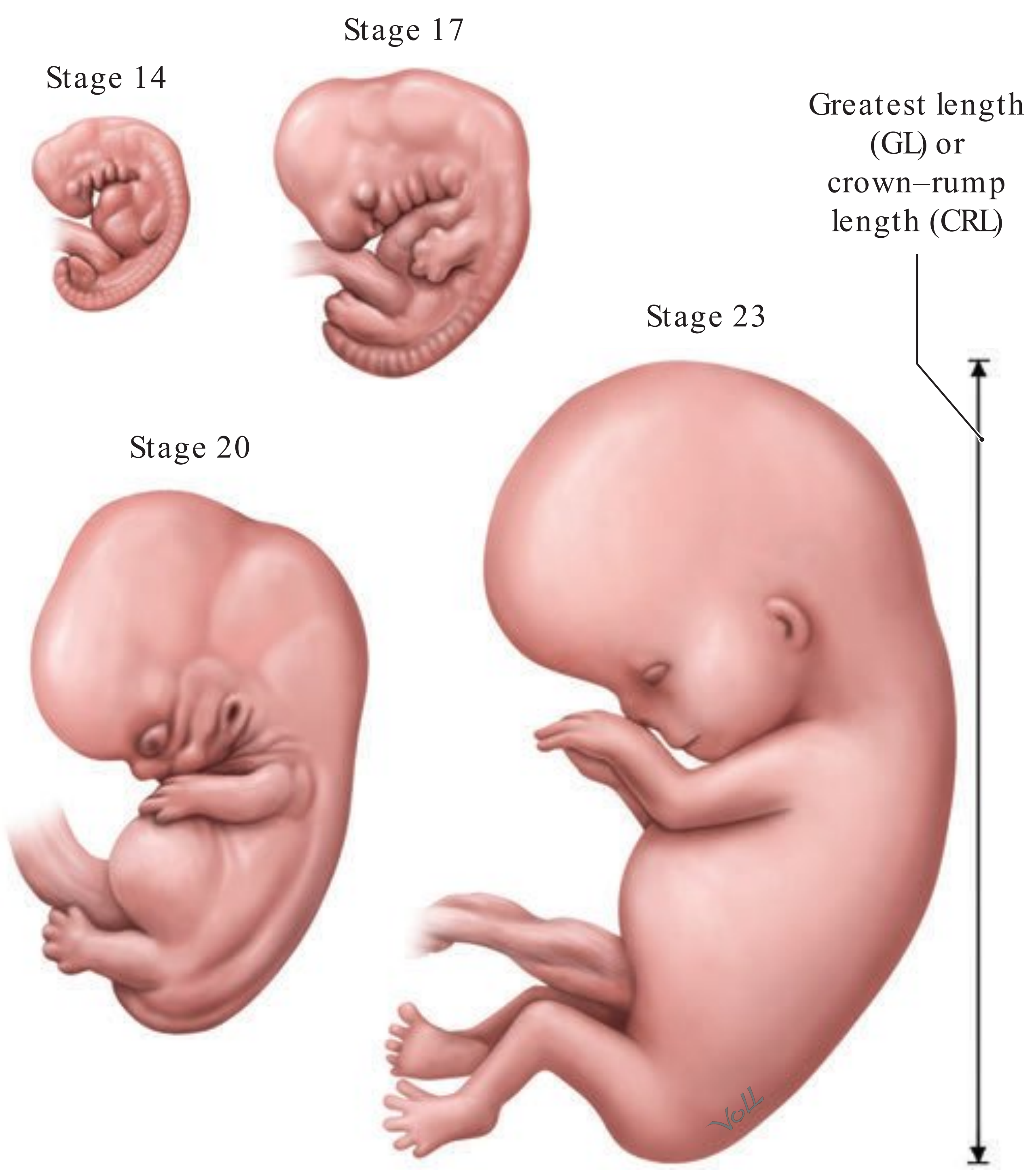
- Nerve cells, sensory organs, and oral apparatus concentrated in the head (cephalization)
- Multipart brain with a hypophysis (pituitary gland)
- Replacement of the chorda dorsalis by the columna vertebralis
- Generally, two pairs of limbs
- Development of branchial arches
- Presence of neural crest cells
- Closed circulatory system with a ventral, chambered heart
- Labyrinthine organ with canales semicirculares
- Stratified epidermis
- Liver and pancreas always present
- Complex endocrine organs such as the thyroid and hypophysis
- 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 musculi cutanei
- Diaphragma is the major respiratory muscle and separates the thoracic and abdominal cavities
- Heterogeneous 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 5- to 8-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**).

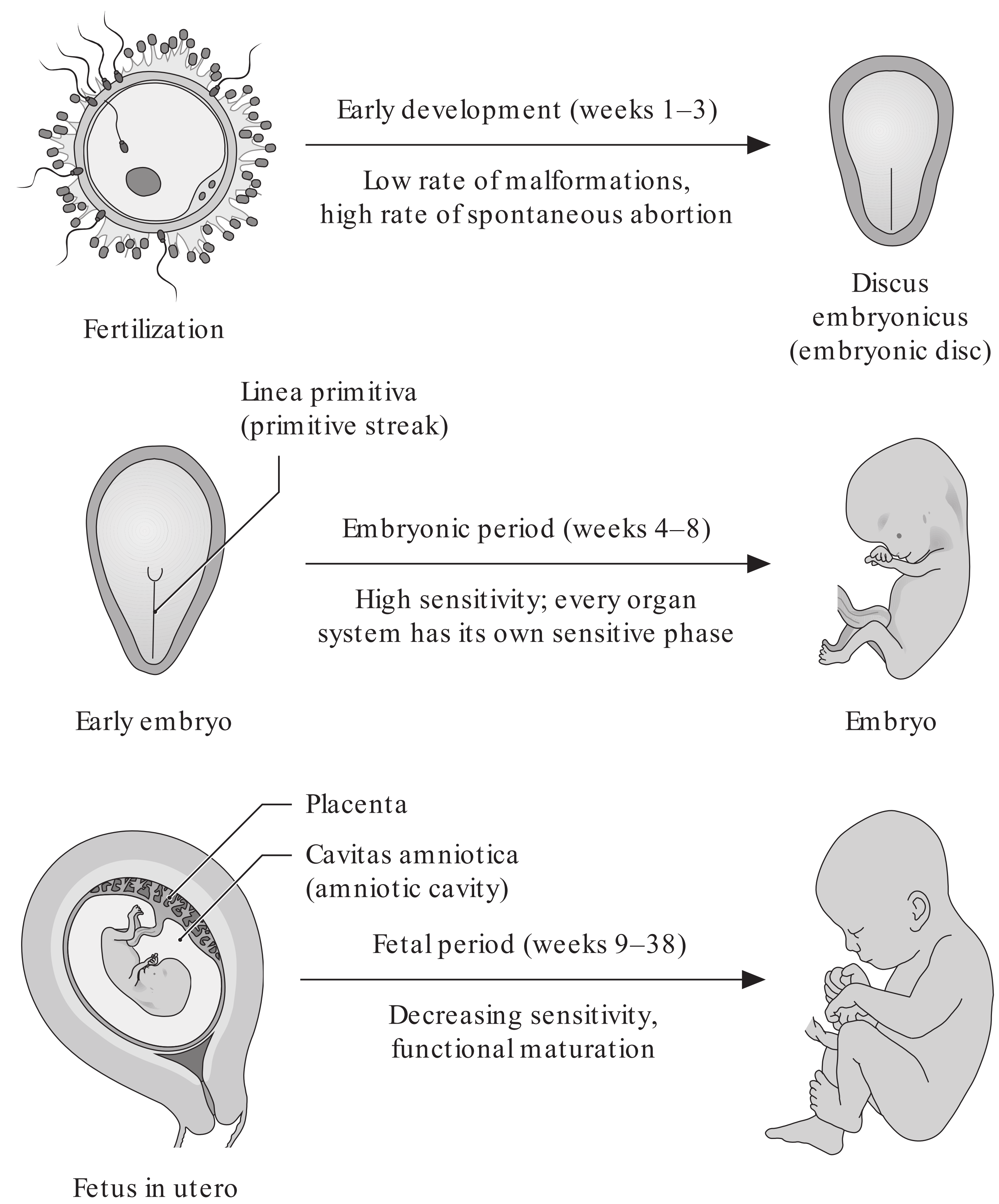
**Stage 14:** 5th week, GL 5–7 mm, future cerebral hemispheres become identifiable
**Stage 17:** 6th week, GL 11–14 mm, digital rays become visible.
**Stage 20:** 7th week, GL 18–22 mm, upper arms bent at the elbow, hands in a pronated position.
**Stage 23:** 8th week, GL 27–31 mm, eyelids fuse, external genitalia begin differentiation.

**B Longitudinal growth and weight gain during the fetal period**

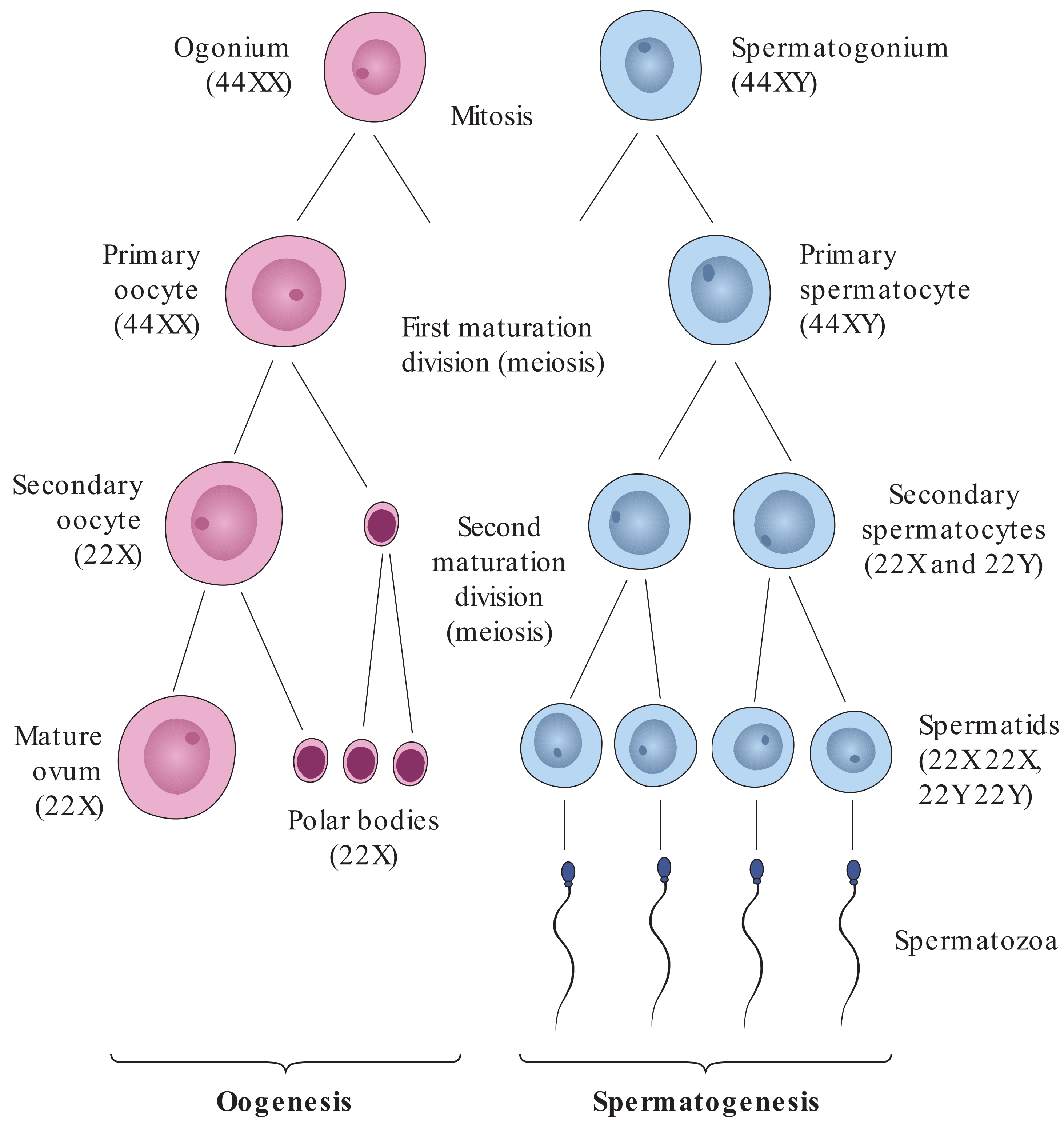
| Age (weeks) | Crown–rump length, CRL (cm) | Weight (g) |
|---|---|---|
| 9–12 | 5–8 | 10–45 |
| 13–16 | 9–14 | 60–200 |
| 17–20 | 15–19 | 250–450 |
| 21–24 | 20–23 | 500–820 |
| 25–28 | 24–27 | 900–1300 |
| 29–32 | 28–30 | 1400–2100 |
| 33–36 | 31–34 | 2200–2900 |
| 37–38 | 35–36 | 3000–3400 |

**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 disc (discus embryonicus), yolk sac (vesicula umbilicalis; stages 4–5) |
| Week 3: | Trilaminar embryonic disc, 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. = post ovulationem | 266 days = 38 weeks |
| • p.m. = post menstruationem | 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)

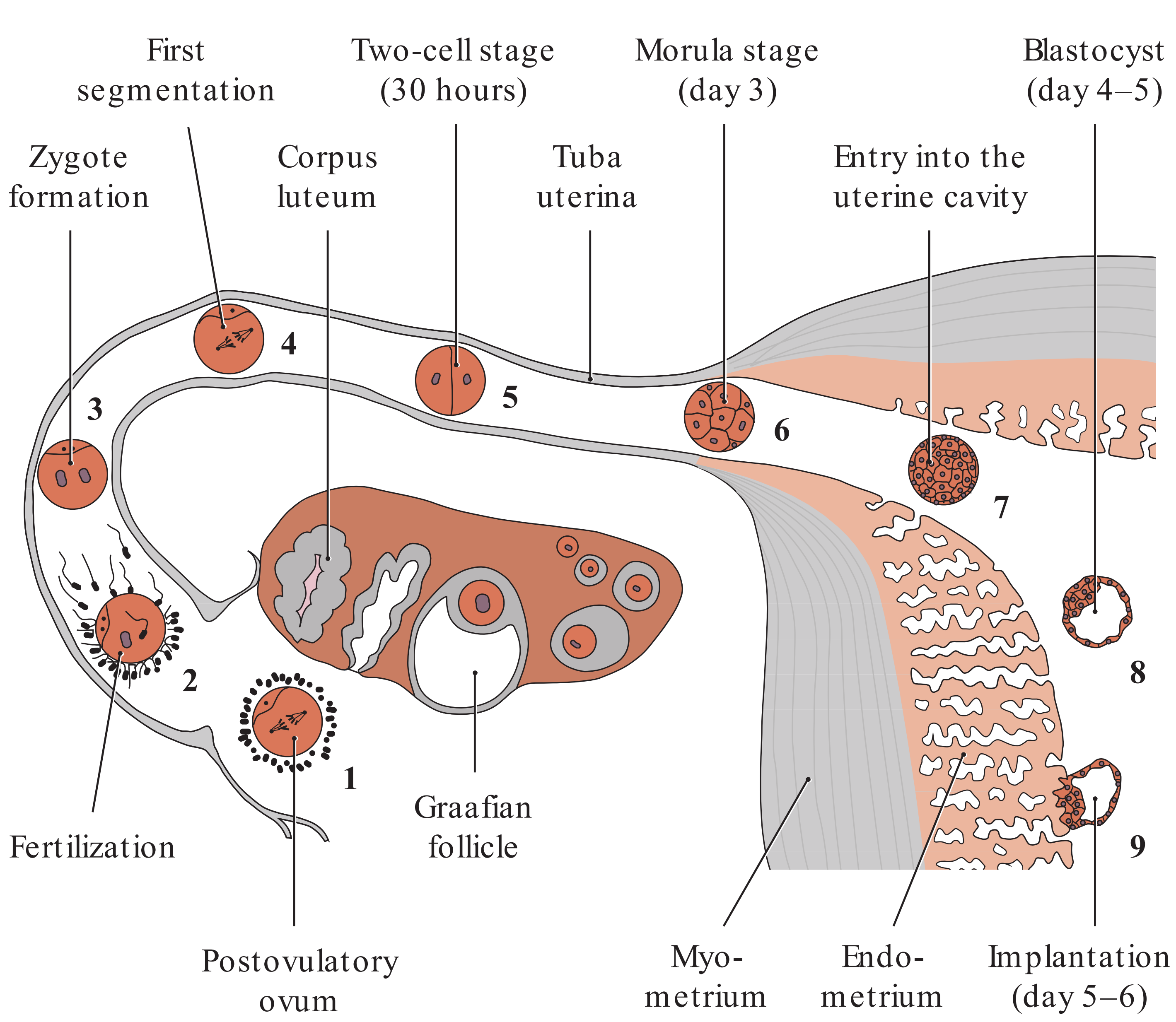


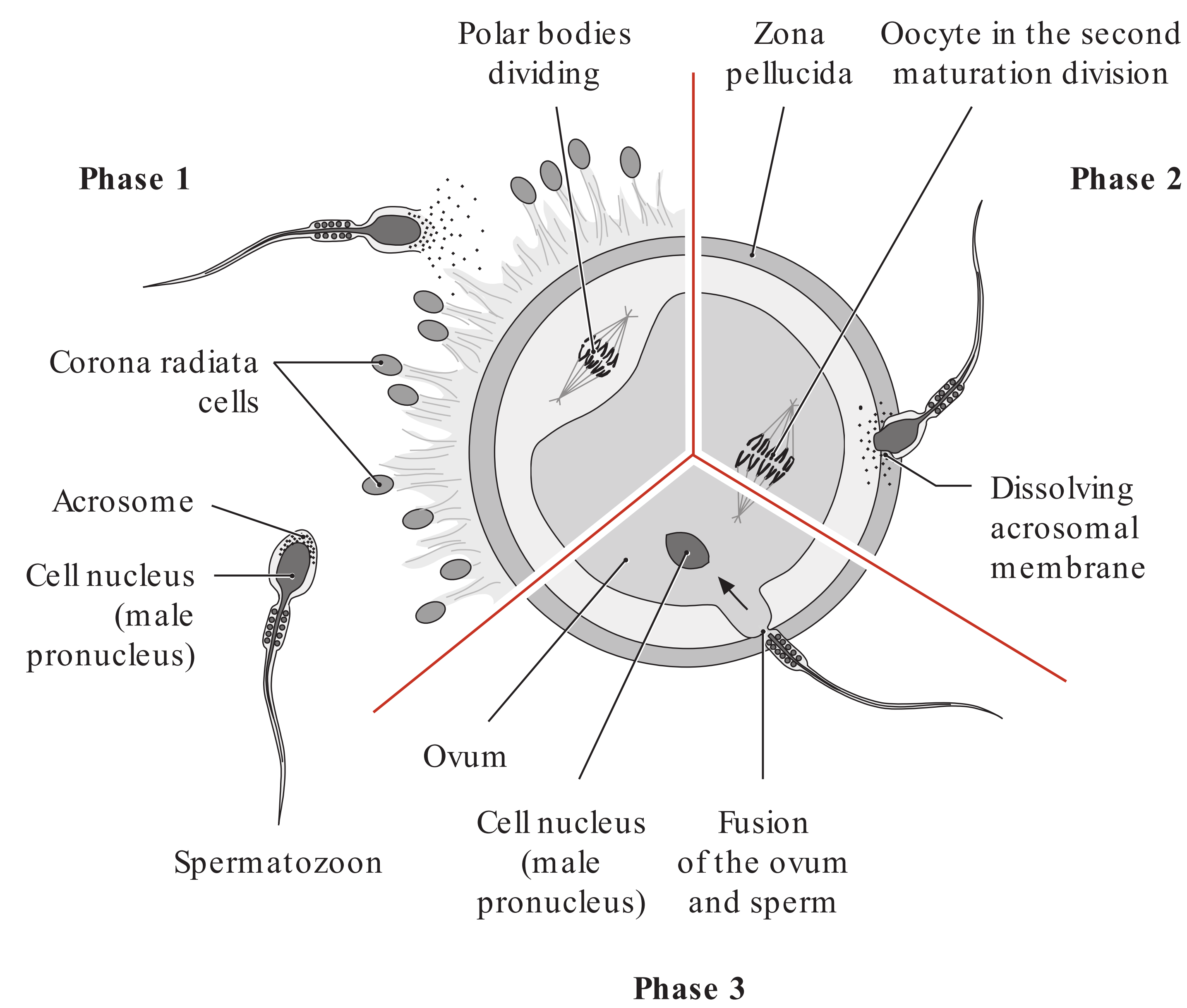

**E Formation of the ovum and sperm** (after Sadler)

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 chromosomal 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 (44XX). Later the primary oocytes undergo a first and second maturation division by meiosis, resulting in four haploid cells (22X): one mature ovum and three polar bodies.

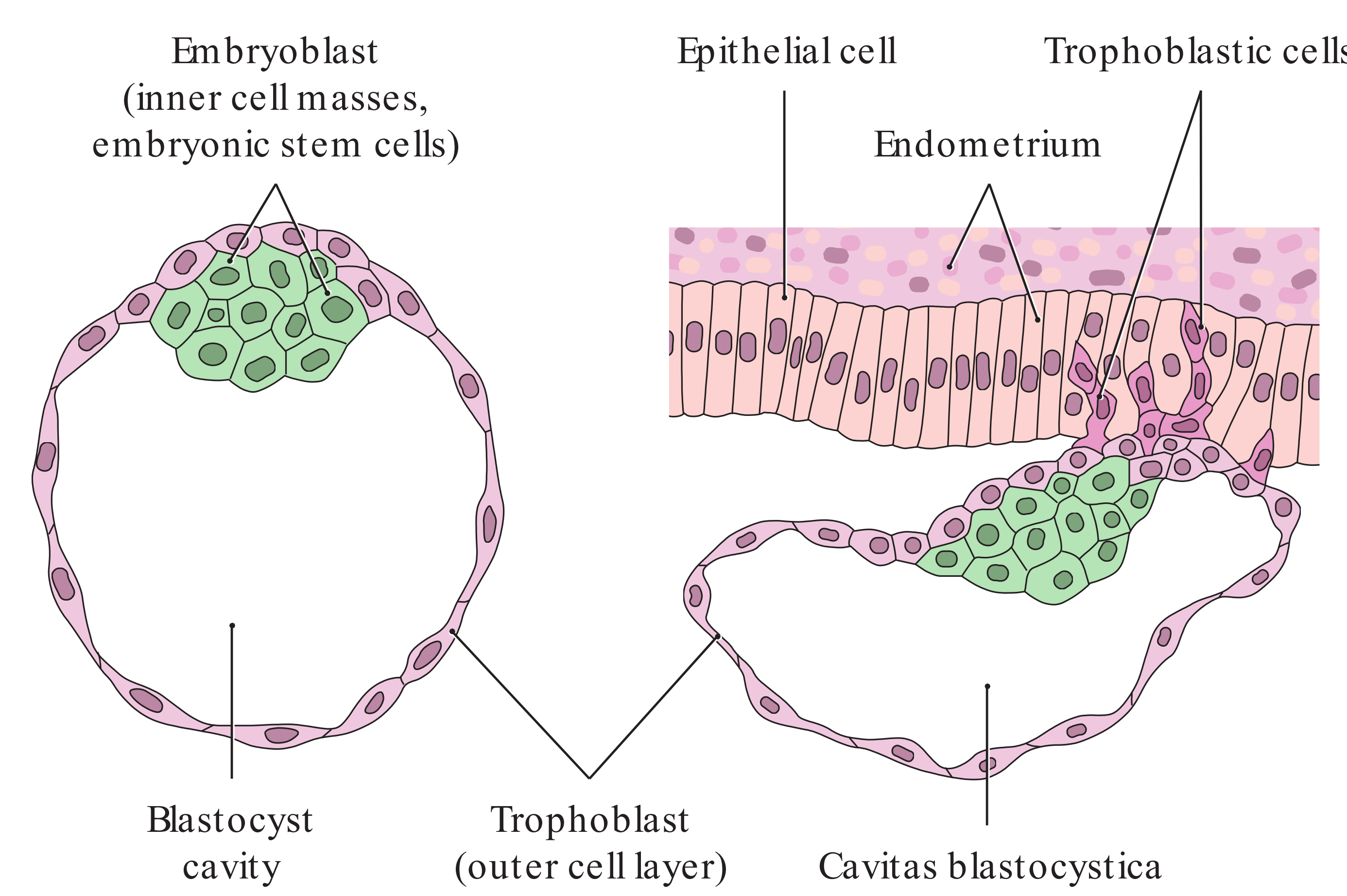
**Spermatogenesis:** Diploid spermatogonia undergo mitosis to form primary spermatocytes (44XY). These cells then divide meiotically to form four haploid spermatids, two of which have an X chromosome (22X) and two a Y chromosome (22Y). The spermatids develop into motile spermatozoa (spermatohistogenesis).




**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.

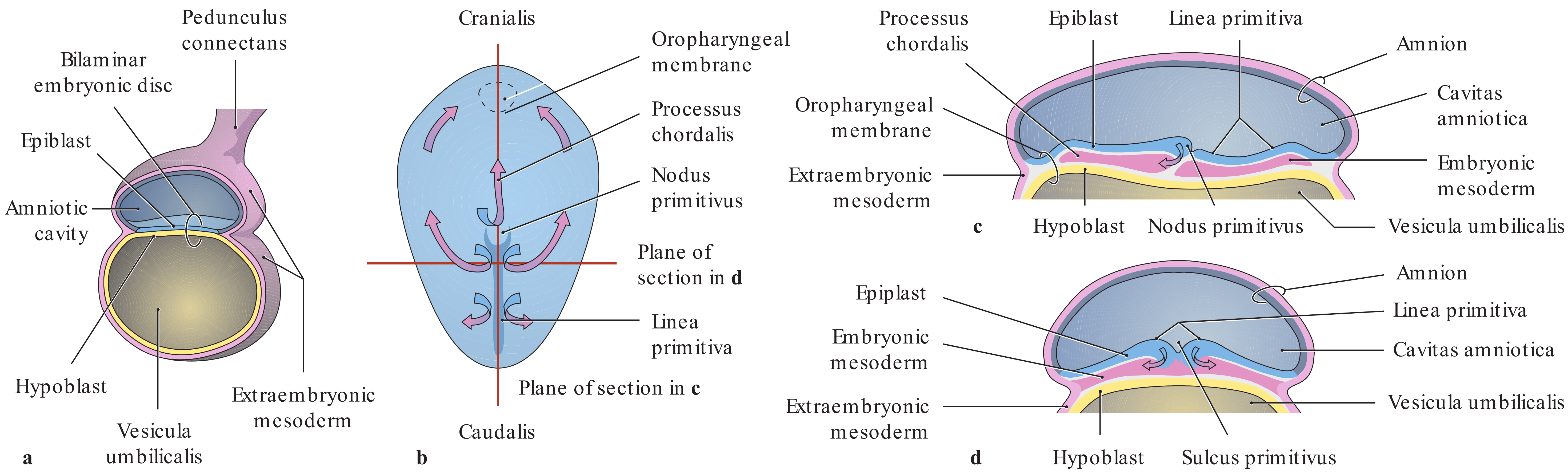



**G Implantation of the blastocyst in the uterine mucosa on postovulatory day 5–6** (after Sadler)

**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



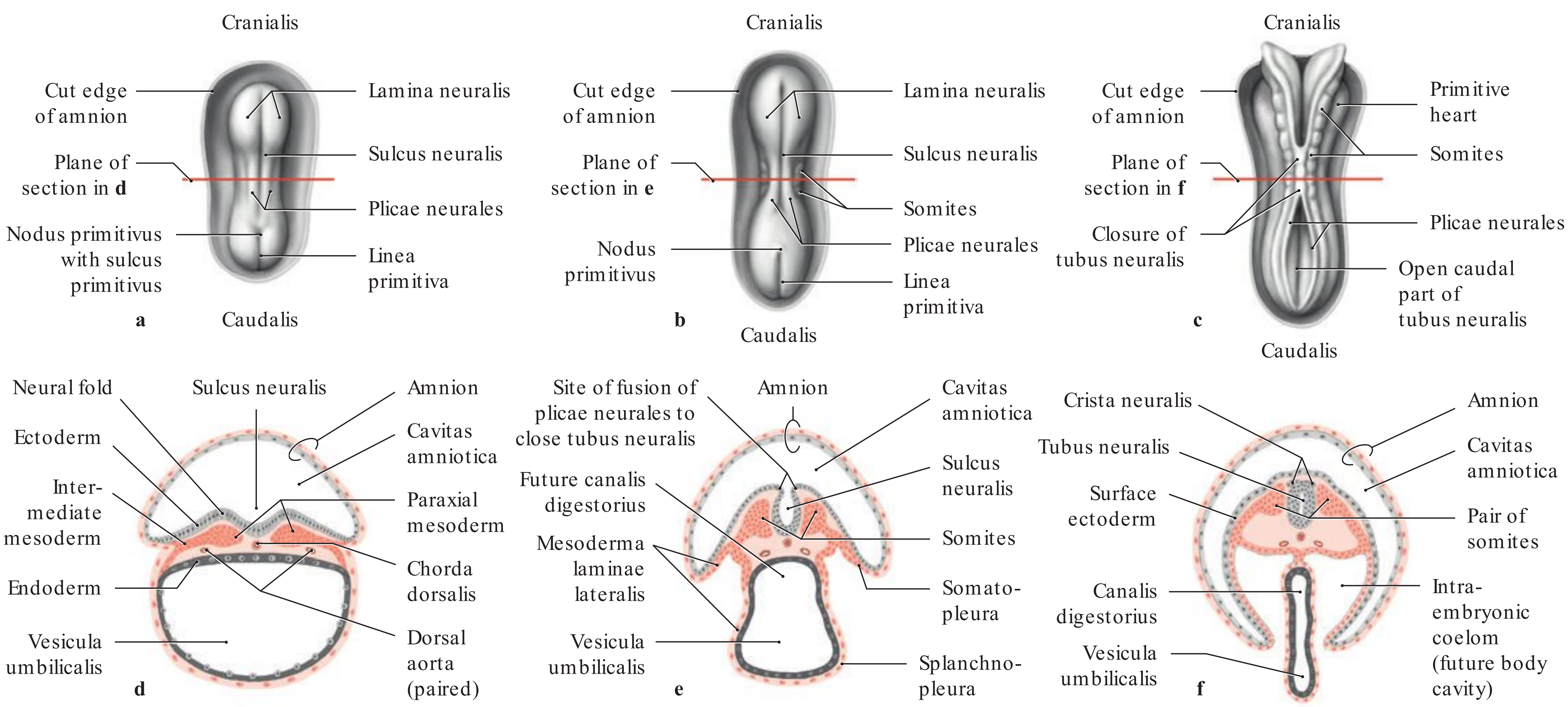

**A Formation of the trilaminar human embryonic disc (gastrulation) at the start of the third postovulatory week** (after Sadler)
As a result of gastrulation, the cell layers become differentiated into an ectoderm, endoderm, and mesoderm, from which all structures of the human body are derived (e.g., 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 disc is still bilaminar and is stretched between the amniotic cavity (cavitas amniotica) and yolk sac (vesicula umbilicalis). The extraembryonic mesoderm, whose formation commences at the posterior pole of the embryonic disc, already covers the entire conceptus, which is attached to the chorionic cavity by a connecting stalk.

**b Dorsal view of an embryonic disc at the start of gastrulation.** The amnion has been removed. At the start of gastrulation, the epiblast develops a primitive streak (linea primitiva), where the embryonic mesoderm is generated and migrates between epiblast and hypoblast. Shortly afterward, at the level of the primitive node (the cranial tip of the primitive streak), epiblast cells migrate cranially to form the processus chordalis and radially to form the definitive endoderm. In the process, the definitive endoderm sequentially replaces the hypoblast, while the processus chordalis only temporarily fuses with the hypoblast layer. The processus chordalis expands cranially from the primitive node to the oropharyngeal membrane.

**c Sagittal section of an embryonic disc along the processus chordalis.**

**d Cross section of an embryonic disc at the level of the primitive groove** (sulcus primitivus, arrows in **c** and **d** indicate the direction of gastrulation movements by the mesoderm).




**B Neurulation during early human development** (after Sadler)

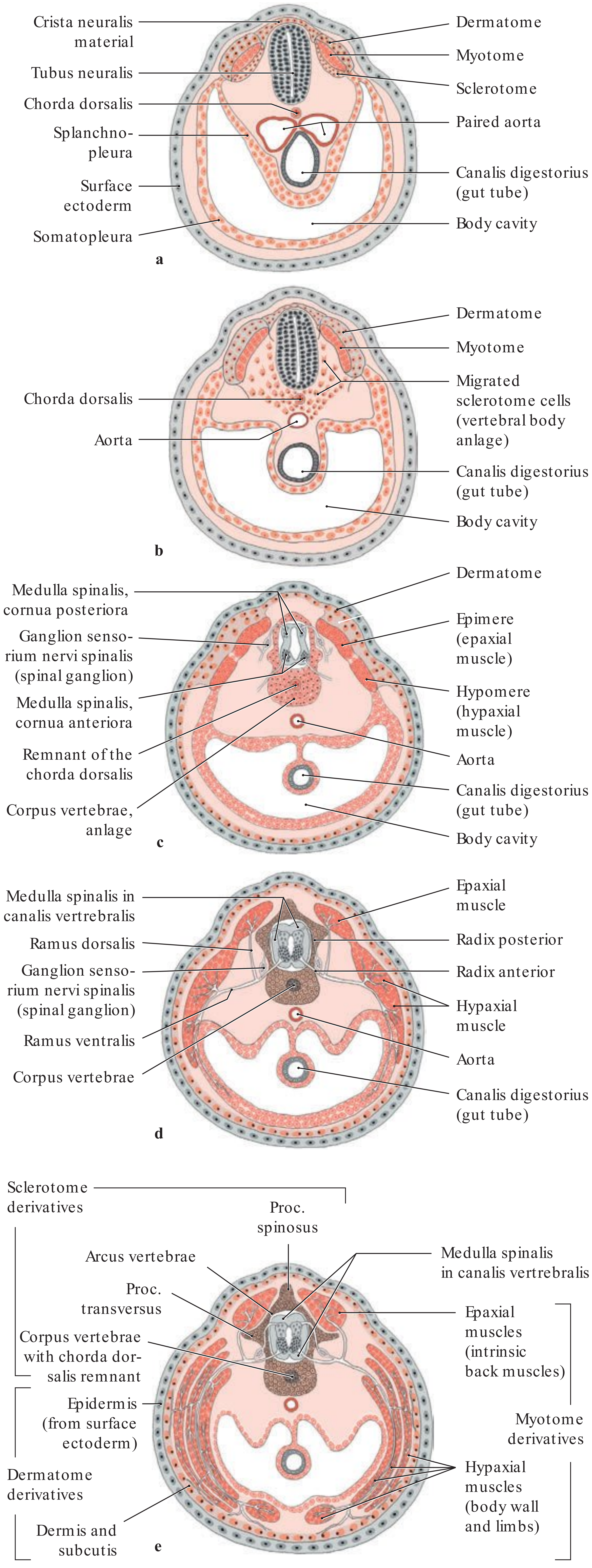
**a–c** Dorsal view after removal of the amnion.

**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 chorda dorsalis.

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

**b, e** Embryonic disc at 20 days. The first somites have formed, and the sulcus neuralis (neural groove) is beginning to close to form the tubus neuralis (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 crista neuralis that 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)

| | | |
|---|---|---|
| Tubus neuralis | | Encephalon (brain), retina, medulla spinalis (spinal cord) |
| Crista neuralis | Crista neuralis of the head | Sensory and parasympathetic ganglia, intramural nervous system of the bowel, parafollicular cells, smooth muscle, pigment cells, glomus caroticum (carotid body), bone, cartilage, connective tissue, dentin and cementum of the teeth, dermis and subcutaneous tissue of the head |
| | Crista neuralis of the trunk | Sensory and autonomic ganglia, peripheral glia, adrenal medulla, pigment cells, intramural plexuses |
| Surface ecto-derm | Ectodermal placodes | Anterior hypophysis, cranial sensory ganglia, olfactory epithelium, auris interna (inner ear), lens |
| | | Enamel organ of the teeth, epithelium of the oral cavity, salivary glands , cavitas nasi, sinus paranasales, lacrimal passages, external auditory canal, epidermis, hair, nails, cutaneous glands |
| Axial | Chorda dorsalis, prechordal mesoderm | Extraocular muscles |
| Paraxial | | Columna vertebralis, costae, skeletal muscle, connective tissue, dermis and subcutis of the back and part of the head, smooth muscle, blood vessels |
| Intermediate | | Renes (kidneys), gonads, renal and genital excretory ducts |
| Meso-derma laminae lateralis | Visceral (splanchno-pleura) | Cor (heart), blood vessels, smooth muscle, bowel wall, blood, cortex glandulae suprarenalis (adrenal cortex), visceral serosa |
| | Parietal (somato-pleura) | Sternum, limbs (cartilage, bones, and ligaments), dermis and subcutis of the anterolateral body wall, smooth muscle, connective tissue, parietal serosa |
| | | Epithelium of the bowel, respiratory tract, digestive glands, glandulae pharyngeales, eustachian tube, tympanic cavity, urinary bladder, thymus, glandulae parathyroideae, 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).

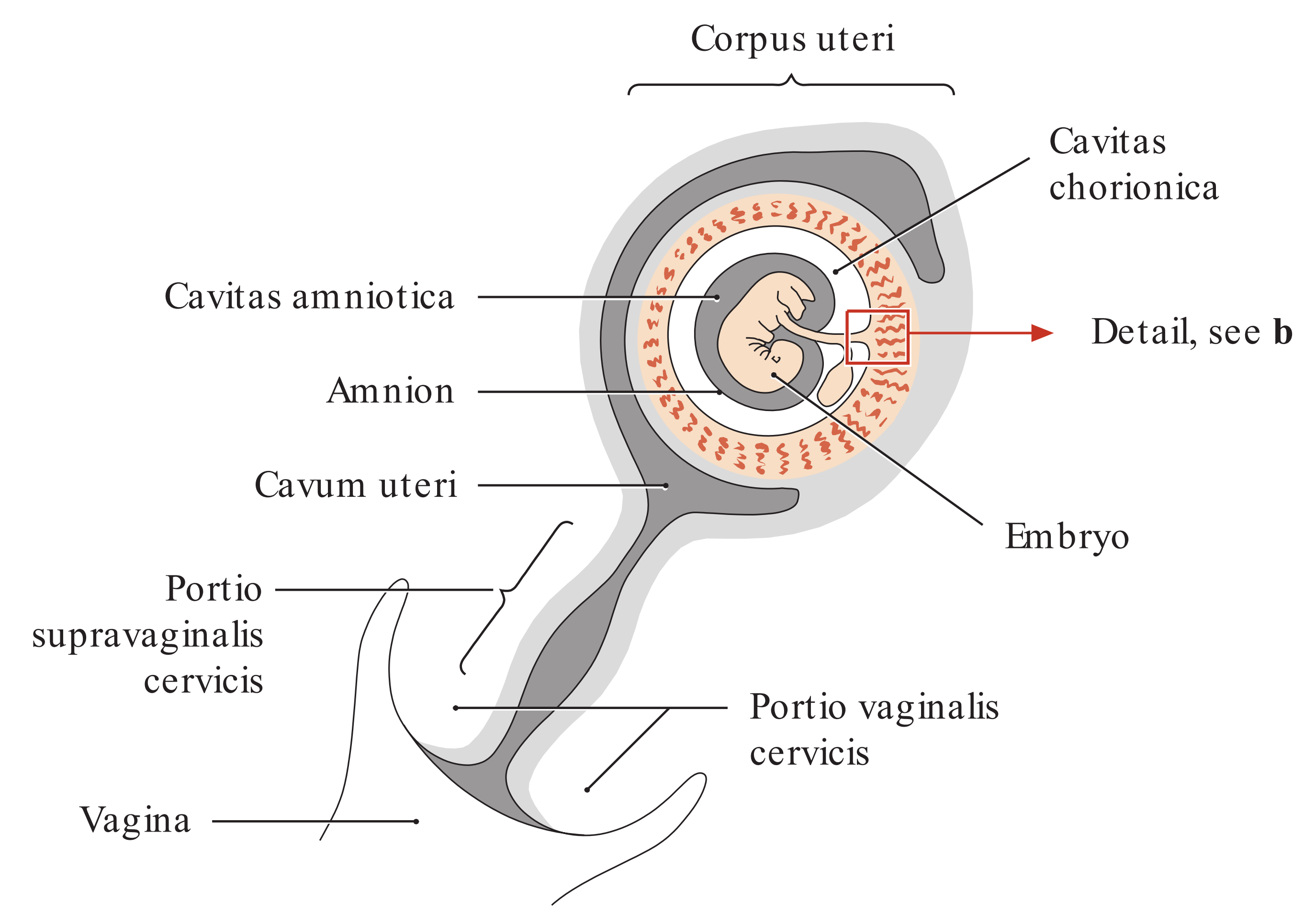
**b** At the end of 4 weeks, the sclerotome cells migrate toward the chorda dorsalis and form the anlage of the spinal column.

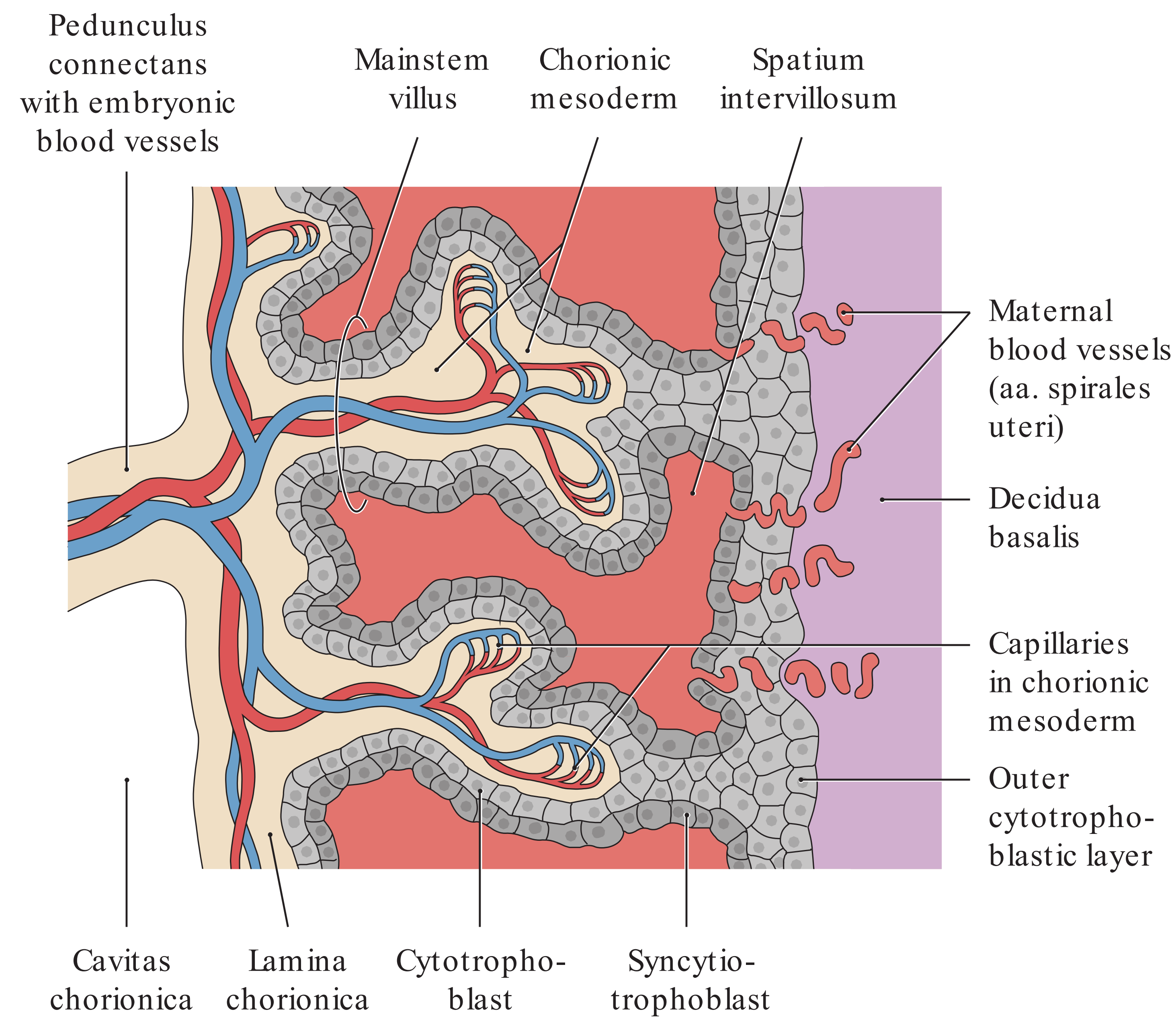
**c** The neural tube—the precursor of the spinal cord and brain—differentiates to form a rudimentary spinal cord with dorsal and ventral horns. Cells within the ventral horn differentiate into motor neurons that sprout axons that form the radix anterior. The crista neuralis has multiple derivatives,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

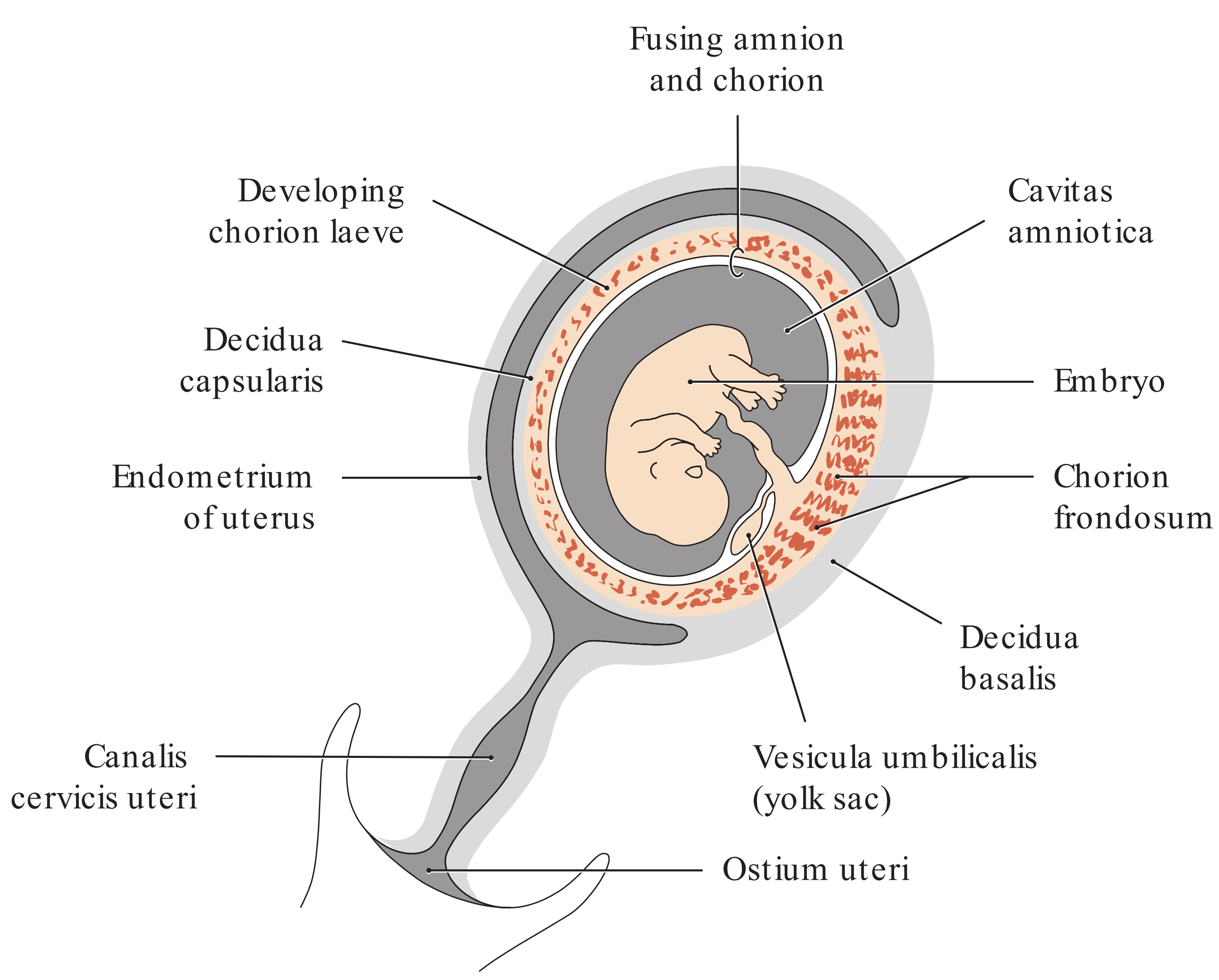
**d** Each pair of radix posterior and radix anterior unites to form a spinal nerve (n. spinalis), which then divides into two main branches (ramus dorsalis and ramus ventralis). The epaxial muscles are supplied by the ramus dorsalis, the hypaxial muscles by the ramus ventralis.

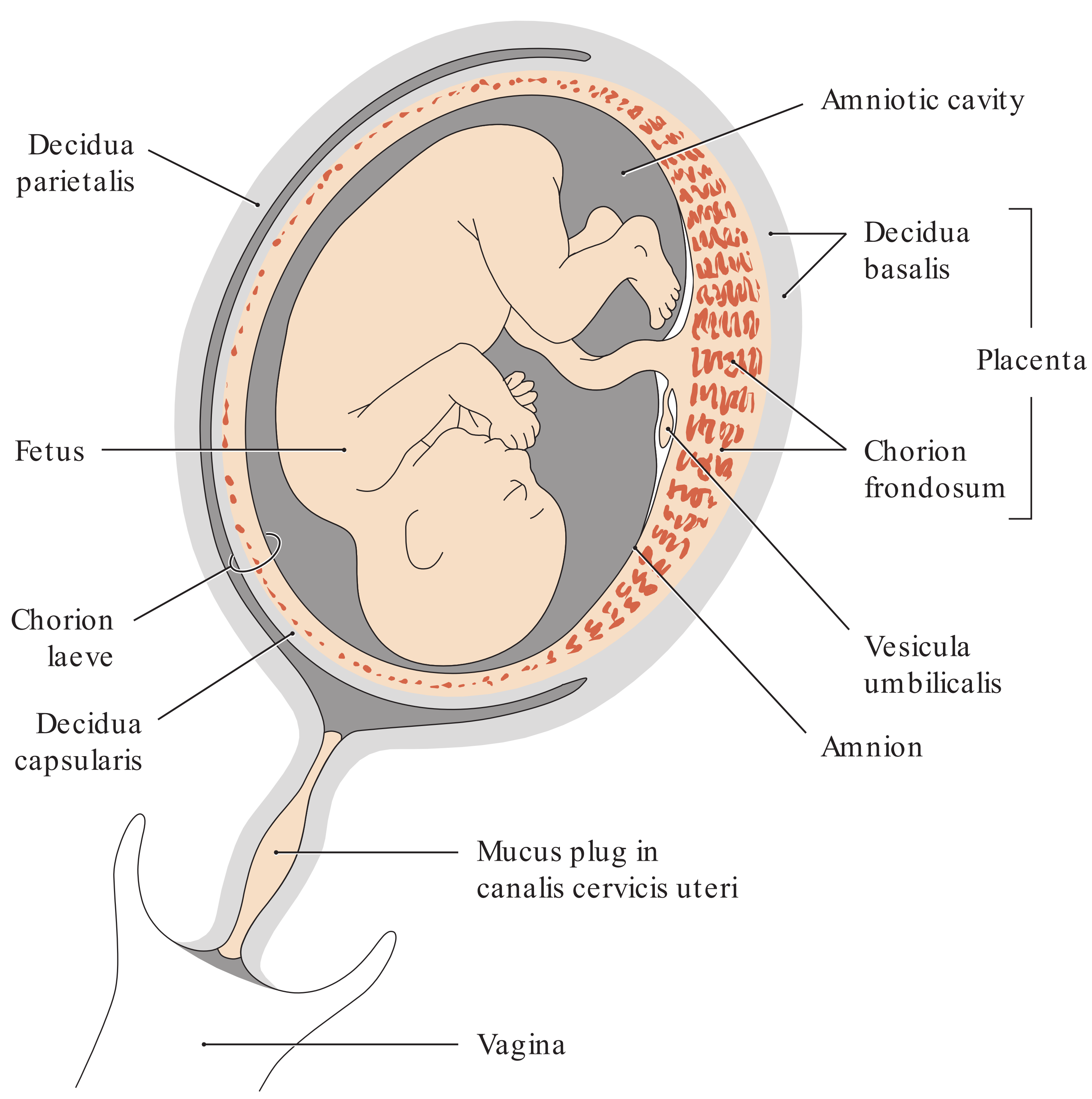
**e** Cross section at the level of the future abdominal muscles. The epaxial muscles become the mm. erector spinae, while the hypaxial muscles develop into structures that include the lateral abdominal muscles (mm. obliqui abdominis externus and internus, m. transversus abdominis) and the anterior abdominal muscles (m. rectus abdominis).

# 1.4 Human Ontogeny: Development of the Fetal Membranes and Placenta




**A Development of the fetal membranes and placenta** (after Sadler and Drews)
**a, c,** and **d** Schematic sections through a pregnant uterus at different points in gestation.
**b** Detail from **a**.

**a Embryo at 5 weeks:** After the blastocyst has implanted in the uterine mucosa, the embryo initially derives its nutrition through the developing trophoblast and chorionic mesoderm. Chorionic villi are formed that surround the entire chorionic sac and embryo. They develop from primary to secondary villi and finally to tertiary villi (see close-up in **b**).

**b Detail from a:** The mainstem villi of the chorionic plate (lamina chorionica) are attached on the maternal side to the lamina basalis of the decidua basalis by compact columns of trophoblastic cells. Like the small villous trees that sprout and branch from them, these mainstem villi have a syncytial covering (syncytial trophoblast), which in turn rests on a continuous layer of trophoblastic cells. Inside the villi, capillaries develop in the chorionic mesoderm and communicate with the vessels in the connecting stalk. Maternal blood flows through aa. spirales uteri into the intervillous spaces (spatium intervillosum).

**c Embryo at 8 weeks:** While the chorionic villi continue to grow and arborize at the embryonic pole, forming the chorion frondosum, the villi outside of this zone begin to regress, forming the nonvillous chorion laeve directly below the decidua capsularis. The amniotic cavity has enlarged at the expense of the chorionic cavity, and the amnion fuses with the chorion.

**d Fetus at 20 weeks:** The placenta is fully formed and consists of two parts: a fetal part formed by the chorion frondosum and a maternal part, the decidua basalis.