Handbook of Spine Surgery

Second Edition

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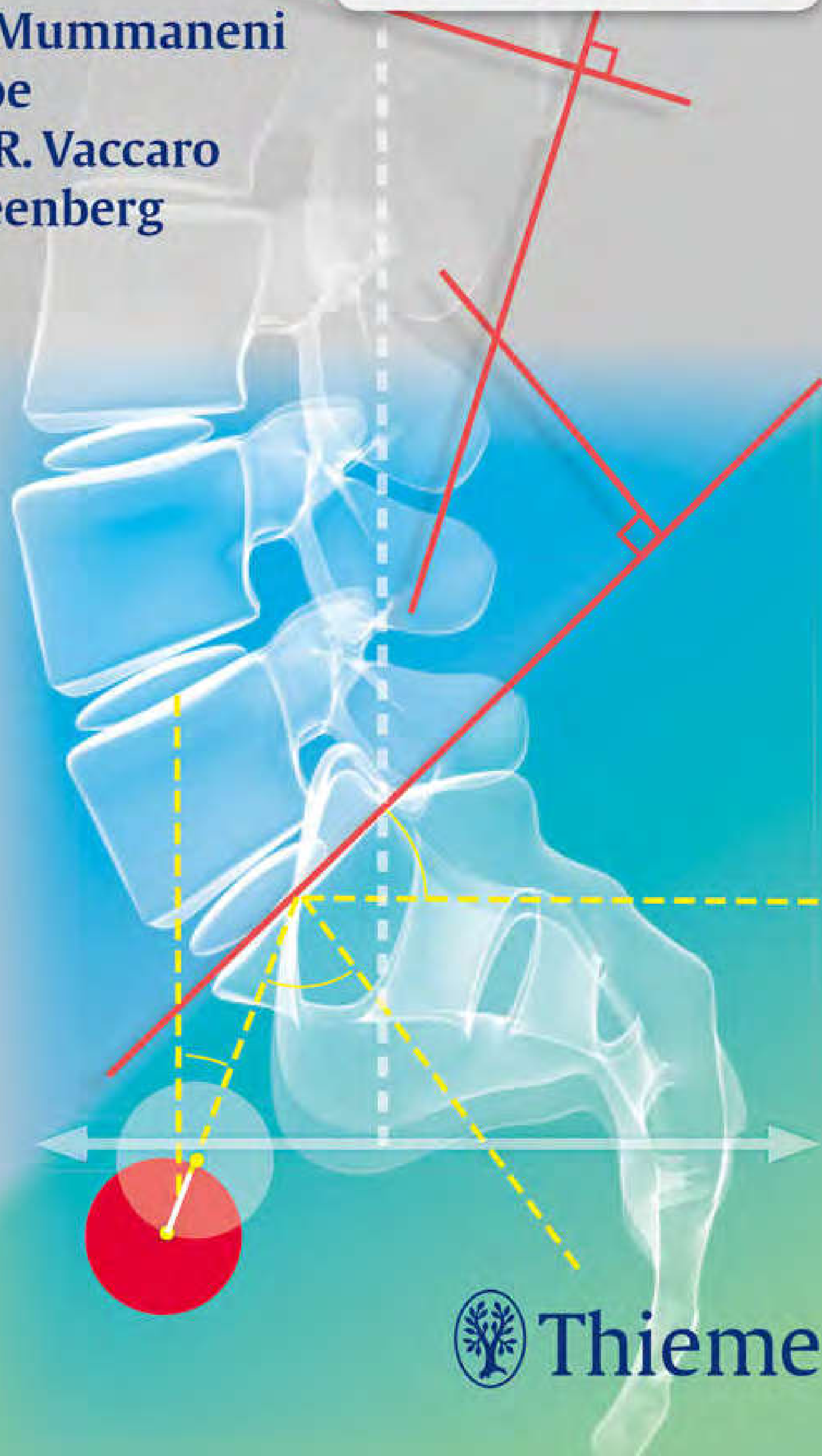

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Handbook of Spine Surgery

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To my parents, Abdulwahab and Hana, to my wife, Gabriela,
to all my mentors of spine surgery, especially Juan Uribe and Ziya Gokaslan,
and to the residents and fellows who give us the reason to do all this.
AAB

For Valli, Nikhita, Nkihil, and Neel for all their love and support.
For the fellows and residents whom I have had the pleasure to help teach.
PVM

I would like to dedicate this book to the birth of my child,
Christian John Vaccaro, and to my beautiful wife, Lauren. Lauren's
gift of caring and love has only added to the joy of our family life.
ARV

To my family.
MSG

To my wife, Catalina, my son, Sebastian, my daughter, Camila, my parents,
Carlos Santiago and Maria Cecilia, and my parents-in-law, Ivan and Maria
Cecilia, for their love and unconditional support.
JSU

Contents

Appendices

Foreword

In this exciting second edition of the *Handbook of Spine Surgery*, editors Ali A. Baaj, Praveen V. Mummaneni, Juan S. Uribe, Alexander R. Vaccaro, and Mark S. Greenberg have configured a virtual step-by-step "cookbook" of all the common and uncommon surgical spine procedures utilized around the globe, with chapters authored by highly recognized spinal surgeons. This task has been expertly accomplished by the overall organization of the chapters into sections: Anatomy, Clinical Spine Surgery, Spinal Pathology, and Surgical Techniques. Specific topics are thoroughly covered within and across sections, such as "Thoracolumbar Trauma" (Chapter 21 in the Spinal Pathology section), "Freehand Thoracic Pedicle Screw Placement Technique" (Chapter 47 in the Surgical Techniques section), and specific surgical procedures, such as "Sacrectomy" (Chapter 69 in the Surgical Techniques section). A common template is followed in which each chapter logically proceeds from Key Points to Indications, Techniques, Complications, Postperative Care, Outcomes, Surgical Pearls, Common Clinical Questions and Answers (as is seen in current CME formats), and Key References. This structure is very effective and ideal for quick and easy review the evening before, or even the morning of, conferences and surgical procedures. Trainees still trying to master these topics, as well as more senior surgeons needing a quick refresher, will benefit. The organizational style is direct and compact but thorough, appropriately illustrated when helpful, and perfectly suited to a busy clinical schedule where essential information and details need to be gleaned in rapid fashion, whether in print, on a phone, tablet, or computer. The organizational consistency of the chapters also aids in quick dissemination and retention, which is critical to our training environment.

I can envision this text being extremely useful to a wide range of individuals: from a third-year medical student performing his or her initial surgical rotation while assigned to the spine service, to a spine physician assistant helping out during surgery, to a spinal surgery fellow gaining technical confidence during the most important year of fellowship training. Those residents, fellows, and attendings utilizing this text will probably find the greatest "bang for their buck" in the pearls and tips, which are written to optimize safety and maximize efficiency during various specific spinal surgery procedures. I also found the Q and A sections a nice refresher for keeping up on the myriad of spine surgery techniques that have rapidly advanced over the past decade, as spine surgery itself continues down a subspecialization pathway distinct from orthopedic surgery and neurosurgery. In that regard, this book would also serve as an excellent review for those studying for board certification or recertification for the American Board of Orthopaedic Surgery or the American Board of Neurological Surgery exams.

I congratulate the editors and contributing authors for this important piece of work. Any "handbook" should, by definition, be able to concisely provide essential details of a condition and various remedies and solutions—as well as obstacles encountered along the way—to best educate the intended audience. I am confident that the *Handbook of Spine Surgery* has more than accomplished these objectives and will have an enduring and important impact on those fortunate enough to benefit from the assembled information provided.

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Foreword

The second edition of the *Handbook of Spine Surgery*, edited by Dr. Ali A. Baaj, Dr. Praveen V. Mummaneni, Dr. Juan S. Uribe, Dr. Alexander R. Vaccaro, and Dr. Mark S. Greenberg, is an outstanding distillation of the current knowledge of the evaluation and surgical management of spinal disorders. The book is divided into four well-organized sections: a detailed synopsis of spinal anatomy, an evaluation of the techniques used for clinical evaluation of spinal surgery, a detailed description of spinal surgical pathology, and a step-by-step description of surgical techniques. In addition, there are appendices on patient positioning, selected spinal orthoses, and commonly used outcome scales.

The Handbook of Spine Surgery particularly excels as a quick reference for almost any type of spinal surgical condition or surgical procedure, from occipitocervical fusion to spinopelvic fixation. Each of the chapters is written by a world-renowned physician. The surgical chapters are authored by experts from the field of orthopaedic or neurosurgical spinal surgery; every chapter has introductory key points and detailed descriptions of indications for each of the surgical procedures. A step-by-step description of instrumentation techniques, frequently asked questions, and surgical pearls are provided by experts in the field.

This book will be an invaluable resource for orthopaedic and neurosurgical residents in training, spinal surgical fellows, and practicing orthopaedic surgeons and neurosurgeons who deal with spinal pathology. The book covers an exhaustive set of topics in a succinct manner, but sufficient information is provided to serve as a surgical atlas. I feel that this will become the standard resource for surgeons in training, early in practice, those preparing for board examinations, and experienced spine surgeons needing a refresher. I am positive that in its electronic form this book will be used as a quick reference on a daily basis by most practicing spine surgeons. I congratulate the editors on this outstanding resource and look forward to having it available to use in my own practice.

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Preface

We are delighted to present the second edition of the *Handbook of Spine Surgery*. As with the previous edition, our goal is to provide a comprehensive yet portable and compact text that distills the basic principles of contemporary spine surgery. We have once again been fortunate to receive contributions from dozens of reputable surgeons representing acclaimed orthopedic and neurosurgery programs.

Whereas the highly popular format of the first edition is once again adopted, we have significantly enhanced the text with several new chapters addressing topics like pediatric scoliosis and adult deformity principles. We have also expanded the spinal trauma section to include dedicated chapters on cervical, thoracolumbar, and sacropelvic injuries. Surgical pearls and board-style questions at the end of each chapter emphasize the salient points of each topic.

We are confident that this text will continue to be an excellent resource for surgeons and trainees alike as we all strive to improve spine education and training and the clinical care of our patients.

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I
Anatomy

1 Embryology of the Spine

Eric Momin, Jared Fridley, and Andrew Jea

1.1 Key Points

- Vertebral body development: Gastrulation gives rise to paraxial mesoderm, which forms somites, which differentiate into sclerotomes, which surround neural tissue then resegment, and ossify into vertebral bodies.
- Vertebral body shape is determined by several homeobox (*Hox*) genes.[1]
- Posterior element development: Cells adjacent to the neural tube form vertebral arches (or neural arches).
- Epiblast cells migrate to form the primitive groove, which in turn forms the notochord.
- The anterior neuropore closes on day 25 and the posterior neuropore on day 27.
- Neuroblasts form the mantle layer; the ventral portion forms the basal plates (motor), and the dorsal portion forms the alar plates (sensory).
- The caudal portion of the tube undergoes retrogressive differentiation and relative ascension of the conus.

1.2 Bony Development

- **Vertebral body:**
  - Somatogenesis: Paraxial mesoderm gives rise to 42 to 44 somites. Somites give rise to ventromedial sclerotomes and dorsolateral dermomyotomes. In week 4, cells of the sclerotomes move to surround the spinal cord and notochord.[2]
  - Resegmentation: Each sclerotome is at first separated by mesenchyme. Sclerotomes undergo resegmentation, which occurs when the caudal half of each sclerotome separates and fuses with the cephalic half of the next sclerotome.
- **Posterior elements:** Cells adjacent to the neural tube form vertebral arches (or neural arches) that give rise to the posterior elements.
- **Disk:** Cells from the caudal portion of the sclerotome form the annulus fibrosus. Notochord remnants form the nucleus pulposus.
- **Ossification:** An ossification center is a cartilaginous “model” that is ossified into bone.
  - Three primary ossification centers for each vertebrae: One for the vertebral body and one for each half of the vertebral arches. Five

secondary ossification centers for subaxial vertebrae: One for the superior and inferior endplates of the body, one for the spinous process, and one at the tip of each transverse process.
  – C2 develops from five primary ossification centers: Two for the body of the dens, one for the vertebral body, and one for each neural arch.[3] The tip of the dens represents a secondary ossification center.
  – *Hox* genes: The shape of vertebral bodies is regulated by *Hox* genes that code for transcription factors.[1]
- **Spinal curves:** Thoracic and sacral curves are present during the fetal period. Cervical lordosis develops when the child learns to hold up the head. Lumbar lordosis develops with walking.

1.3 Neural Development

- **Primitive pit:** The bilaminar disk consists of epiblast and hypoblast layers. Some epiblast accumulates at each side of the dorsal midline to form the primitive streak and, subsequently, the primitive groove. At the rostral edge of the primitive groove is a pit, the primitive node.
- **Genesis of notochord:** After gastrulation occurs, epiblast migrates rostrally from the primitive node, which is called the notochordal process. (This phenomenon can be compared to pushing one's finger into an inflated balloon.) The tube is formed exactly between the ectoderm and endoderm, and it divides the mesoderm. Thus, it is bordered laterally by mesoderm, superiorly by ectoderm, and inferiorly by endoderm.
- **Induction of neural plate:** At 3 weeks' gestation, the edges of the neural plate begin to elevate to form neural folds that begin to fuse in the cervical region, forming the neural tube **(Fig. 1.1)**.[2]
  – Anterior neuropore closes on the 25th day.
  – Posterior neuropore closes on the 27th day.

Neural crest cells detach from the neural folds and migrate to form glia, arachnoid, pia, melanocytes, chondrocytes, chromaffin cells, osteocytes, Schwann cells, and enteric ganglia.

- **Mantle layer:** Neuroblasts form a mantle layer around the neuroepithelial layer that forms the gray matter of the spinal cord **(Fig. 1.2)**.[2]
  – The ventral mantle layer forms the basal plates (motor horn), and the dorsal mantle layer forms the alar plates (sensory horn). The boundary between the plates is called sulcus limitans.
  – At the thoracic (T1–T12) and upper lumbar (L1–L2) region, the intermediate horn contains sympathetic neurons of the autonomic nervous system.

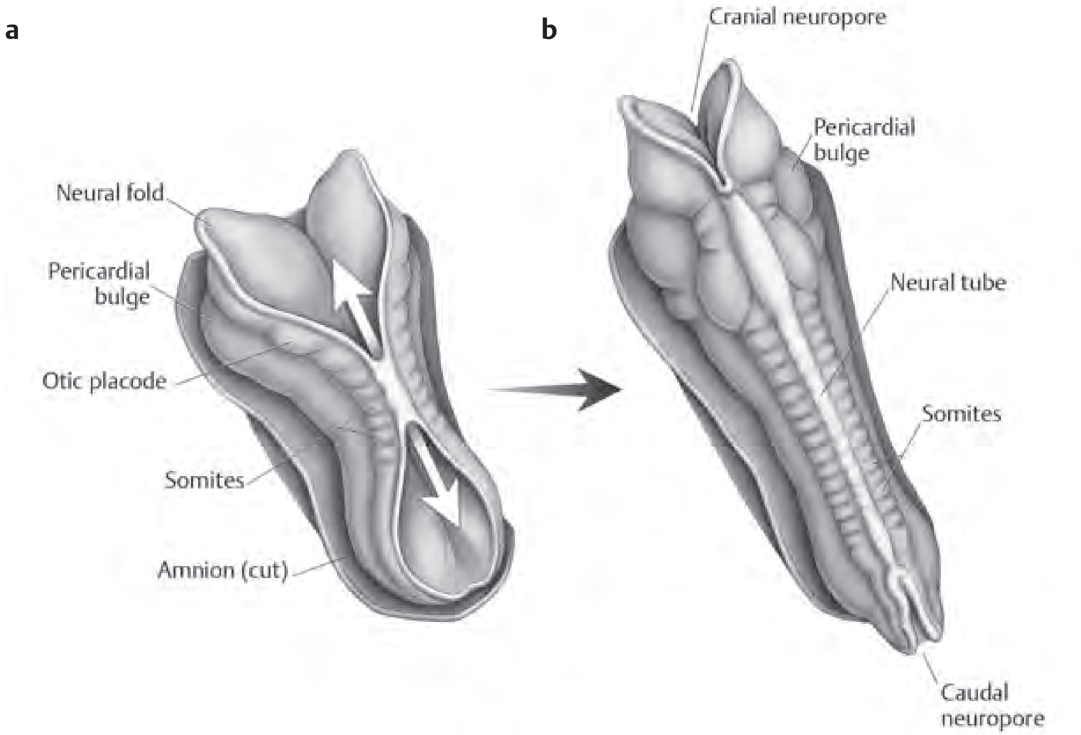

Fig. 1.1 (a) Dorsal view of the human embryo during the third week of gestation. Note the somites on each side of the neural tube as it begins to fuse in the cervical region. **(b)** The fused neural tube then continues to close both rostrally and caudally.

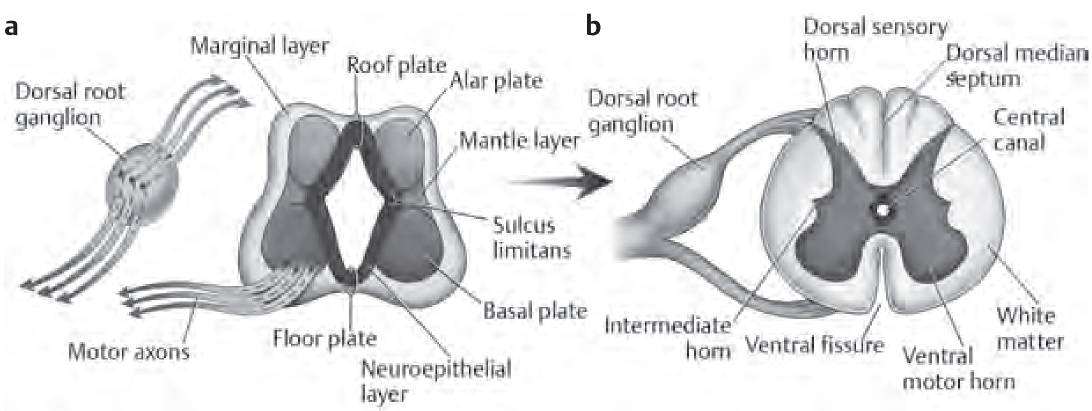

Fig. 1.2 (a) Cross-section of the developing spinal cord demonstrates how the migrating neuroblasts from the neuroepithelial layer form dorsal and ventral mantle layers. These ultimately become the gray matter of the spinal cord. **(b)** In addition, note the development of the dorsal root ganglion, as well as the outward growth of the motor axons.

- **Marginal layer:** The marginal layer contains nerve fibers from neuroblasts in the mantle layer that ultimately form the white matter of the spinal cord.
- The caudal tube forms during canalization (days 28–42).
- From day 43 to day 48, the ventriculus terminalis (a cystic structure at the caudal neural tube end) undergoes retrogressive differentiation, which is completed postnatally at 2 months.[2]
  - This results in relative ascension of the conus to its final level of L1/L2 and formation of the cauda equina and filum terminale **(Fig. 1.3)**.

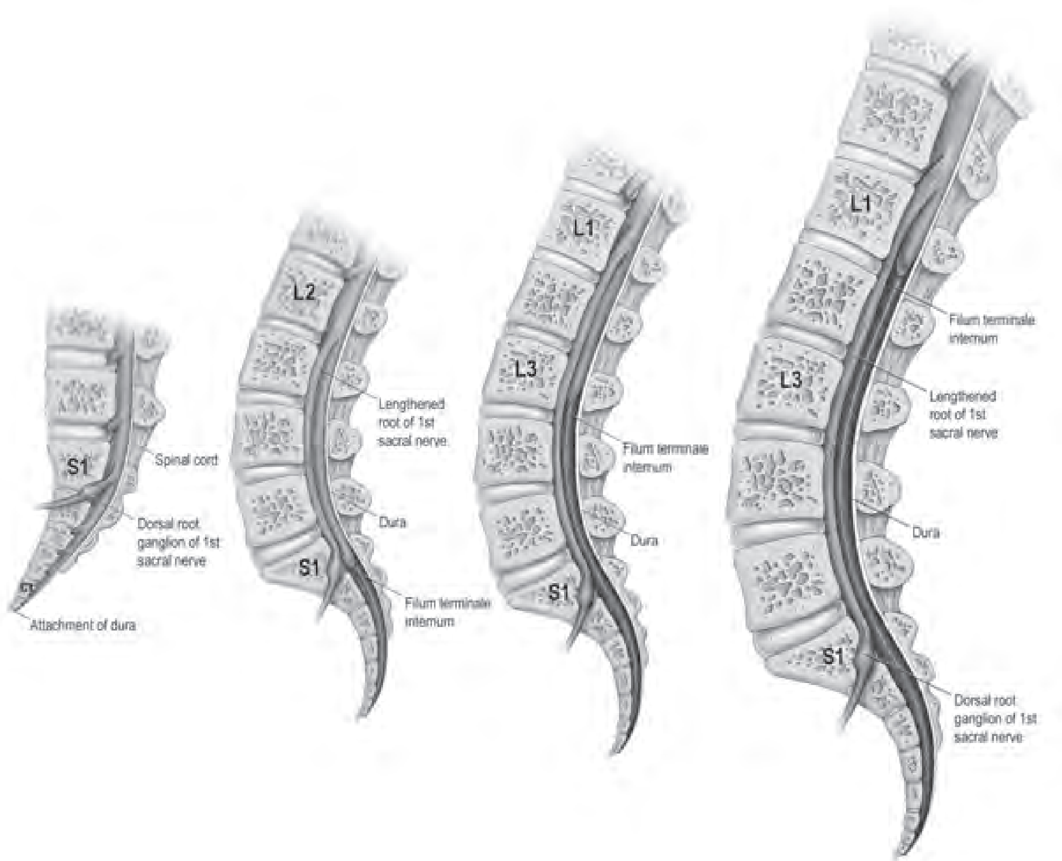

Fig. 1.3 The relative ascension of the conus and formation of the filum terminale via retrogressive differentiation.

1.4 Clinical Correlates

- The conus ascends to L1 to L2 by 2 months of age and may be lower in a neonate (keep in mind for lumbar punctures).
- Complete fusion of the ossification centers of C2 does not occur until age 12 (synchondroses between ossification centers can be mistaken for fractures).
- Incomplete closure of
  - Anterior neural ***tube*** (22 days) → occipital encephalocele
  - Anterior neuro*pore* (24 days) → anencephaly
  - Anterior neuro*pore* + anterior neuro*tube* → craniorachischisis (brain and upper spinal cord remain open)
  - Posterior neuro*pore* (26 days) → spina bifida/spinal dysraphism below L1/L2
  - Neural tube (defect of secondary neurulation, 28 to 35 days) → spinal dysraphism above L1/L2
  - Ventriculus terminalis → terminal myelocystocele (cyst lined with ependymal cells, communicates with the central canal)

Common Clinical Questions

1. Which structures border the notochordal process?
2. Why is the dorsal midline devoid of vascular structures?
3. Why do most mammalian species have seven cervical vertebrae?

Answers to Common Clinical Questions

1. Mesoderm laterally, ectoderm superiorly, endoderm inferiorly.
2. Mesoderm does not cross the dorsal midline in development, so the vascular structures derived from mesoderm are not present on the dorsal midline.
3. The *Hox* genes are highly conserved between species.

References

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2 Craniovertebral Junction

Jonathan Hobbs and Edwin Ramos

2.1 Key Points

- The craniovertebral junction (CVJ) is composed of the occiput (O), occipital condyles, atlas (C1), and axis (C2) and represents the transition between the cranium and mobile cervical spine.
- CVJ is composed of osseous structures articulated with synovial joints, muscles, ligaments and membranes.
- The principal motion segment of the O–C1 joint is flexion extension; the C1 to C2 motion segment is the most flexible of the cervical spine in respect to axial rotation.
- The unique ligament and membrane configuration of the CVJ provide stability and permit movement without compromising the traversing neural elements **(Fig. 2.1)**.

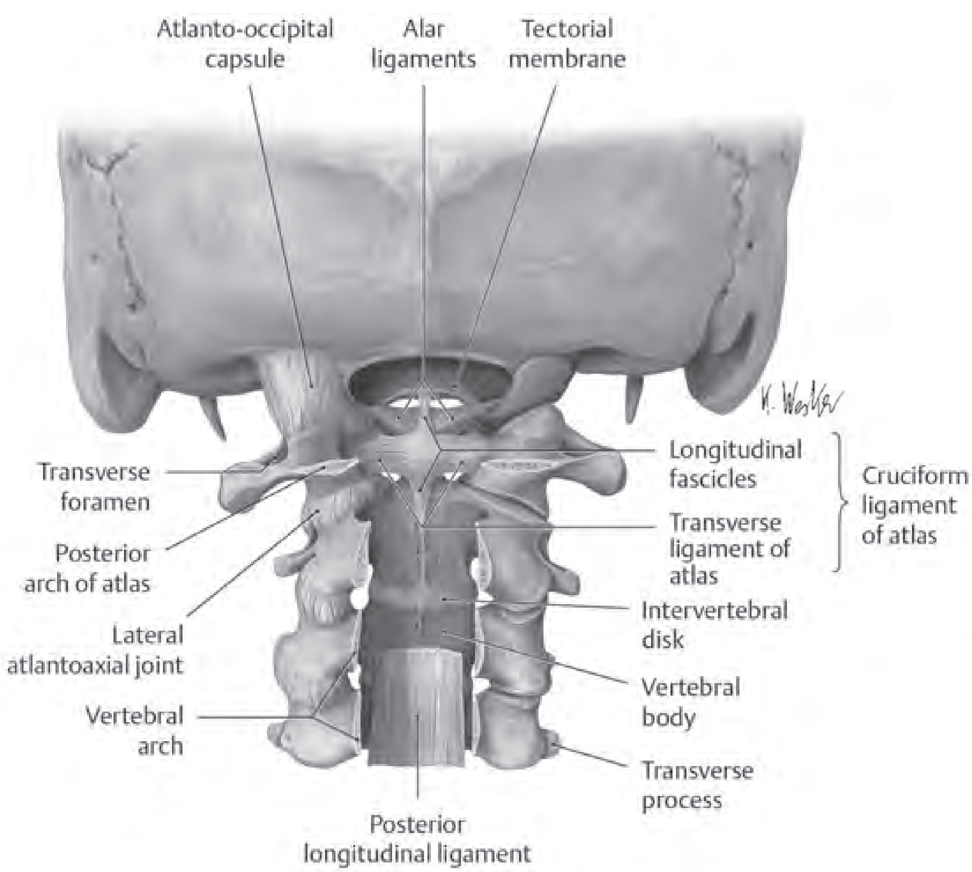

Fig. 2.1 CVJ ligamentous structures. (From Thieme *Atlas of Anatomy, General Anatomy and Musculoskeletal System*, © Thieme 2005, illustration by Karl Wesker.)

2.2 Bony Anatomy

- The CVJ consists of the base of the occiput, the atlas (C1), and the axis (C2).
- The boundaries of the foramen magnum are the basion anteriorly, the opisthion posteriorly, and the occipital condyles inferolaterally.
- The atlas (C1) has no vertebral body or spinous process. It is comprised of an anterior arch, a posterior arch, and two lateral masses. The superior facets are concave and accommodate the convex occipital condyles, allowing for flexion-extension motion segments **(Fig. 2.2)**.
- The C1 anterior tubercle (C1 "button") is the attachment site of the anterior longitudinal ligament (ALL) and the longus colli muscle.

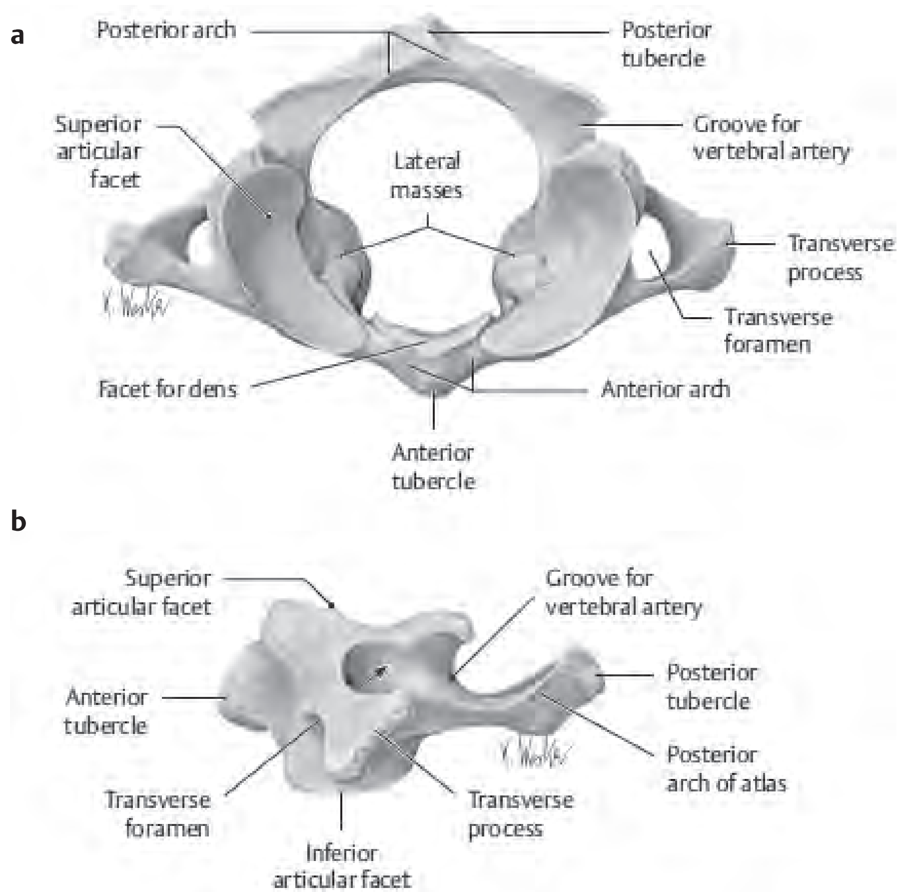

Fig. 2.2 **(a)** Superior and **(b)** lateral view of the atlas. (From Thieme *Atlas of Anatomy, General Anatomy and Musculoskeletal System*, © Thieme 2005, illustration by Karl Wesker.)