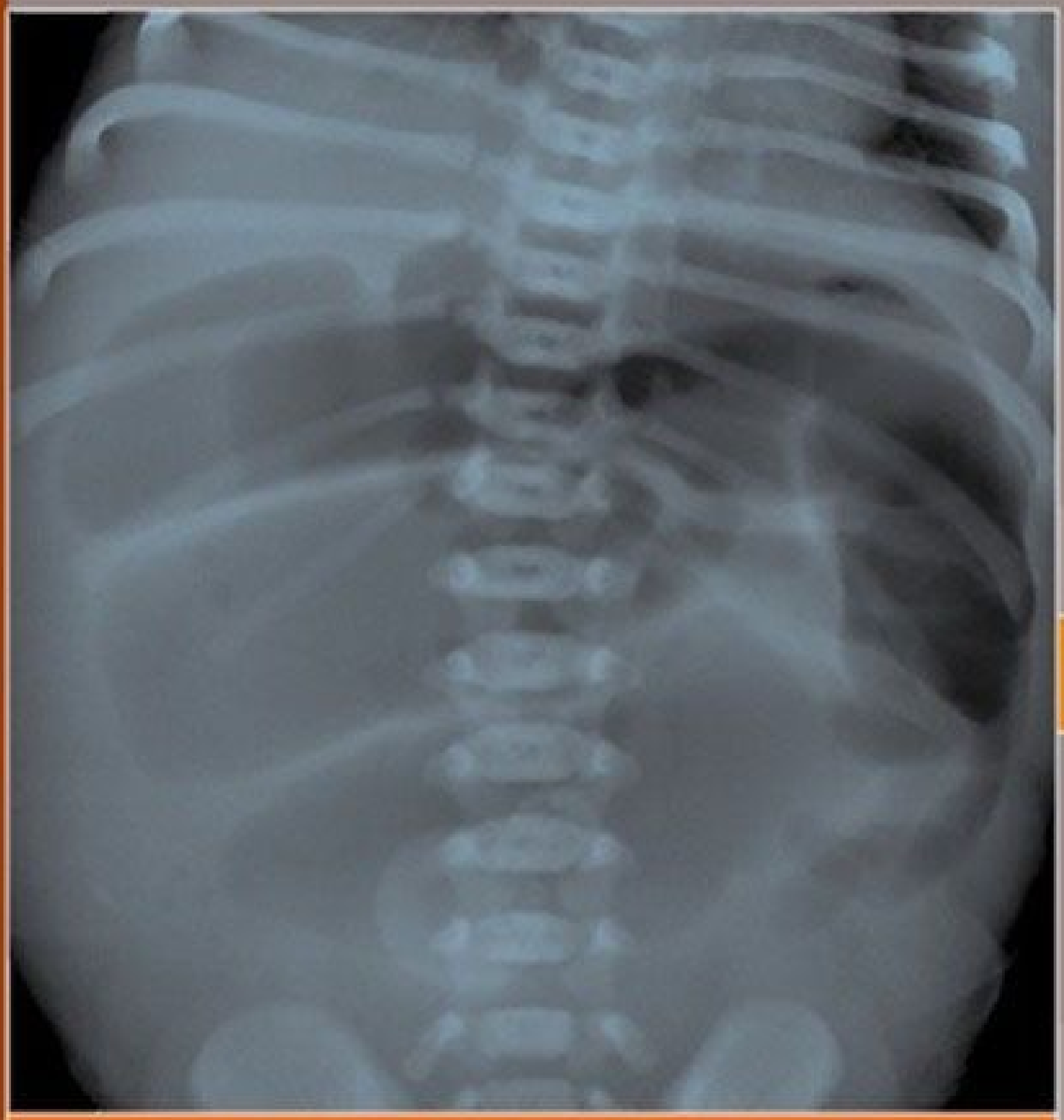

EDITION 2

FUNDAMENTALS OF Pediatric Imaging

Lane F. Donnelly

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FUNDAMENTALS OF RADIOLOGY SERIES

Fundamentals of Pediatric Imaging

SECOND EDITION

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FUNDAMENTALS OF PEDIATRIC IMAGING, SECOND EDITION ISBN: 978-0-323-41619-1

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Previous edition copyrighted 2009

Library of Congress Cataloging-in-Publication Data
Names: Donnelly, Lane F., editor. | Preceded by (work): Donnelly, Lane F.
Pediatric imaging.

Title: Fundamentals of pediatric imaging / [edited by] Lane F. Donnelly.
Description: Edition 2. | Philadelphia, PA : Elsevier, Inc., [2017] |
Preceded by Pediatric imaging : the fundamentals / Lane F. Donnelly.
c2009. | Includes bibliographical references and index.
Identifiers: LCCN 2016029806 | ISBN 9780323416191 (pbk.)
Subjects: | MESH: Diagnostic Imaging--methods | Child | Infant
Classification: LCC RC78.7.D53 | NLM WN 240 | DDC 616.07/54--dc23
LC record available at https://lccn.loc.gov/2016029806

Executive Content Strategist: Robin Carter
Content Development Specialist: Stacy Eastman
Publishing Services Manager: Catherine Jackson
Senior Project Manager: Doug Turner
Designer: Brian Salisbury

Printed in China

Last digit is the print number: 9 8 7 6 5 4 3 2 1

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Preface

When I was a radiology resident at the University of Cincinnati, one of the senior musculoskeletal imaging faculty members was Dr. Aaron Weinstein. He had originally gone into surgery, but when he was the chief surgical resident at the University of Cincinnati, he developed rheumatoid arthritis and decided to switch to radiology. As a senior radiology faculty person, Dr. Weinstein ran Bone Conference every Thursday morning at 7 a.m. For Bone Conference, residents brought cases, often from the teaching files, and presented them as unknowns that other residents had to take. Dr. Weinstein commented on and critiqued the job done by the resident taking the unknown case (and often the resident who picked the case) and then offered his opinion of the case. Not only was Dr. Weinstein an expert in musculoskeletal imaging, but he also had been at the University of Cincinnati for so long that he had already seen every interesting musculoskeletal case there, usually multiple times; so he was impossible to stump. He was also a cantankerous old man (though much of it was a show), and he smoked constantly, even during Bone Conference, which gave the whole thing an added cinematic flare. We usually just referred to him as "the old man." The entire process was terrifying to me as a young resident. I was always concerned about being humiliated in front of my peers and superiors. So every Wednesday evening of my residency I read the little *Fundamentals of Skeletal Radiology* textbook by Clyde Helms…cover to cover. I figured that having very good grasp of the basics of musculoskeletal imaging would minimize my chance of looking like an idiot. It worked pretty well. Certainly, I learned bone radiology. I loved that book, and I often wondered why really good, short practical books about the other radiology subspecialties did not exist. I know that I retained more useful information when I read short and basic books over and over than when I read longer, more detailed texts once.

In the late 1990s, I was on the faculty in the Department of Radiology at Duke University and had the opportunity to work with and learn from Clyde Helms. I shared with him my love for his book, the story of how I read this book every Wednesday evening when I was in residency, and my disappointment that there were not other high quality fundamental books in the other subspecialties in our field. He encouraged me to write such a book on pediatric radiology and put me in contact with the folks at what was then WB Sanders (now part of Elsevier). I was in my early thirties and just a couple of years out of training at the time and probably had no business writing a textbook about anything. However, I proceeded and that led to *Fundamentals of Pediatric Radiology* and subsequently to the first edition of *Pediatric Imaging: The Fundamentals*. By medical textbook standards, the books have been very successful—more than 20,000 copies have been sold. They have been particularly popular among radiology residents and fellows. It's funny, but despite other accomplishments on which I have worked hard, my name is predominantly associated with these books.

The intention of the book you are now reading is to serve as a basic introductory text on pediatric imaging. It is written in prose, rather than as an outline, and is intended to be readable. The emphasis is on commonly encountered imaging scenarios and pediatric diseases. The topics included reflect questions commonly asked by residents on the pediatric radiology service, important issues that rotating residents often seem not to know, and commonly made mistakes. The book is intended to serve as an introduction or review for a resident or medical student who is about to begin a rotation in pediatric radiology, as a resource to a general or pediatric radiologist who wishes to brush up on pediatric radiology, or as a guide for a pediatric resident or pediatrician who wants to learn more about pediatric radiology.

Given the growing scope and complexity of pediatric imaging, for the first time I have brought in additional pediatric radiologists to contribute chapters in their areas of expertise. They include Drs. Monica Epelman ("Chest" and "Genitourinary"), Carolin V. Guimaraes ("Neuro"), Daniel J. Podberesky ("Cardiac"), and Alex J. Towbin ("Musculoskeletal"). I am deeply indebted to these authors for their

expertise, contributions, and help. Dated portions of the text have been updated, older images replaced with more modern imaging, and suggested readings updated. Thus I am pleased to present the second edition of *Fundamentals of Pediatric Imaging*. I think you will find the same practicality and easy-to-read prose as in the previous addition.

Much of what appears in this book is the summation of what numerous radiologists have taught us, and I would like to thank them for their time and efforts. I have had the honor and privilege to work at great organizations and for great leaders and mentors. The case material in this book is the result of the hard work of the faculty, technologists, and trainees in those departments and the referring physicians who care for their patients. I would like to acknowledge their efforts, without which this book would not be possible. Finally, and most importantly, I would like to thank my wife, Carolina, and children, Piper, Griffin, and Enzo, for all of their love and support.

Best of luck with pediatric imaging.

Lane F. Donnelly, MD

CHAPTER 1

Special Considerations in Pediatric Imaging

Lane F. Donnelly

▪ Pediatric Radiology As a Potential Career

Most pediatric radiologists are very happy with both their jobs and career choice. There are a number of attractive aspects about pediatric radiology. First, one of the most important elements of job satisfaction is the quality of the interactions one has with the people with whom one works. In general the physicians who choose to go into pediatric subspecialties, as well as other health care workers who choose to work at pediatric institutions, tend to be nice people. Aggressive, power-hungry people tend not to want to work with children. This makes a huge difference in the quality of daily life. In addition, pediatric subspecialists seem to rely on the opinions of pediatric radiologists more than many of their adult subspecialist counterparts. Similarly, pediatric radiology does not seem to have the same number of turf battles that many adult-oriented departments have.

Another unique feature of pediatric radiology is that one gets to be a "general specialist." Pediatric radiology is a small part of medical imaging overall, and in this sense the pediatric radiologist is very much a subspecialist. Compared with general radiologists who must have a working knowledge of a daunting amount of information, most pediatric radiologists feel comfortable that they have an adequate command of the knowledge they need to provide outstanding care. At the same time, pediatric radiologists are generalists in the sense that many pediatric radiologists deal with all modalities and organ systems. They get the best of both worlds. It is also possible in pediatric radiology to become a sub-subspecialist, such as a pediatric neuroradiologist, pediatric interventional radiologist, pediatric cardiac imager, or pediatric fetal imager.

The most powerful and fulfilling aspect of becoming a pediatric health care provider is probably the satisfaction that comes from working with and for children. Few activities are more rewarding than helping children and their families. There are many other attractive aspects of pediatric care. First, most kids recover from their illnesses, as compared with elderly adults. Most pediatric illnesses are not self-induced. Pediatric diseases are highly varied and interesting. In addition, pediatric conditions are being increasingly recognized as important precursors to adult illnesses that cause significant morbidity and mortality—obesity, osteoporosis, and glucose intolerance. Finally, children and their families are highly appreciative of pediatricians' help.

▪ Introduction: Special Considerations in Pediatric Imaging

Many issues are unique to the imaging of children as compared with that of adults. Imaging examinations that are easily carried out in adults require special adjustments to be successfully achieved in children. The rotating resident on a pediatric imaging rotation and the general radiologist who occasionally images children must be prepared to deal with these issues and to adjust imaging techniques to safely and successfully obtain imaging examinations. In this introductory chapter, several of the general issues that can arise when imaging children are addressed briefly.

Relationship Between Imager and Parents

In both pediatric and adult patient care situations, there are family members with whom the imager

must interact. However, in the pediatric setting there are several unique features in the relationship among imager, patient, and family. When caring for children, communication more often takes place between the radiologist and parent than between the radiologist and patient. Obviously, communication directly with the child is also paramount to success. In addition, the degree of interaction between the imager and the child-parent unit may be greater in the pediatric setting than in the adult setting because of associated issues, such as the potential need for sedation, the need for consent from the parent rather than the child (if the child is a minor), and the need for intense explanation of the procedure on the levels of both the child and the parent. Most people are also much more inquisitive and protective when their children are involved. Because of these reasons, descriptions of what to expect during the visit to the imaging area may have to be more detailed when dealing with pediatric patients and their parents.

The stress level of parents when their child is or may be ill is immense, and such stress often brings out both the best and worst in people. Because of the intense bonds between most parents and their children, the relationship between imager and parents is most successful when the radiologist exercises marked empathy, patience, professionalism, and effective communication.

Professionalism and Effective Communication

It is interesting to note that in pediatric health care most of the complaints by parents and families are not related to technical errors; they are more commonly related to issues of professionalism and communication. Of reported parent complaints 30% are related to poor communication and unprofessional behavior. In addition, practicing effective communication has been shown to have multiple positive outcomes, including better patient outcome, decreased cost, increased patient and family satisfaction, and decreased chance of litigation in the presence of adverse events.

Although physicians are referred to as health care professionals, historically they have not received formal training in professionalism and communication, have had poor role models, and have been seen as individual practitioners rather than as members of health care teams. Radiology departments and individual radiologists must be proactive in making improvements in this area. Having a program to improve and standardize interactions with families can be helpful. Scripting expected interactions can help improve patient and family interactions, such as defining how physicians introduce themselves to patients and families (including stating positions and roles in the upcoming procedure), as well as behaviors to avoid (such as stating that the patient's ordering physician does not know how to order or that one does not have time to talk to a referring physician because one is too busy). Scripting both the type of conversation and process in general is also very helpful for the delivery of difficult news, such as defining the process for communicating with the family when a child is diagnosed with a new tumor.

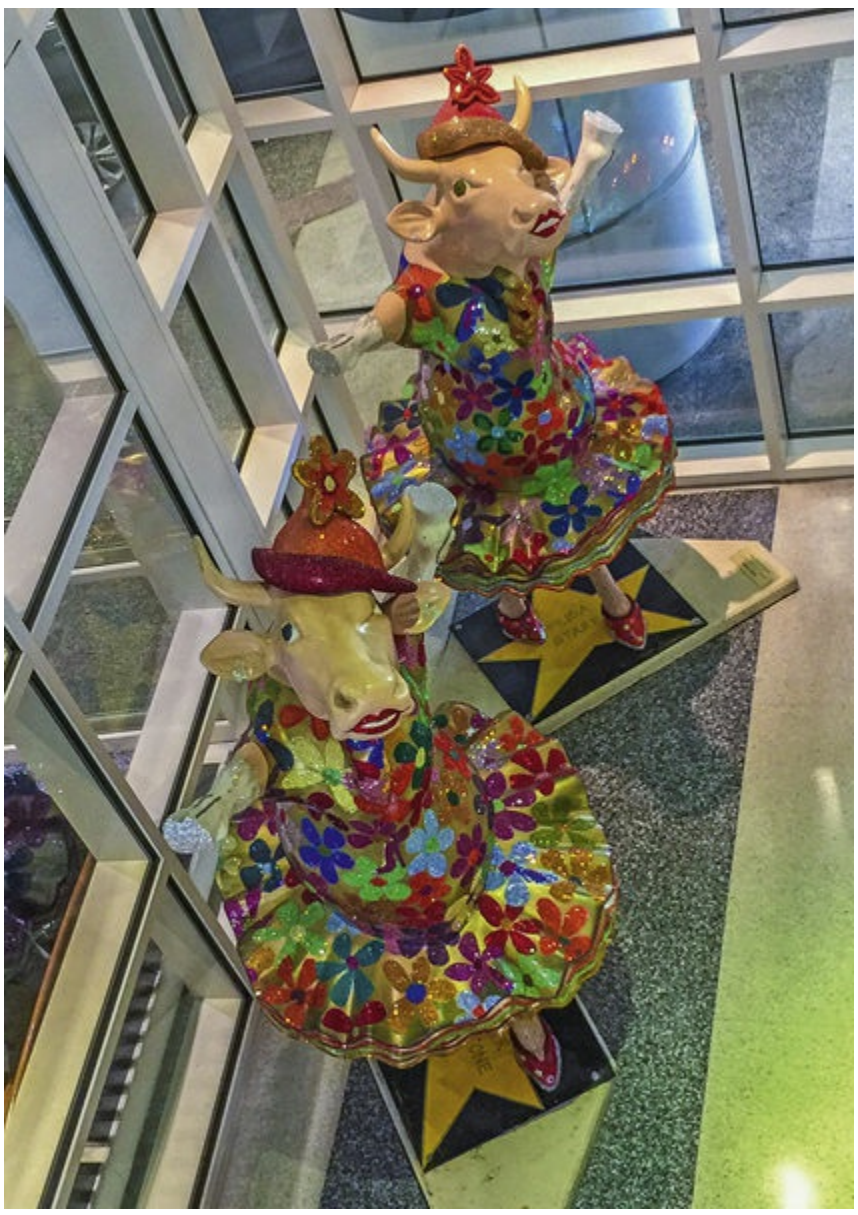
Inability to Cooperate

Infants and young children are commonly unable to cooperate with requirements that typically are easily met by adults. For example, they may be unable to keep still, remain in a certain position, concentrate for more than a brief moment, or breath-hold. Children of various ages have unique limitations. Infants and toddlers are unable to stay still, whereas 3-year-olds are more apt to refuse to cooperate. These limitations affect almost all pediatric imaging examinations: radiography, fluoroscopy, ultrasound, computed tomography (CT), magnetic resonance imaging (MRI), nuclear imaging, and interventional radiology. There are a number of potential solutions that can be helpful in these situations. Commonly employed techniques include distracting the child, providing child-friendly surroundings (Figs. 1-1 through 1-7), immobilization, and sedation.

Distracting the child with something other than the procedure is often a simple and easy tactic to use. Talking to older children about school and other activities can be helpful. Certified child-life specialists are very successful in helping to coach and distract children so that they can complete imaging exams without sedation. They often use rattles and noise-making toys with very young children. Video players are a very useful distraction technique for ultrasound, fluoroscopy, and CT, and video goggles (see Fig. 1-7) have been very successful in decreasing sedation for MRI. Children can be encouraged to bring their own movies or choose from the department's stock. It is amazing how cooperative many children will be when they are able to watch television. Using a combined program that includes the introduction of a child-life specialist, a combination of the tactics discussed earlier to calm infants and young children, and the promotion of a culture that avoids sedation whenever possible was shown to reduce the frequency of need for sedation in children less than 7 years of age by

34.6% for MRI and 44.9% for CT.

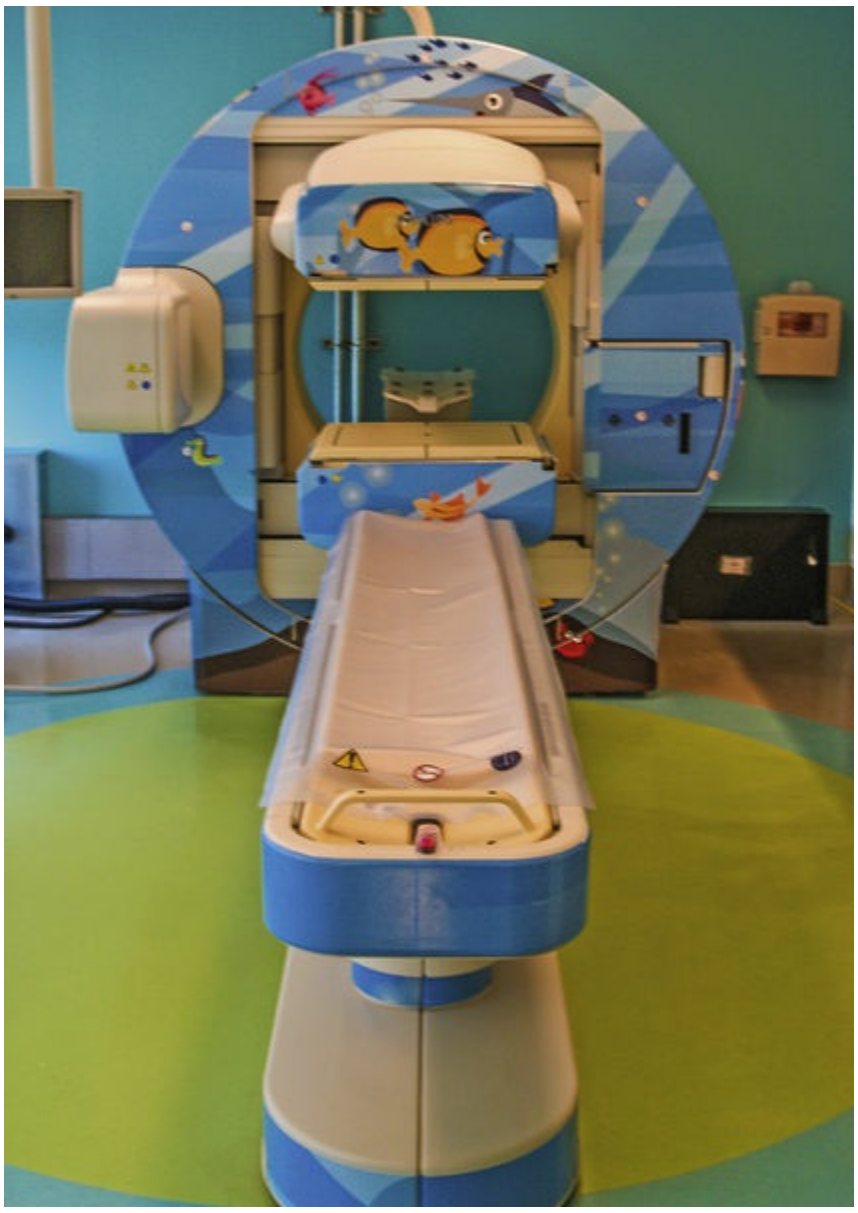
▪ **FIGURE 1-1** Colorful, child-friendly décor in pediatric waiting area. Many children's hospitals are now being decorated with modern, brightly colored, open areas without "cartoonish" themes.



▪ **FIGURE 1-2** Child-friendly waiting area with dancing cows.

▪ **FIGURE 1-3** CT scanner decorated with child-friendly decals.

▪ **FIGURE 1-4** Portable radiograph unit decorated with child-friendly decals.



▪ **FIGURE 1-5** SPECT/CT unit decorated with child-friendly decals.

▪ **FIGURE 1-6** Imaging room outfitted with custom lighting control, at this time turned to pink at request of child.

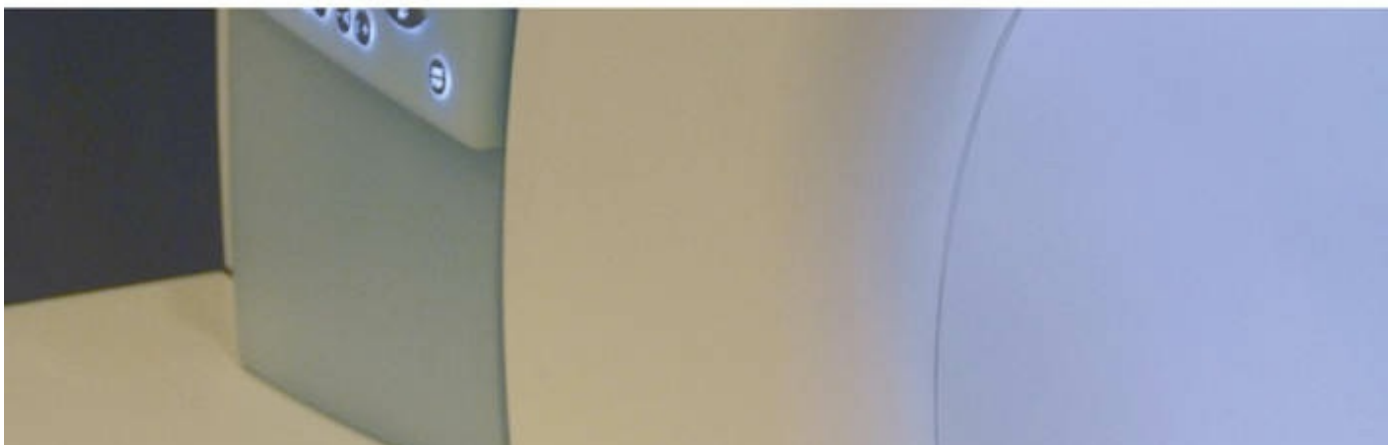
Providing child-friendly surroundings may help to ease a young child's anxiety and cause him or her to be more cooperative. Paintings on the walls and equipment and cartoonish figures in the examination rooms can be helpful. Eliminating or minimizing painful portions of the examination can also be very helpful in keeping a young child cooperative. The placement of an intravenous line often causes a great deal of patient anxiety and renders the child uncooperative for a subsequent imaging study, such as a CT scan. Using topical analgesia to decrease the pain of the intravenous line placement commonly makes this portion of the examination less traumatic. In addition, it is helpful to schedule appropriate sequencing of imaging examinations so that the most difficult exam is performed last. For example, it can be much easier to perform a renal ultrasound before rather than after the child has experienced a voiding cystourethrogram.

Immobilization is also a helpful technique. Infants who are bundled or "papoosed" in a blanket are more apt to stay still than infants who are not. This may make the difference between needing or not needing sedation to obtain an examination. There are also a number of commercially available

immobilization devices that are helpful when performing certain examinations, such as the use of an octagon board when obtaining fluoroscopic studies of young children. There are other devices that enhance proper positioning for specific modalities, such as chest radiographs. Imaging departments that image children should consider making such equipment available.

In certain situations, distraction and immobilization may not be successful, and sedation or general anesthesia may be necessary to obtain imaging studies. Many children younger than 6 years of age require sedation for MRI studies because of the prolonged nature of the examination and the need for the patient to be completely still. Sedation is needed much less often now than in the past for children undergoing CT examination because of the increased speed of acquisition by the newer CT scanners and the previously mentioned sedation reduction program. Other procedures that might require sedation include some nuclear medicine studies and most interventional procedures.


A


B

▪ **FIGURE 1-7** Video goggles can help young children to cooperate for MR examination, thus avoiding sedation. **A,** Video goggles on a child preparing for an MR examination. **B,** Video goggles with audio headphones in place as child is slid into scanner. Note happy demeanor.

Standards of care for conscious sedation are required by The Joint Commission and are based on standards published by several organizations, including the Committee on Drugs and the American Academy of Pediatrics. Any imaging department planning to sedate children must have a defined sedation program that is in concordance with these guidelines. The sedation program must have protocols for presedation preparation, sedative agents used, monitoring during sedation and during postsedation recovery, and discharge criteria. There has been a national shift concerning who provides sedation for pediatric imaging studies in pediatric radiology departments. In the 1990s' most pediatric radiology sedation programs were run by radiologists. Currently, multiple factors have led to such programs being run by anesthesiologists, emergency physicians, or intensive care physicians. At many institutions, such physicians have access to sedatives that are better for imaging sedation, such as propofol or dexmedetomidine.

Variable Size and Physiology

Because of the size variability from infant to adult-sized children, many adaptations must be considered for pediatric imaging studies in relation to size. The doses of contrast and drugs used in imaging examinations need to be adjusted according to a child's size, often on a per-weight (mg/kg) basis. Oral contrast dosing is also based on patient weight or age. Using CT as an illustrative example, other variables may also be affected by patient size. In small children the largest possible intravenous line may be very small, often 22 gauge or 24 gauge. The intravenous line may be placed in the foot or hand. The length of the region of interest to be imaged is variable, and the lengths of the patient's veins are variable. Physiologic parameters, such as the patient's cardiac output, are also more variable in children than in adults. These factors affect parameters such as the time between contrast injection and onset of scanning, as well as choices in contrast administration technique (hand bolus versus power injector). Slice thickness should be smaller in younger children because of the smaller anatomic parts. Similar adjustments must be considered in all other imaging modalities when applied to children. Radiation dose reduction is discussed in Patient Safety.

Age-Related Changes in Imaging Appearance

Another factor that makes imaging in children different from that in adults is the continuous changes in the imaging appearance of multiple organ systems during normal childhood development. The normal imaging appearance of certain aspects of organ systems can be different both at varying ages during childhood and between children and adults. For example, the kidneys look different on ultrasound in neonates from the way they look in a 1-year-old child. The developing brain demonstrates differences in signal at varying ages on MRI, which is related to changes in myelination. A large mediastinal shadow related to the thymus may be normal or severely abnormal depending upon the child's age. The skeleton demonstrates marked changes at all ages of childhood; this is related to the maturation of apophyses and epiphyses and the progressive ossification of structures. Knowledge of the normal age-related appearances of these organ systems is vital to appropriate interpretation of imaging studies. Lack of this knowledge is one of the more common causes of errors made in the interpretation of pediatric imaging studies.

Age-Related Differential Diagnoses

The types of diseases that affect children are vastly different from those that commonly affect adults. Therefore the differential diagnosis and significance of a particular imaging finding in a child are dramatically different from those determined by the identical imaging finding in an adult. In addition, the diseases that affect specific age groups of children are different. Therefore the differential diagnosis and significance of a particular imaging finding in a 2-month-old infant may differ dramatically from those determined by the identical imaging finding in a 10-year-old child.

Quality and Patient Safety

A lot of national attention has been paid to patient safety initiatives since the 1999 Institute of Medicine's report stating that somewhere between 44,000 and 98,000 deaths per year are caused by medical errors in the United States alone. This poor safety record would be the equivalent of the airline industry's having a large passenger plane crash in the United States every single day! If this were the case, we would probably think twice about flying. However, this is what our patients potentially face when they enter the current health care system. If looked at from the patients' perspective, even more important to them than "Heal me" (quality of care) and "Be nice to me" (customer service) is the plea "Don't harm me" (patient safety). No higher priority exists than patient safety.

There are numerous schools of thought related to both improvement and safety. Almost all of them emphasize the cultural aspects needed to reach a level of high reliability and minimize errors that may cause harm. There has to be a recognition that safety is an issue and that it is part of everybody's role to speak up in the face of uncertainty or when an individual "feels" that something is not right. The old culture of a medical hierarchy, in which the physician is in charge and is not to be questioned, does not promote safety. Medical staff, trainees, and even family members need to feel comfortable "stopping the line" and asking for clarification if things do not seem right.

Also important to create a reliable system of care that is both safe and of high quality is the acceptance of standardization. Henry Ford stated in 1926 that

> *Today's standardization is the necessary foundation on which tomorrow's improvement will be based. If you think of "standardization" as the best you know today, but which is to be improved tomorrow—you get somewhere. But if you think of standards as confining, then progress stops.*

Ideally the only variation in a health care system should be that related to the condition of the patient. There should not be variability related to technologists, protocols, care sites, or physicians. Radiologists need to work together to create evidence-based standardized imaging protocols and procedures, as well as reports, and continuously strive to improve them.

In addition, key in reaching a state in which high quality and safe care are provided is a robust daily management system. Daily management systems are designed to quickly identify issues, empower front-line areas to solve those issues, and, when the front line cannot resolve them, escalate the issues to those who can help. Increasingly in medicine, as well as other fields, tiered huddle systems are used to create daily readiness. Radiologists, technologists, and managers come together in a brief huddle each morning to make sure that they are ready to care for the patients scheduled for that day. Such processes often have three parts: daily readiness, problem accountability, and metrics evaluation. One approach to daily readiness is evaluating the volume scheduled for that day and organizing the approach to concerns around safety and the acronym MESA (Methods, Equipment, Supplies, Associates). Does anyone have any safety concerns? Do we have the right ***M***ethods to take care of the patients today (does anyone have questions around protocols or atypical patients?)? Do we have the right ***E***quipment to take care of the patients today (is there any planned downtime, broken equipment, or information technology [IT] issues?)? Do we have the ***S***upplies we need to take care of the patients today? Do we have the right ***A***ssociates to take care of the patients today (did anybody call in sick, do we have the right people with the right expertise)? Going through a set of such questions leads to a list of issues. Having a defined problem accountability process that assigns each issue a single owner and defines the immediate countermeasure and the date at which the owner will come back to report an update at the huddle is important so that issues do not go unresolved or only partially remedied.

Radiation Safety

Safety issues specific to radiology include radiation safety, MRI safety, and correct and effective communication of the information in and interpretation of imaging examinations. We will touch here on radiation safety because it is germane to pediatric radiology. Although there is much uncertainty, children are much more sensitive to the potential harmful effects of radiation than are adults, and children also have a longer expected life span during which to develop potential complications of radiation, such as cancer. Therefore attention to radiation safety in all areas of pediatric radiology is paramount. CT delivers higher doses of radiation than do other diagnostic imaging modalities. The exact radiation risk in CT examinations and even whether a risk absolutely exists are controversial topics. However, some researchers estimate the increased risk that a young child might develop cancer related to an abdominal CT scan is in the magnitude between 1:1000 and 1:10,000. Given the unknown and potentially small risk, it is essential for all radiologists to practice dose-reduction techniques in

pediatric CT. Such tactics include avoiding CT when unnecessary; using alternative diagnostic methods that do not use radiation, such as ultrasound, when possible; and adjusting CT parameters to minimize dose when CT is performed. Because children are smaller than adults and need less radiation to create the same signal-to-noise ratios, the tube current (mA), as well as kilovolts and other factors, can be greatly reduced when imaging a small child. Many other factors can be adjusted to reduce dose as well.

It is also very important not to overreact to this potentially small risk related to radiation dose for CT. For any clinically indicated examination the risk of not doing the CT and not having that information is often magnitudes greater than that related to radiation risk.

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CHAPTER 2

Airway

Lane F. Donnelly

Problems with the airway are much more common in children than in adults. It has been said that one of the differentiating features between a pediatric and general radiologist is that a pediatric radiologist remembers to look at the airway. For practical purposes, abnormalities of the airway can be divided into acute upper airway obstruction, lower airway obstruction (extrinsic compression, intrinsic obstruction), obstructive sleep apnea (OSA), and congenital high airway obstruction syndrome (CHAOS).

Clinically, children with acute upper airway obstruction (above the thoracic inlet) tend to present with inspiratory stridor, whereas children with lower airway obstruction (below the thoracic inlet) are more likely to present with expiratory wheezing. However, the categorization of a child with noisy breathing into one of these two groups can be very difficult. The primary imaging evaluation of the pediatric airway for acute conditions should include frontal and lateral high-kilovolt radiography of the airway and frontal and lateral views of the chest.

▪ Acute Upper Airway Obstruction

Acute stridor in a young child is the most common indication for imaging the pediatric airway. The most common causes of acute upper airway obstruction in children include inflammatory disorders and foreign bodies. The most common inflammatory disorders include croup, epiglottitis, exudative tracheitis, and retropharyngeal cellulitis and abscess. Anatomic structures that are especially important to evaluate on radiographs of children with acute upper airway obstruction include the epiglottis, aryepiglottic folds, subglottic trachea, and retropharyngeal soft tissues.

Croup

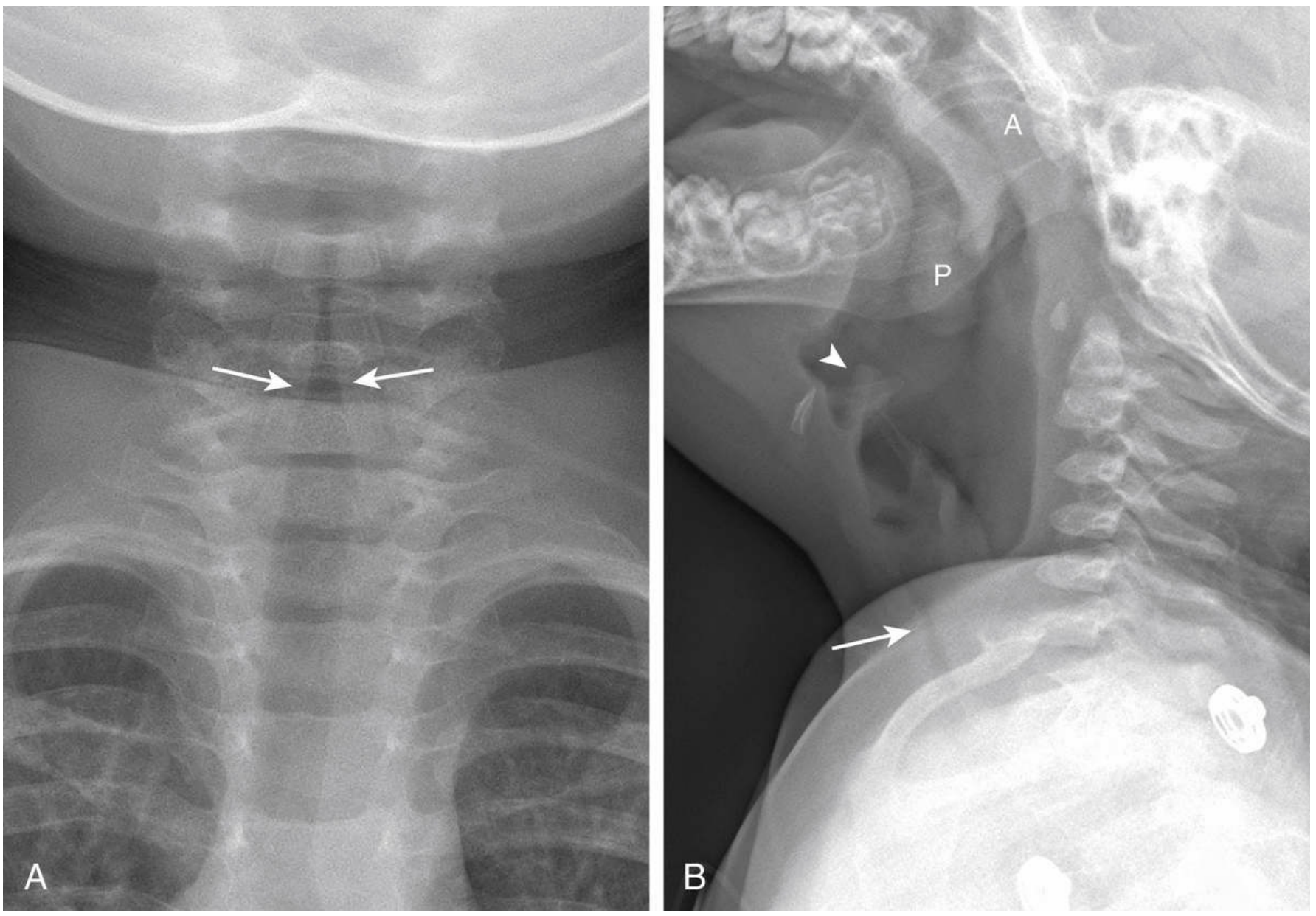
Croup (acute laryngotracheobronchitis) is the most common cause of acute upper airway obstruction in young children. The peak incidence occurs between 6 months and 3 years of age. The mean age at presentation of croup is 1 year of age. In children older than 3 years, other causes of airway obstruction should be suspected. Croup is viral in cause and is usually a benign, self-limited disease. Redundant mucosa in the subglottic region becomes inflamed, swells, and encroaches upon the airway. The children present with a barky ("croupy") cough and intermittent inspiratory stridor. It usually occurs following or during other symptoms of lower respiratory tract infection. Most children with croup are managed supportively as outpatients, and the parents are managed by reassurance. Inhaled corticosteroids are becoming a popular therapy in children with croup. They have been shown to reduce the length and severity of illness.

The purpose of obtaining radiographs in a patient with suspected croup is not so much to confirm the diagnosis but rather to exclude other, more serious causes of upper airway obstruction that require intervention. However, characteristic radiographic findings that indicate croup are best seen on frontal radiographs. With croup, there is loss of the normal shoulders (lateral convexities) of the subglottic trachea secondary to symmetric subglottic edema (Fig. 2-1). Normally, the subglottic trachea appears rounded, with "shoulders" that are convex outward (Fig. 2-2). In croup, the subglottic trachea becomes long and thin, with the narrow portion extending more inferiorly than the level of the pyriform sinuses. The appearance has been likened to an inverted V or a church steeple (see Fig. 2-1). The term *church steeple* can be confusing because some steeples look like croup and some are shaped like the normal subglottic airway (Fig. 2-3). Lateral radiographs may demonstrate a narrowing or loss of definition of the lumen of the subglottic trachea (see Fig. 2-1) or hypopharyngeal overdistention. With croup, the

epiglottis and aryepiglottic folds appear normal.

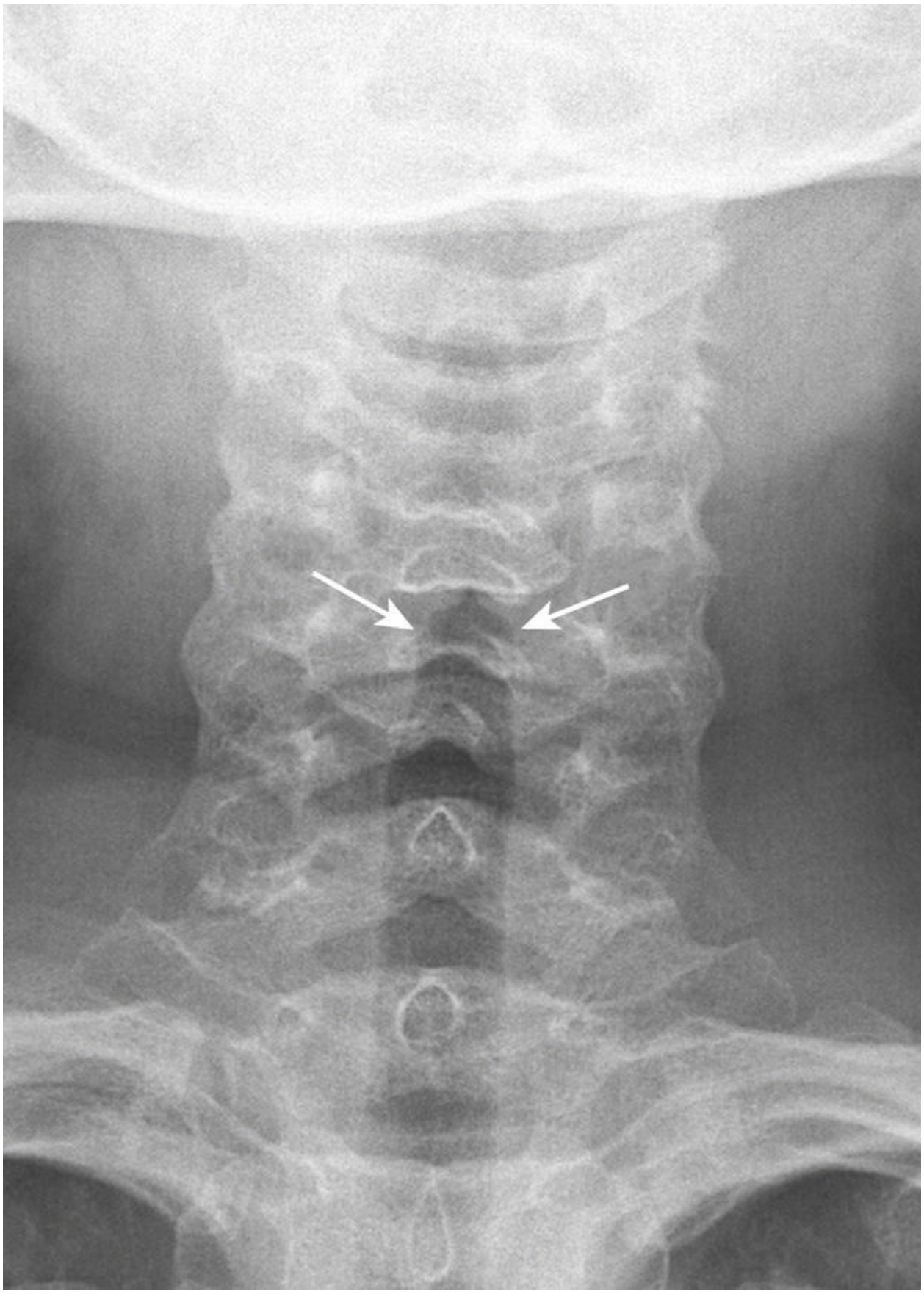
Epiglottitis

In contrast to croup, epiglottitis is a life-threatening disease that can potentially require emergent intubation. The possibility that a child with epiglottitis might arrive in a deserted radiology department was once a constant source of anxiety for on-call radiology residents. However, most cases of epiglottitis are caused by *Haemophilus influenzae* and are now preventable by immunization (HiB vaccine), so the incidence of epiglottitis has dramatically decreased. The causes of epiglottitis are now also more heterogeneous. Related to this, care of children with epiglottitis is now more of a challenge because health care workers are less used to recognizing and treating patients with this disorder. Children with epiglottitis are usually toxic appearing and present with an abrupt onset of stridor, dysphagia, fever, restlessness, and an increase in respiratory distress when recumbent. In the pre-HiB vaccine era, the classically described peak age of incidence was 3.5 years. However, since the introduction of the HiB vaccine, there has been a marked increase in the mean age of presentation to 14.6 years. Because of the risk for complete airway obstruction and respiratory failure, no maneuvers should be performed that make the patient uncomfortable. If the diagnosis is not made on physical examination, a single lateral radiograph of the neck should be obtained, usually with the patient erect or in whatever position that allows the patient to breathe comfortably. Children with epiglottitis should never be made to lie supine against their will to obtain a radiograph because it can result in acute airway obstruction and, potentially, death.



▪ **FIGURE 2-1** **Croup.**

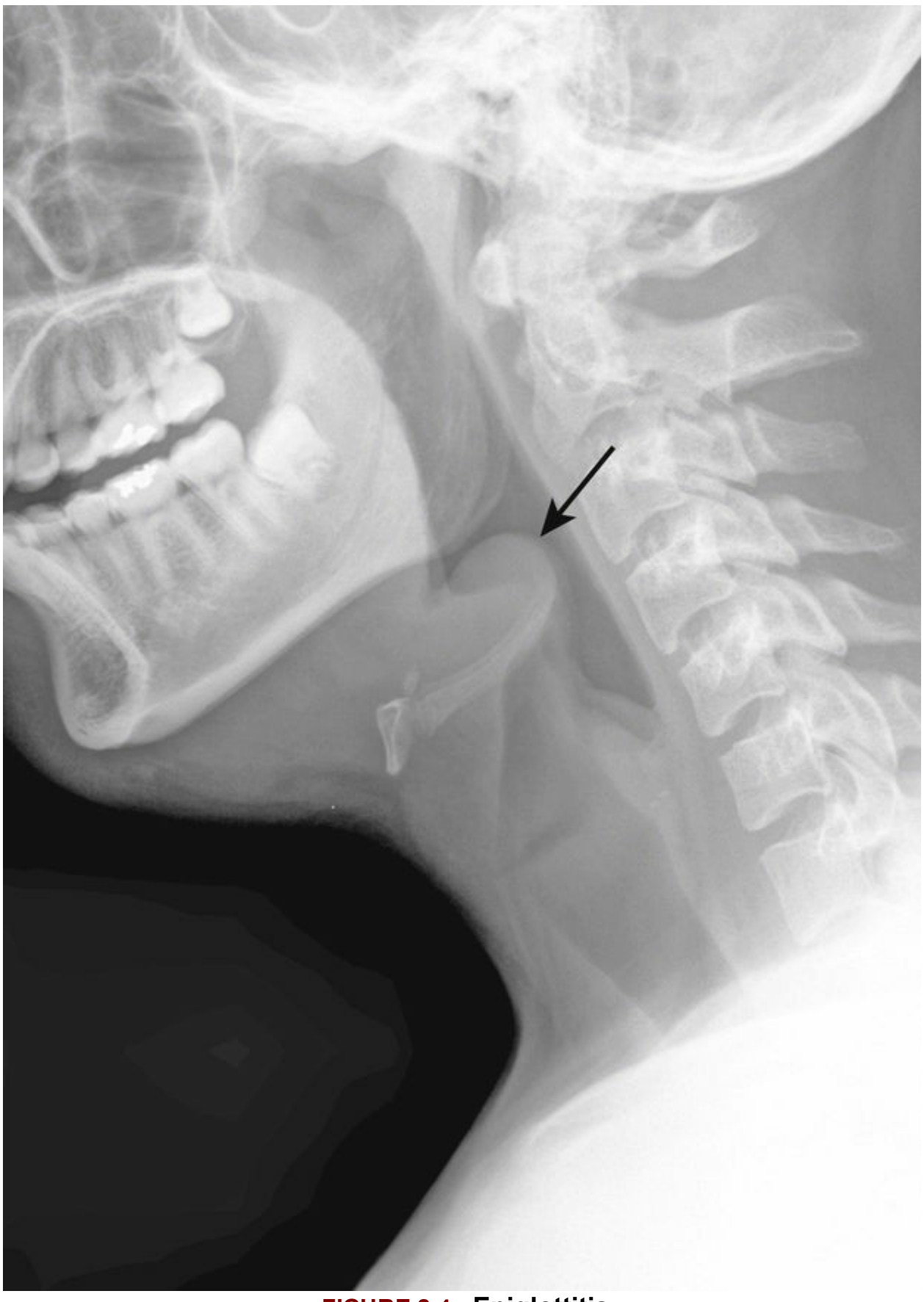
A, Frontal radiograph showing symmetric subglottic narrowing *(arrows)* with loss of normal shouldering. The narrowing extends more inferiorly than the piriform sinuses. **B,** Lateral radiograph showing subglottic narrowing *(arrow)*. Note normal-appearing epiglottis *(arrowhead)* and thin aryepiglottic folds. Also note mildly enlarged adenoid *(A)* and palatine *(P)* tonsils.



▪ **FIGURE 2-2** **Normal frontal radiograph of the airway.**
The subglottic airway demonstrates rounded shoulders *(arrows)* that are convex outward.

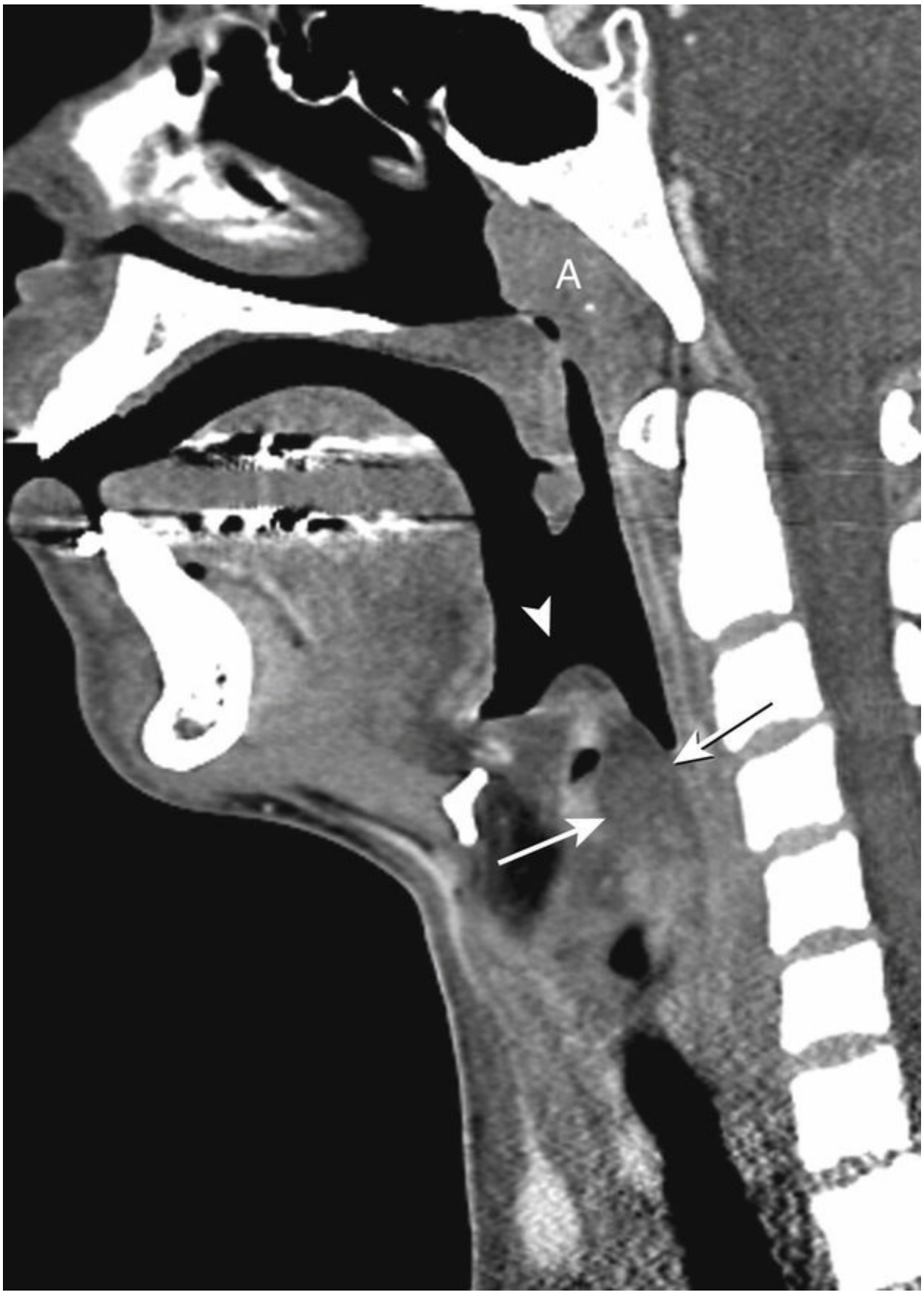
▪ FIGURE 2-3 Steeple sign.

The term *steeple sign* can be confusing. It is meant to denote the pointed configuration of the subglottic trachea on a frontal radiograph of the airway when subglottic edema has effaced the normally convex lateral shoulders in this region. However, some steeples look like croup *(white arrows)*, and some look like a normal subglottic airway *(black arrow)*.



▪ **FIGURE 2-4** **Epiglottitis.**
Lateral radiograph showing marked thickening of the epiglottis *(arrow)*. The aryepiglottic folds are also narrowed.

With epiglottitis, on the lateral radiograph, there is marked enlargement of the epiglottis. A normal epiglottis typically has a thin appearance with the superior aspect being sharply pointed. The swollen epiglottis has been likened to the appearance of a thumb. With epiglottitis, there is also thickening of the aryepiglottic folds (Figs. 2-4 and 2-5). The aryepiglottic folds are the soft tissues that extend from the epiglottis anterosuperiorly to the arytenoid cartilage posteroinferiorly and normally are convex downward. When the aryepiglottic folds become abnormally thickened, they appear convex superiorly. Symmetric subglottic narrowing, similar to croup, may be seen on frontal radiography (if obtained); do not let that be confusing.



▪ **FIGURE 2-5** **Epiglottitis.**
Sagittal CT image showing low-attenuation swelling of the epiglottis *(arrowhead)*. Also note marked thickening and low-attenuation edema of the aryepiglottic folds *(arrows)*.

An obliquely imaged, or so-called omega-shaped, epiglottis may artifactually appear wide because both the left and right sides of the epiglottis are being imaged adjacent to each other. This should not be confused with a truly enlarged epiglottis. The absence of thickening of the aryepiglottic folds can be helpful in making this differentiation. With an omega-shaped epiglottis (normal variant), often both the left and right walls of the epiglottis are visible.

In current times, related to both the uncommon occurrence of epiglottitis and the frequent reliance on computed tomography (CT) to evaluate more common inflammatory neck conditions (such as retropharyngeal abscess), it is increasingly more common to see and diagnose epiglottitis on CT rather than on radiography. Although not classically advocated as a diagnostic tool for epiglottitis (given the risks of laying such patients supine and giving them intravenous [IV] contrast), the findings of epiglottitis are easily identified on CT (see Fig. 2-5). Findings include swelling and low-attenuation edema of the epiglottis and aryepiglottic folds associated with inflammatory stranding in adjacent fat.

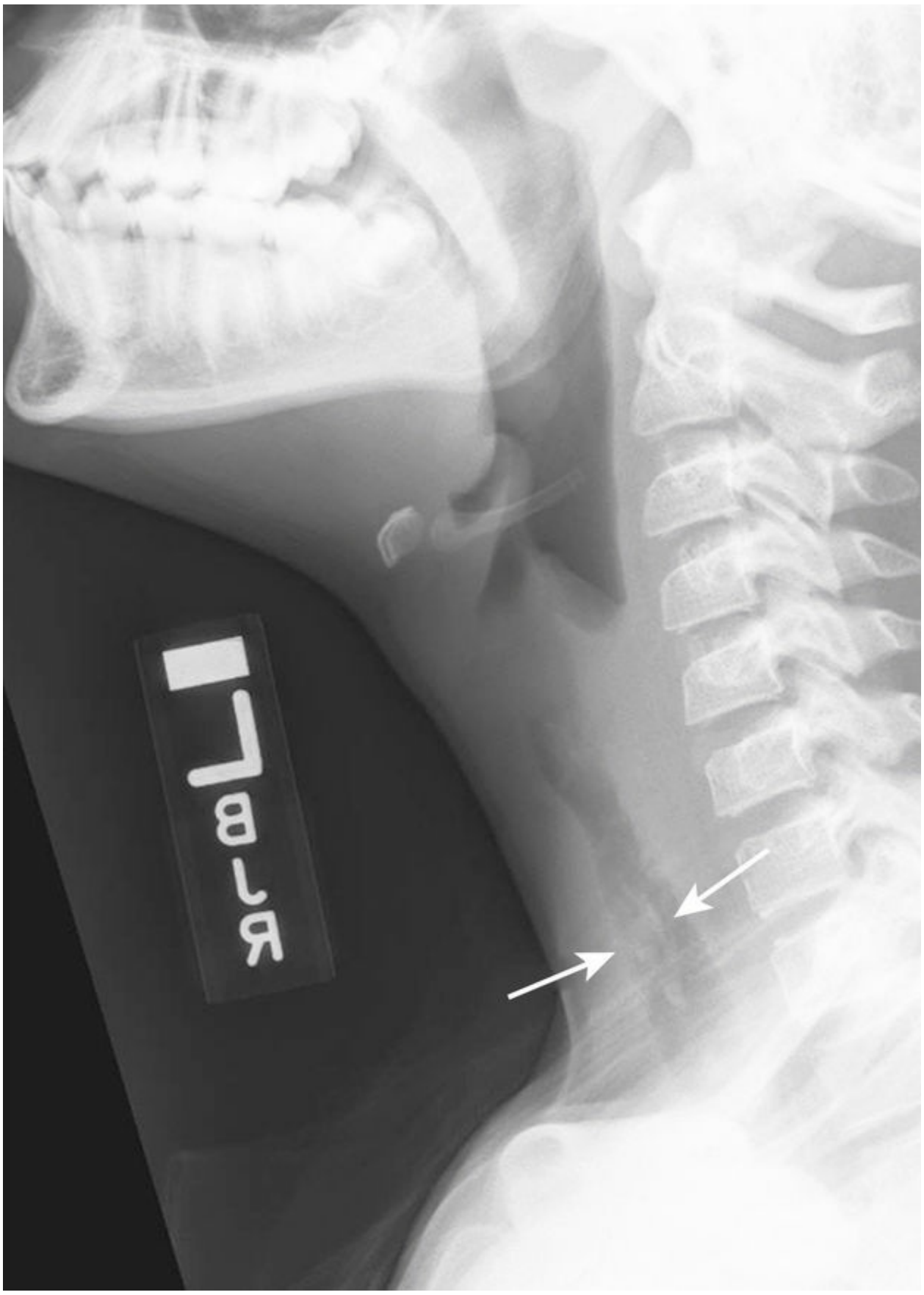
Exudative Tracheitis

Exudative tracheitis (also known as bacterial tracheitis, membranous croup, or membranous laryngotracheobronchitis) is another uncommon but potentially life-threatening cause of acute upper

airway obstruction. The disorder is characterized by a purulent infection of the trachea in which exudative plaques form along the tracheal walls (much like those seen in diphtheria). Affected children are usually older and more ill than those with standard croup; typically their ages range from 6 to 10 years. Although initial reports described most cases to be secondary to infection by *Staphylococcus aureus*, other reports have noted multimicrobial infections. It is unclear whether the disease is a primary bacterial infection or a secondary bacterial infection that occurs following damage to the respiratory mucosa by a viral infection. A linear soft tissue filling defect (a membrane) seen within the airway on radiography is the most characteristic finding. A plaquelike irregularity of the tracheal wall is also highly suspicious (Fig. 2-6). Nonadherent mucus may mimic a membrane radiographically. In cooperative patients, having them cough and then repeating the film may help to differentiate mucus from a membrane. Other findings include symmetric or asymmetric subglottic narrowing in a child too old typically to have croup and irregularity or loss of definition of the tracheal wall. Membranes and tracheal wall irregularities may be seen on frontal or lateral radiographs and often seen on one but not the other; therefore it is important to get both views.

If one of these exudative "membranes" is sloughed into the lumen, it can lead to airway occlusion and respiratory arrest. Therefore children who are suspected to have exudative tracheitis are often evaluated endoscopically, the exudative membranes are stripped, and elective endotracheal intubation is performed.

A number of controversies regarding exudative tracheitis exist. First, it is seen with great frequency at some institutions and not at all at others. Second, although it is considered a life-threatening condition, to my knowledge, no patient has ever died at home of this disease—which seems odd. Both of these points raise the question of the validity of this diagnosis. My take is that there are definitive cases of this disease, but it is probably overdiagnosed and overtreated at some institutions.



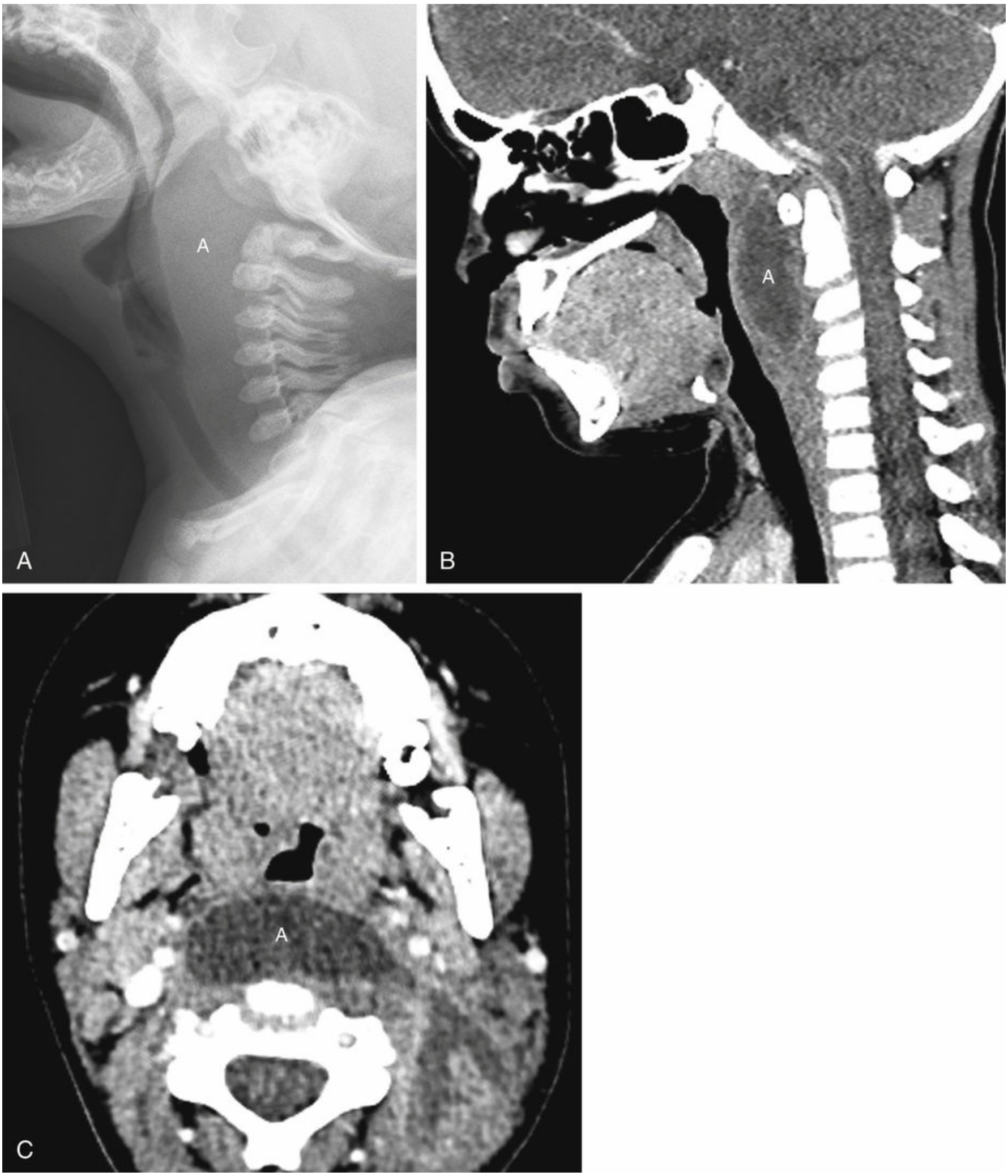
▪ **FIGURE 2-6** **Exudative tracheitis.**
Lateral radiograph showing irregular plaquelike filling defects *(arrows)* and airway wall irregularities within trachea. Again, note the normal appearance of the nonthickened epiglottis in this patient.

Retropharyngeal Cellulitis and Abscess

Retropharyngeal cellulitis is a pyogenic infection of the retropharyngeal space that usually follows a recent pharyngitis or upper respiratory tract infection. Children present with sudden onset of fever, stiff neck, dysphagia, and occasionally stridor. Most affected children are young, with more than half of the cases occurring between 6 and 12 months of age. On lateral radiography, there is thickening of the retropharyngeal soft tissues (Fig. 2-7). In a normal infant or young child, the soft tissues between the posterior aspect of the aerated pharynx and anterior aspect of the vertebral column should not exceed the anterior-to-posterior diameter of the cervical vertebral bodies. If these soft tissues are thicker, an abnormality should be suspected. Apex anterior convexity of the retropharyngeal soft tissues provides supportive evidence that there is true widening of the retropharyngeal soft tissues (see Fig. 2-7).

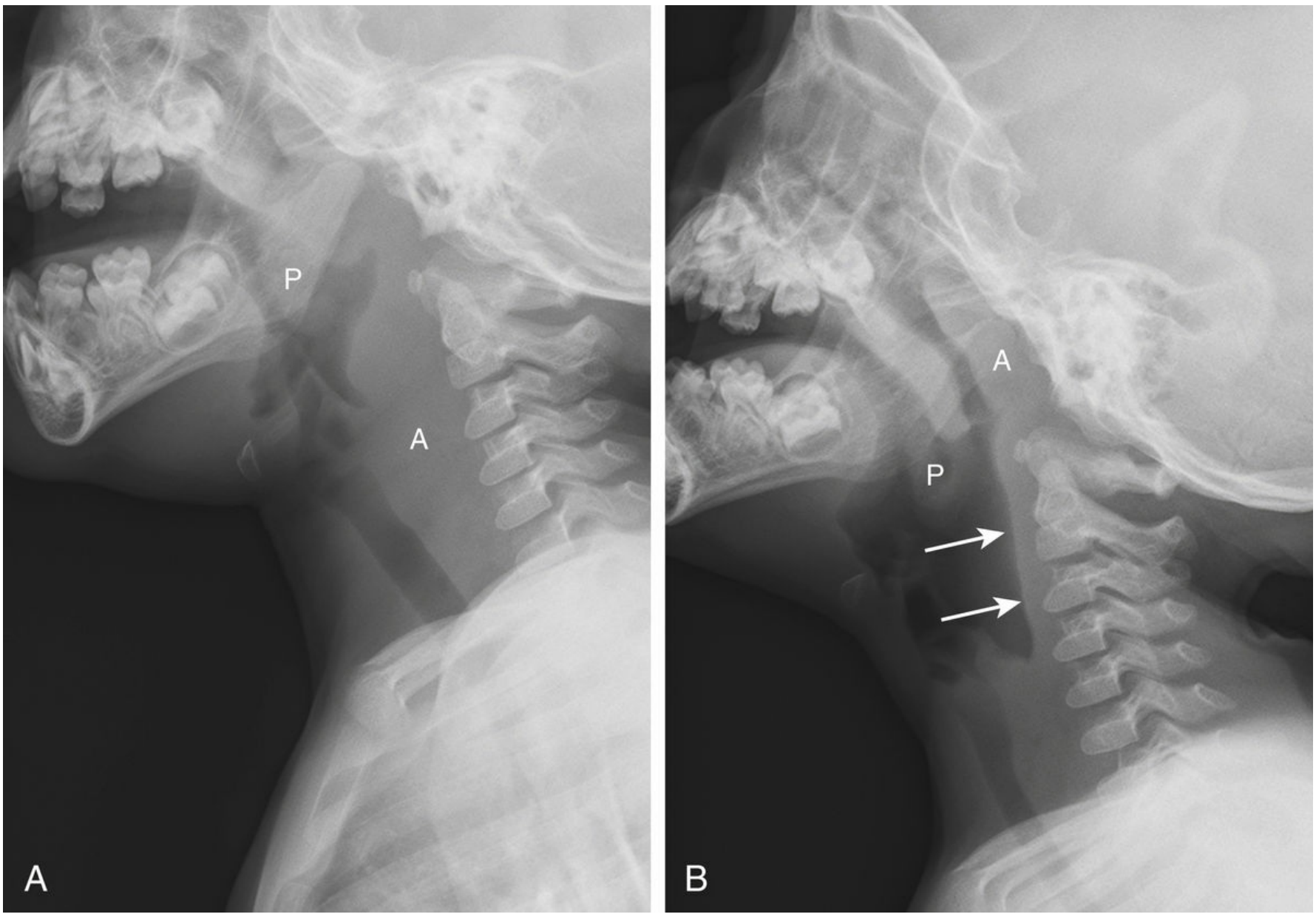
However, in infants, who have short necks, it is common to see pseudothickening of the retropharyngeal soft tissues when the lateral radiograph is obtained without the neck being well extended (Fig. 2-8). If it is unclear on the initial lateral radiograph whether the soft tissues are truly rather than artifactually widened, it is best to repeat the lateral radiograph with the neck placed in full extension (see Fig. 2-8). Fluoroscopy can also be used to evaluate whether the pseudothickening is

persistent. The only radiographic feature that can differentiate abscess from cellulitis is the identification of gas within the retropharyngeal soft tissues.



▪ **FIGURE 2-7** **Retropharyngeal abscess.**
A, Lateral radiograph showing marked thickening of the retropharyngeal soft tissues *(A)*, which are wider than the adjacent vertebral bodies. Note the anterior convexity of soft tissues. **B** and **C,** Contrast-enhanced CT in sagittal and axial planes shows a low-attenuation region with enhancing rim *(A)*, suggestive of a drainable abscess.

CT is commonly performed to define the extent of disease and to help to predict cases in which a drainable fluid collection is present (see Fig. 2-7). On CT, a low-attenuation, well-defined area with an enhancing rim is suspicious for a drainable fluid collection (see Fig. 2-7). Cellulitis without abscess is actually more common than the presence of a drainable abscess.



▪ **FIGURE 2-8** **Pseudoretropharyngeal soft tissue thickening secondary to lack of extended neck positioning.**

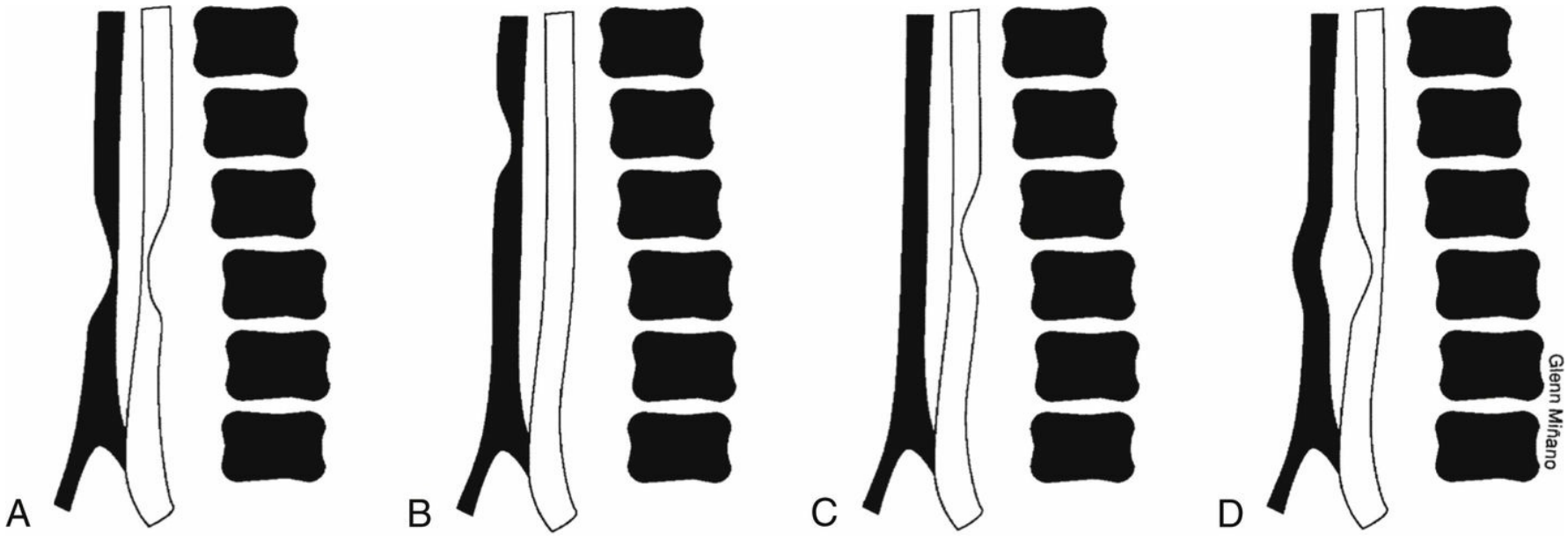
A, Initial lateral radiograph showing apparent thickening of retropharyngeal soft tissues mimicking potential retropharyngeal abscess *(A).* Note mildly enlarged palatine tonsils *(P).* **B,** Repeat lateral radiograph with neck extended, shows normal thickness of retropharyngeal soft tissues *(arrows)*, much narrower in thickness than adjacent vertebral bodies. Note palatine *(P)* and adenoid *(A)* tonsils.

▪ Lower Airway Obstruction

The most common cause of wheezing in children is small airway inflammation, such as is caused by asthma and viral illness (bronchiolitis). When the wheezing persists, presents at an atypical age for asthma, or is refractory to treatment, other reasons for lower airway obstruction are entertained. Other causes of lower airway obstruction can be divided into those that are intrinsic to the airway (such as bronchial foreign body, tracheomalacia, or intrinsic masses) and those that cause extrinsic compression of the trachea (such as vascular rings). The initial radiologic screening procedure for wheezing is frontal and lateral radiography of the airway and chest. Radiographs are used to exclude acute causes of upper airway obstruction, evaluate for other processes that can cause wheezing (such as cardiac disease), and help to categorize the abnormality as being more likely to be an intrinsic or an extrinsic airway process. Important findings to look for on the radiographs include evidence of tracheal narrowing, position of the aortic arch, asymmetric lung aeration, radiopaque foreign body, and lung consolidation. When tracheal compression is present on radiography, it is important to note both the superior to inferior level of the compression and whether the compression comes from the anterior or posterior aspect of the trachea because various vascular rings present with different patterns of tracheal compression (Fig. 2-9).

If the radiographs suggest an intrinsic abnormality, bronchoscopy is the next procedure of choice. If the radiographs suggest an extrinsic compression, cross-sectional imaging is performed. There has been a shift from using primarily magnetic resonance imaging (MRI) for the evaluation of extrinsic airway compression in the 1990s to using predominantly CT now. This shift is related to the rapid acquisition times of the newer multidetector CT scanners. The advantages of CT over MRI are that most infants can be scanned without sedation on CT (which is a significant factor in an infant with airway

difficulties) and that better evaluation of the lungs is possible. The disadvantages of CT are the radiation exposure and dependence upon IV contrast. With modern technology, both CT and MRI can be used to create dynamic cine images to depict abnormal airway motion (malacia).



▪ **FIGURE 2-9 Patterns of compression of the trachea and esophagus in common vascular rings.** The diagrams are comparable to a lateral radiograph of the chest. The trachea is black; the esophagus is white. **A,** Double aortic arch. The trachea is compressed on its anterior aspect, and the esophagus is compressed on its posterior aspect. **B,** Innominate artery compression. The trachea is compressed on its anterior aspect. The level of compression is just below the thoracic inlet, higher than other vascular causes of compression. **C,** Left arch with aberrant right subclavian artery or right arch with aberrant left subclavian artery. There is compression of the posterior aspect of the esophagus. The trachea is not compressed. **D,** Aberrant left pulmonary artery (pulmonary sling). The trachea is compressed on its posterior aspect and the esophagus is compressed on its anterior aspect.

Extrinsic Lower Airway Compression

Almost any process that causes either a space-occupying mass within the mediastinum or the enlargement or malposition of a vascular structure can lead to compression of the airway. The classically described vascular causes of lower airway compression include double aortic arch, anomalous left pulmonary artery, and innominate artery compression syndrome. However, other causes of airway compression include middle mediastinal masses, such as a bronchogenic cyst (Fig. 2-10) or large anterior mediastinal masses (Fig. 2-11); enlargement of the ascending aorta, such as is seen in Marfan syndrome; enlargement of the pulmonary arteries, as in congenital absence of the pulmonary valve; malposition of the descending aorta, as in midline descending aorta-carina-compression syndrome; enlargement of the left atrium; or abnormal chest wall configuration, such as a narrow thoracic inlet. With the congenital vascular causes of airway compression, in addition to the obvious anatomic extrinsic compression, there is also often a component of intrinsic malacia related to the long-term nature of the airway being compressed. This can cause persistent symptoms even after the extrinsic compression has surgically been remedied.

On axial imaging, the trachea is normally rounded in configuration (Fig. 2-12), sometimes with a flattened posterior wall related to the noncartilaginous portion. A normal trachea is never oblong, with a greater left-to-right than anterior-to-posterior diameter (never "pancake-shaped"). When the airway appears pancake-shaped, it is abnormal.

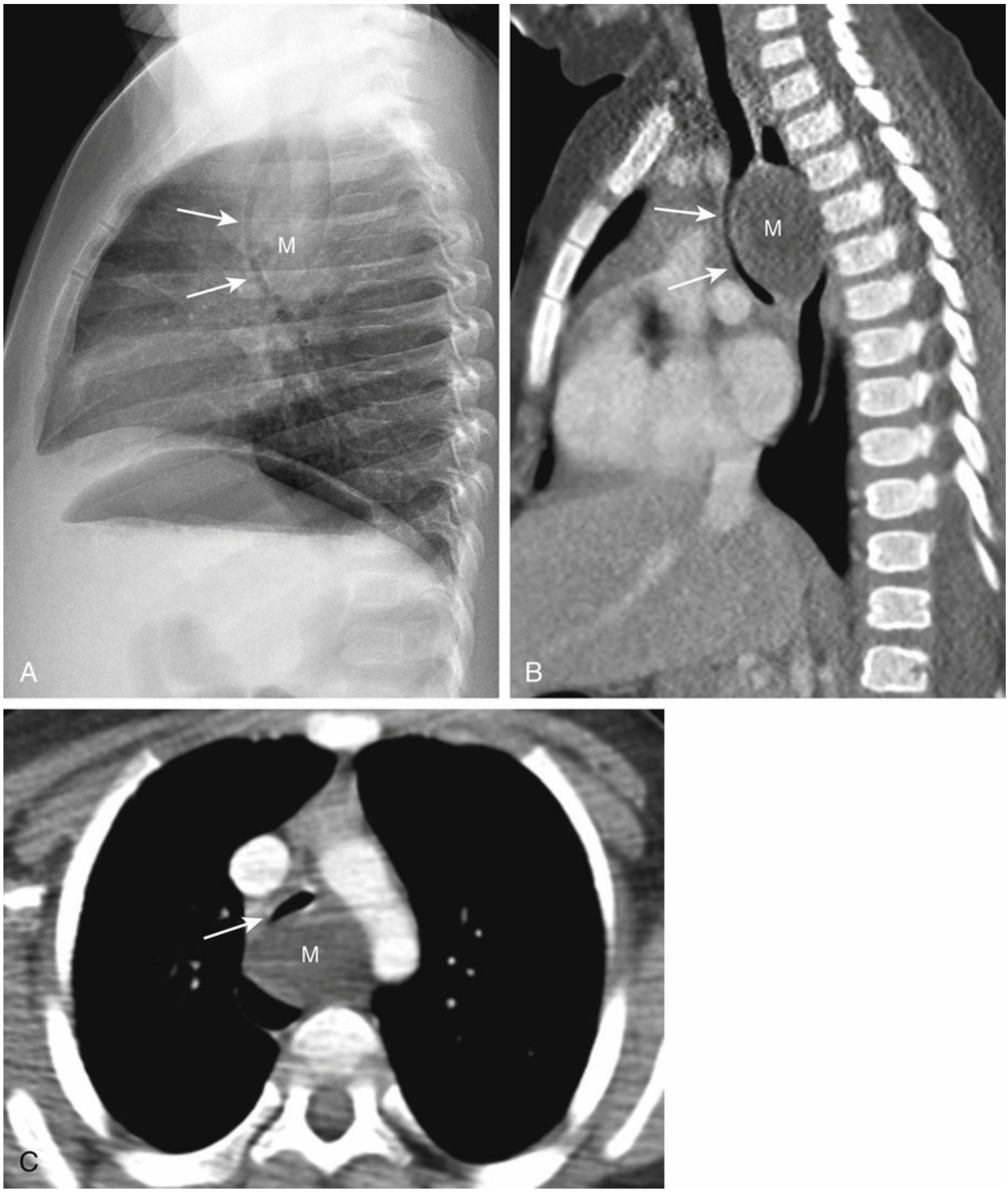
Double Aortic Arch

Double aortic arch is a congenital anomaly related to the persistence of both the left and right fourth aortic arches. It is the most common symptomatic vascular ring. Usually an isolated lesion, it typically presents with symptoms early in life (soon after birth). Anatomically, the two arches surround and compress the trachea anteriorly and esophagus posteriorly. Typically the right arch is dominant, both larger and positioned more superiorly (Fig. 2-13). In such cases, the left arch is ligated by performing a left thoracotomy. When the left arch is dominant, a right thoracotomy is performed and the right arch is ligated. Related to surgical planning, determining the dominant arch is one of the goals of cross-sectional imaging. With double aortic arch, the level of compression is the mid to lower intrathoracic

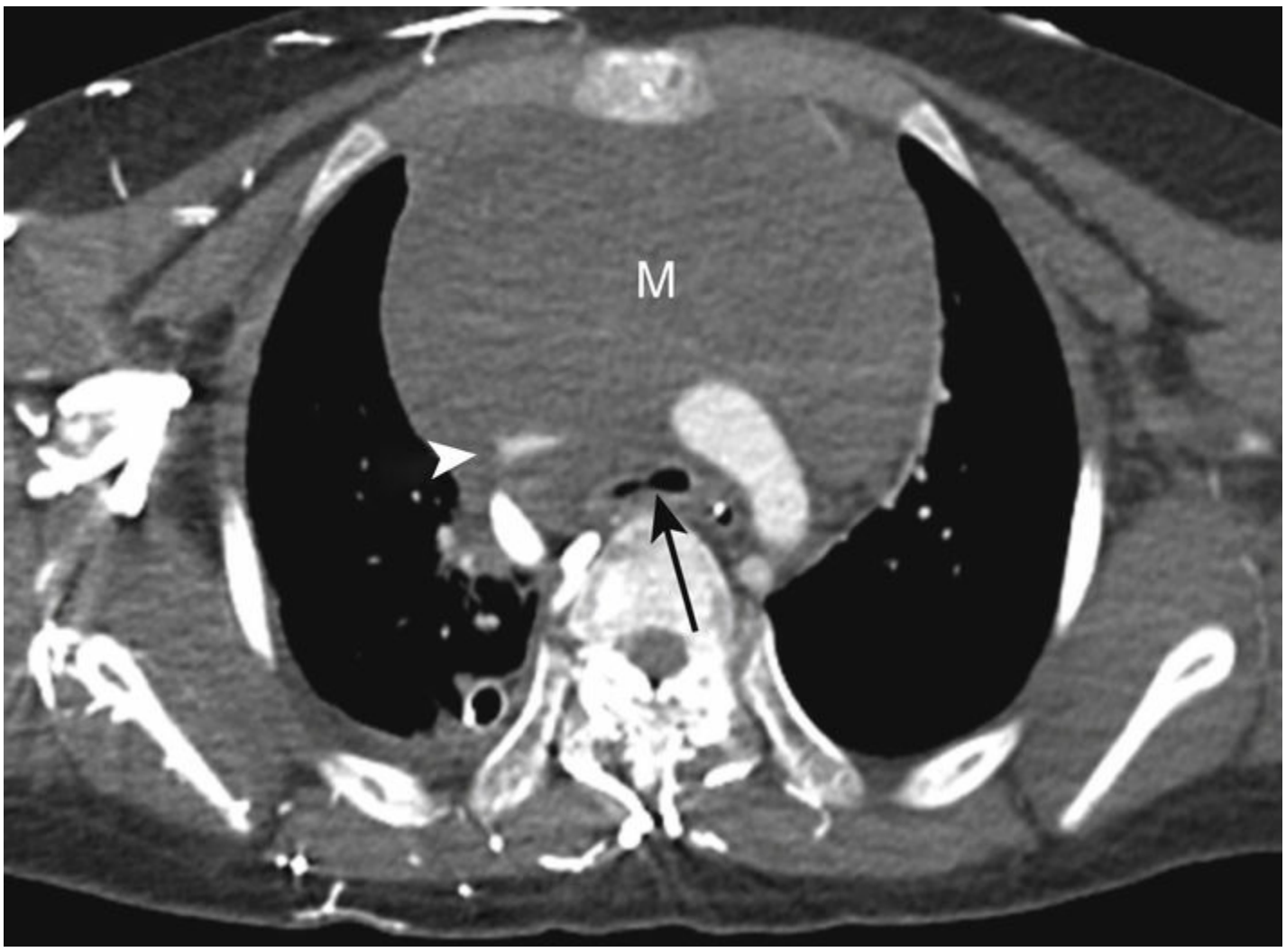
trachea. In addition, there is symmetric take-off of four great arteries from the superior aspect of the arches.

Anomalous Origin of the Left Pulmonary Artery (Pulmonary Sling)

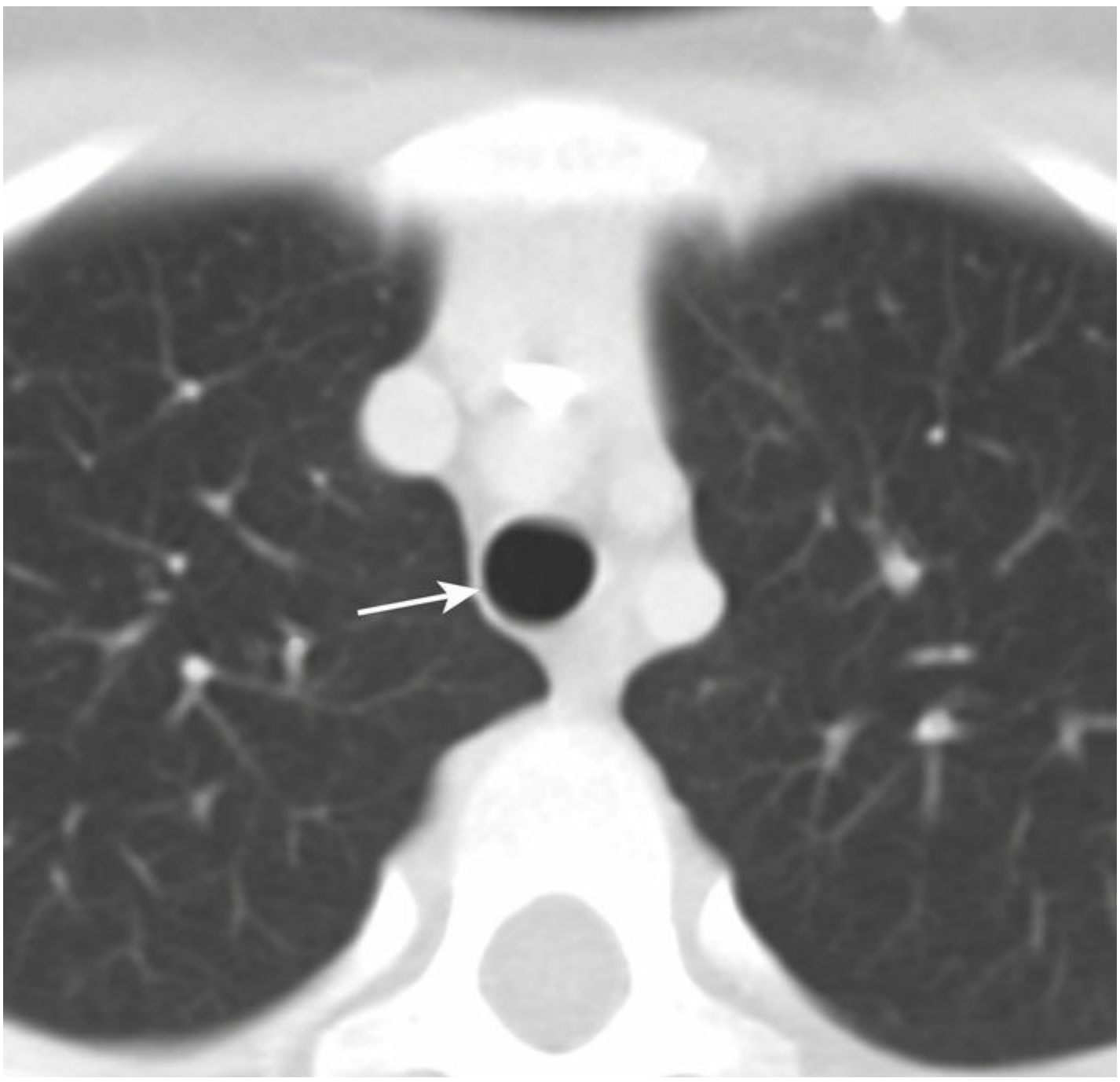
In cases of anomalous origin of the left pulmonary artery (pulmonary sling), the left pulmonary artery arises from the right pulmonary artery rather than from the main pulmonary artery and passes between the trachea and esophagus as it courses toward the left lung. The resultant sling compresses the trachea. Pulmonary sling is the only vascular anomaly to course between the trachea and esophagus (Fig. 2-14). Therefore compression of the posterior aspect of the trachea and the anterior aspect of the esophagus on lateral imaging is characteristic. It is the only vascular cause of airway compression that is associated with asymmetric lung inflation on chest radiographs (see Fig 2-14). Pulmonary sling can be associated with congenital heart disease, complete tracheal rings (an additional cause of airway problems), and anomalous origin of the right bronchus (see Fig. 2-14). On CT, the trachea is compressed at the level of the sling and appears flattened in the anterior to posterior direction—like a pancake. If complete tracheal rings are present, the rings are typically superior to the pulmonary sling, and the trachea appears very small in caliber and very round at the level of the rings (see Fig. 2-14).



▪ **FIGURE 2-10** **Bronchogenic cyst causing compression of the distal trachea.**
A, Lateral chest radiograph showing a soft tissue density mass *(M)* posterior to and anteriorly displacing the trachea *(arrows)*. **B** and **C,** Sagittal and axial contrast-enhanced CT shows mass *(M)* compressing and anteriorly displacing the adjacent trachea *(arrows)*.



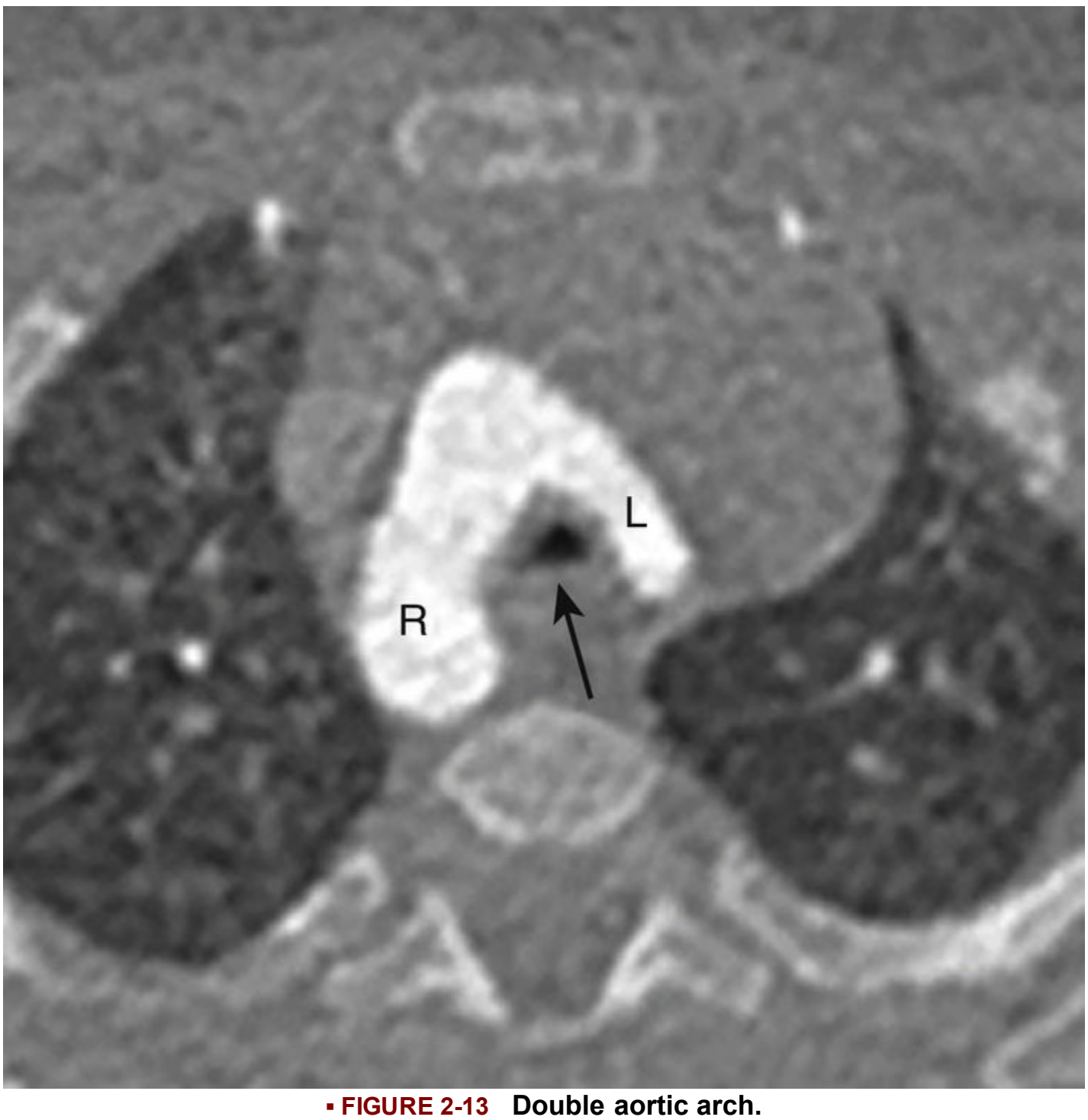
▪ **FIGURE 2-11** **Lymphoma causing compression of the trachea.**
CT shows a large anterior mediastinal mass *(M)* with posterior displacement and severe compression of the trachea *(arrow)*. The superior vena cava is also compressed *(arrowhead)*. Note multiple collateral veins on the right related to the obstructed superior vena cava.



▪ **FIGURE 2-12** Normal configuration of trachea on cross-sectional imaging is round *(arrow)*. An oval or pancake-shaped intrathoracic trachea is not normal.

Right Aortic Arch with Aberrant Left Subclavian Artery

Right aortic arch with an aberrant left subclavian artery (RAA-ALSCA) is another arch anomaly that can be associated with airway compression (Fig. 2-15). Airway compression typically occurs when there is a persistent ductus ligament completing the ring. However, you cannot see or know whether this is the case by imaging. There are several mechanisms by which RAA-ALSCA contributes to airway compression in addition to compression by the completed ring. Often there is dilatation of the subclavian artery at the origin from the right aorta (called a Kommerell diverticulum), which can contribute to airway compression. In addition, the descending aorta may lie in the midline, immediately anterior to the vertebral bodies, as the descending aorta passes from right to left as it descends (see Fig. 2-15). This midline descending aorta can contribute to airway compression as the result of the abnormal stacking of anatomic structures in the limited space between the sternum and vertebral bodies and typically causes that compression at the level of the distal tracheal carina. There is often a component of dynamic airway collapse (malacia) associated.



▪ **FIGURE 2-13** **Double aortic arch.**
CT image shows right and left arches *(R, L)* surrounding a small compressed trachea *(arrow)*. The arches rejoin to form the descending aorta posteriorly (not shown). The right arch is larger than the left.

Innominate Artery Compression Syndrome

The innominate artery passes immediately anterior to the trachea just inferior to the level of the