Diseases Associated with Childhood Obesity

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OBJECTIVE. Radiologists can play an active role in children's health by increasing awareness of diseases associated with obesity. This article reviews key imaging findings in obesity-related diseases, current issues in imaging obese children, and treatment strategies.

CONCLUSION. There has been a well-documented pediatric obesity epidemic and a dramatic increase in clinical diseases associated with it. These serious health consequences affect nearly every organ system. Despite the increasing prevalence of obesity and the associated health hazards, pediatric obesity as a diagnosis is often overlooked by health care providers.

Obesity is a major threat to children's health today. The prevalence of obesity has been steadily increasing; over the past 25 years, the number of obese children has nearly tripled [1–3]. By body mass index (BMI) criteria (≥ 95th percentile for age and sex), approximately 15% of children 6–19 years old are obese [4].

Longitudinal studies now show that 60% of children who are overweight during preschool years are overweight at the age of 12 years [2]. Data regarding trends show that children who are overweight anytime during childhood are more likely to continue to gain weight and to reach overweight status by adolescence. Multiple other studies have shown that overweight during adolescence is a good predictor of overweight in adulthood. Some have claimed that pediatric obesity has emerged as a new chronic disease [5].

Obesity is a disease that can lead to myriad comorbid conditions. It has been shown to substantially increase years of life lost [6], mortality [7], and health care costs [8, 9]. An American Academy of Pediatrics policy statement described the significant health and financial burdens of pediatric obesity and the need for strong and comprehensive prevention efforts [4]. However, despite the gravity of the disease and its rising prevalence, primary care givers do not consistently diagnose obesity in children and miss significant opportunities for intervention [10, 11]. In addition, pediatric radiologists usually do not include obesity as a diagnosis on imaging reports [12].

Childhood is a critical time for physicians to act as child advocates by attempting to prevent, identify, and treat obesity before these obese children become obese adults and the associated morbidity worsens. The serious complications associated with obesity occur in nearly every organ system.

The purpose of this article is to increase awareness among radiologists of the diseases associated with pediatric obesity and of the need to use the radiology report to note obesity or large body habitus in order to increase awareness of referring physicians. Another way to emphasize the radiographic finding is to state that likely the specific condition is associated with pediatric obesity. When clinicians treat the comorbid disease such as hypertension or gallstones and do not address the underlying disease of obesity, an opportunity to prevent other comorbid diseases is lost.

Diseases Associated with Childhood Obesity

Metabolic Syndrome

Pediatric metabolic syndrome is a group of risk factors in one person that includes obesity, insulin resistance, hypertension, and other metabolic abnormalities; it is present in nearly half of all severely obese children and it worsens with increasing body mass index or insulin resistance [13]. Children have abnormal results of glucose tolerance tests, high triglycerides, and low HDL (high-density lipoprotein) cholesterol concentrations [13].

Childhood obesity has been accompanied by an increase in the prevalence of type 2 di-

Keywords: obesity, pediatric radiology, practice of radiology

DOI:10.2214/AJR.06.0651

Received May 15, 2006; accepted after revision December 6, 2006.

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AJR 2007; 188:1118–1130

0361–803X/07/1884–1118

abetes [14]. Children with obesity-related diabetes face a much higher risk of many comorbid diseases, especially kidney failure [15], by middle age and death from cardiovascular events, when compared with adult onset of diabetes [16].

Cardiac Disorders

As the prevalence of pediatric obesity increases, so does pediatric primary hypertension [17, 18]. Obese children have an approximately threefold higher risk for hypertension than nonobese children [19]. Obese children with hypertension also frequently have other components of the metabolic syndrome, including dyslipidemia, insulin resistance, and hyperinsulinemia [20].

The metabolic syndrome is well recognized as posing a major risk for cardiovascular disease in adults; however, substantial evidence now indicates that this syndrome begins in childhood, and therefore significant cardiovascular risk begins in childhood [20]. In addition, obese hypertensive patients often develop left ventricular hypertrophy (LVH), which also increases the risk of cardiovascular morbidity and mortality [21] (Fig. 1).

The fundamental impact of weight control on the risk of disease and longevity is now well established. A recent analysis concluded that obesity has a detrimental effect on longevity and that the steady rise in life expectancy during the past two centuries may soon come to an end [22].

Respiratory Disorders

Obstructive sleep apnea syndrome (OSAS) is a significant problem in children and has adverse consequences for growth and development [23]; it often results in neurocognitive deficits [23]. OSAS is characterized by recurrent episodes of partial or complete obstruction of the upper airway during sleep, which disrupt the normal ventilation and sleep patterns [23]. Obese children are more apt to have persistent OSA after tonsillectomy and adenoidectomy than are nonobese children [24] (Fig. 2). It is not clear whether the mechanism of OSA is related to increased visceral fat having an effect on decreasing airway tone and predisposing the airways to collapse, or whether increased fat in the neck decreases the caliber of the airway. Cine MRI sleep studies can be used to evaluate both static anatomy abnormality and dynamic abnormalities that lead to functional collapse of the airway in these children [25] (Fig. 3).

Gastrointestinal Disorders

Nonalcoholic fatty liver disease is associated with obesity and insulin resistance [25]. As the prevalence of obesity and insulin resistance in children has been increasing dramatically, so has pediatric nonalcoholic fatty liver disease [26, 27], which is now probably the most common form of chronic liver disease in children [28]. Nonalcoholic fatty liver disease is characterized by an abnormal accumulation of fat in the liver. It is usually asymptomatic and is often found incidentally when hepatic steatosis is documented on abdominal imaging [27]. It may be associated with moderate elevations in levels of serum aminotransferases, triglycerides, and cholesterol. Although hepatic steatosis alone has a good prognosis [26], as fibrosis develops there is an increased likelihood of progression to nonalcoholic steatohepatitis, cirrhosis, and end-stage liver disease, even in children [26–28]. Nonalcoholic fatty liver disease may be detected on both sonography and contrast-enhanced helical CT (Fig. 4). Nonalcoholic steatohepatitis is usually diagnosed at biopsy (Fig. 5).

The presence of moderate to severe (≥ 30%) steatosis is a contraindication for being a living donor; it also increases the risk of postoperative complications for the donor after resection [29]. Unenhanced CT with a multivoxel study of attenuation values in multiple segments excels in the qualitative diagnosis of steatosis of 30% or greater and would serve as a useful tool in screening potential liver donors [30, 31].

Obesity is well recognized as a risk factor for the development of cholesterol gallstones in adults and children [32, 33]. Cholesterol stones are the most common type of gallstone. When bile is supersaturated with cholesterol, it can crystallize and form a nidus for stone formation (Fig. 6). Dietary factors such as consumption of simple sugars and saturated fat have also been associated with a higher risk of cholesterol gallstone formation [32].

Gynecologic Disorders

Another complication of pediatric obesity and associated insulin resistance is polycystic ovary syndrome (PCOS). Like pediatric hypertension and nonalcoholic fatty liver disease, pediatric PCOS is increasing in prevalence with the rise in obesity in children [34]. In addition to polycystic ovaries (Fig. 7), PCOS is associated with hyperandrogenism and associated symptoms (irregular menses, hirsutism, and acne) [34, 35].

Pediatric obesity has also been associated with premature adrenarche or the increase in adrenal androgen production. Evidence exists that prepubertal increases in adrenal androgens in the presence of obesity may be associated with earlier onset of sexual maturity [36, 37]. Premature adrenarche can also lead to a transient acceleration of growth and bone maturation [36–38]. Therefore, accelerated maturation may be noted on skeletal radiography of obese children (Fig. 8).

Musculoskeletal Disorders

Slipped capital femoral epiphysis (SCFE) is a hip disorder in adolescents that causes symptoms of hip or knee pain. It occurs when the femoral head slips off the femoral neck along a weakened growth plate. SCFE is more likely to occur in boys and in overweight patients (Fig. 9). In addition, the possibility exists that SCFE occurs in younger children in the presence of obesity, and that early age of onset and obesity increase the risk for bilateral disease (Strife JL, unpublished data).

Adolescent tibia vara (Blount disease) is also related to obesity [39, 40]. Obesity predisposes to repetitive trauma, with abnormal force being directed on the medial tibial growth plate, which results in growth plate suppression [39]. This leads to decreased growth and a varus deformity. Both metaphyseal–diaphyseal and anatomic tibiofemoral angle measurements show greater malalignment in overweight patients [41]. Early degenerative arthritis of the knee may result. MRI shows features of failure of enchondral ossification of the medial growth plate, unossified medial epiphysis, edema of the medial epiphysis, varus deformity, and hypertrophy of the medial meniscus [42] (Fig. 10).

Children and adolescents who are overweight are more likely than their normal-weight counterparts to have fractures [42]. Dual-energy X-ray absorptiometry (DXA) shows that overweight children have a greater bone density, but it does not protect them from fractures. The cause is speculative, but it has been suggested that the overweight boy is likely to fall with a greater force than a nonoverweight boy and more likely to suffer a fracture.

Finally, it is well recognized that the abnormal mechanical joint loading that occurs in obesity is a primary cause of osteoarthritis [43], which has been documented as occurring in obese adolescents [44] (Fig. 11).

Neurologic Disorders

Idiopathic intracranial hypertension (pseudotumor cerebri) is a condition characterized by increased intracranial pressure with no evidence of a specific cause, such as a space-occupying lesion [45]. Idiopathic intracranial hypertension occurs with significantly greater frequency in obese children and adults [45, 46] (Fig. 12).

Vascular Disorders

Obesity is well recognized in adults to be a risk factor for venous thromboembolic disease [47, 48]. Although the same association has not yet been shown in children, it is reasonable to believe that obesity may pose an increased risk for the development of deep venous thrombosis and subsequent pulmonary embolism in children as well (Figs. 13 and 14). Obesity has also been shown to be independently associated with abnormal arterial function and structure, with an increased intimal–medial thickness in otherwise healthy young children [49]. Intimal–medial thickness is a noninvasive marker for early atherosclerotic changes and is related to the cardiovascular risk factors of obesity, especially hypertension, chronic inflammation, and impaired glucose metabolism [50].

Causes of Pediatric Obesity

What are the causes of the pediatric obesity epidemic? The answers are complex and multifactorial, but the epidemic has been recognized in other countries. Pediatric obesity has been associated with a sedentary lifestyle; increased television viewing; an increase in computer games; lack of physical activity; and dietary causes including increased fat content of food, large proportions, and high-calorie drinks. Pediatric obesity is also affected by sex, ethnicity, culture, and hereditary factors.

One of the most striking findings is that a child who is overweight at 2 years has a greater than 50% chance of being overweight by adolescence, a tendency that will continue into adulthood. Significant research is being funded that is directed to seeking associations and causes. More recently, it has been suggested that prenatal characteristics, including race, ethnicity, maternal smoking during pregnancy, and maternal prepregnancy obesity, exert an influence on the child's weight status through an early tendency toward overweight that is then perpetuated as the child ages. Overweight prevention may need to begin before pregnancy or in early childhood [1, 51].

Treatment of Pediatric Obesity

Treating pediatric obesity is now recognized as a significant health care issue. Minimal approaches promote healthy eating and lifestyle changes and advocate an increase in physical activity. However, selected interventional treatment through decreased caloric intake and increased physical activity has been minimally effective in achieving sustained weight loss in the markedly obese. Specific management also includes referring to specialists, dieticians, screening laboratories, and endocrinologists, and referring for preventive cardiology. Surgical weight loss has been advocated as the only treatment shown to achieve durable weight loss in the obese patient. Bariatric surgery has increased substantially among pediatric adolescents. Surgical treatment of pediatric obesity allows resolution of associated comorbidities and improved quality of life [52, 53].

Some have advocated an antiobesity campaign focusing on creating new social policies that encourage weight loss, such as adjustments in insurance premiums; compulsory exercise for students from elementary schools through college; health food choices in cafeterias; and an educational campaign to enable children, adolescents, and adults to make informed choices. The U.S. population has already shown the ability to shift to a healthier lifestyle. The examples cited include the national initiatives to reduce morbidity and mortality associated with motor vehicle accidents through the use of mandated seat belts, to reduce the spread of AIDS through the prevention of disease, and to reduce the incidence of lung cancer through an increased awareness of the consequences of smoking cigarettes.

Some evidence exists as to the effectiveness of population-based interventions, the potential benefits of increased awareness, and possibly the benefits of routine screening [2]. Nevertheless, good evidence shows that maintaining a normal weight is a positive health goal, and efforts to reduce overweight should begin in childhood.

Obesity Imaging

Several difficulties may be encountered during imaging of obese patients. Larger radiation exposures occur in obese patients because higher doses are necessary to penetrate increased soft tissues. Image quality can be compromised, resulting in nondiagnostic examinations in very large patients (Fig. 15). This occurs during radiography, fluoroscopy, sonography, CT, and MRI. Obesity can also compromise the quality of an examination because of the patient's inability to move and cooperate with proper positioning for radiologic imaging and procedures. Finally, obese patients may exceed the weight and size limitations for standard imaging equipment, including CT, MRI, fluoroscopy, and interventional radiology equipment [54].

Conclusion

Although the prevalence of childhood obesity has reached epidemic proportions, it is underrecognized and undertreated by pediatric primary care providers [5]. Preventing, recognizing, and treating obesity are some of the most challenging dilemmas facing pediatrics [55]. A recent study in an outpatient pediatric academic center showed that in children who meet the criteria for obesity, providers of care document obesity in their clinical assessments in only 53% [5]. Our study highlights the need for increased awareness and identification of obesity and the potential contributing role of the radiologist. If a problem is not recognized, it cannot be treated.

Finding effective strategies to treat obesity through the timely identification of its presence by health care providers is a crucial step in recognizing the disease and in its potential management. Despite the fact that the radiologists are aware of the clinically associated diseases, they rarely mention these associations in their reports. In so doing, radiologists miss their opportunity to be advocates and to identify children at risk of serious health consequences.

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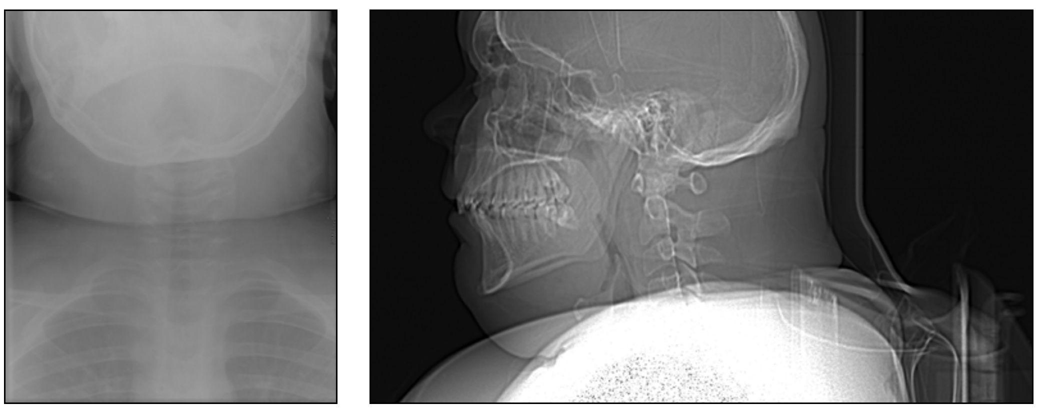
A **B**

Fig. 1—Left ventricular hypertrophy (LVH), echocardiographic views in 16-year-old girl.
A, Parasternal short-axis sonogram shows no evidence of LVH. Arrows indicate normal-sized left ventricular wall.
B, Parasternal short-axis sonogram shows LVH in 314-lb (142-kg) adolescent girl with markedly thickened left ventricular wall (*arrows*).



A **B**

Fig. 2—13-year-old girl referred for evaluation of sleep apnea and airway obstruction.
A, Anteroposterior radiograph of neck shows massive soft-tissue obesity.
B, Lateral scout image from CT shows narrowing of nasopharynx and excessive soft tissue.

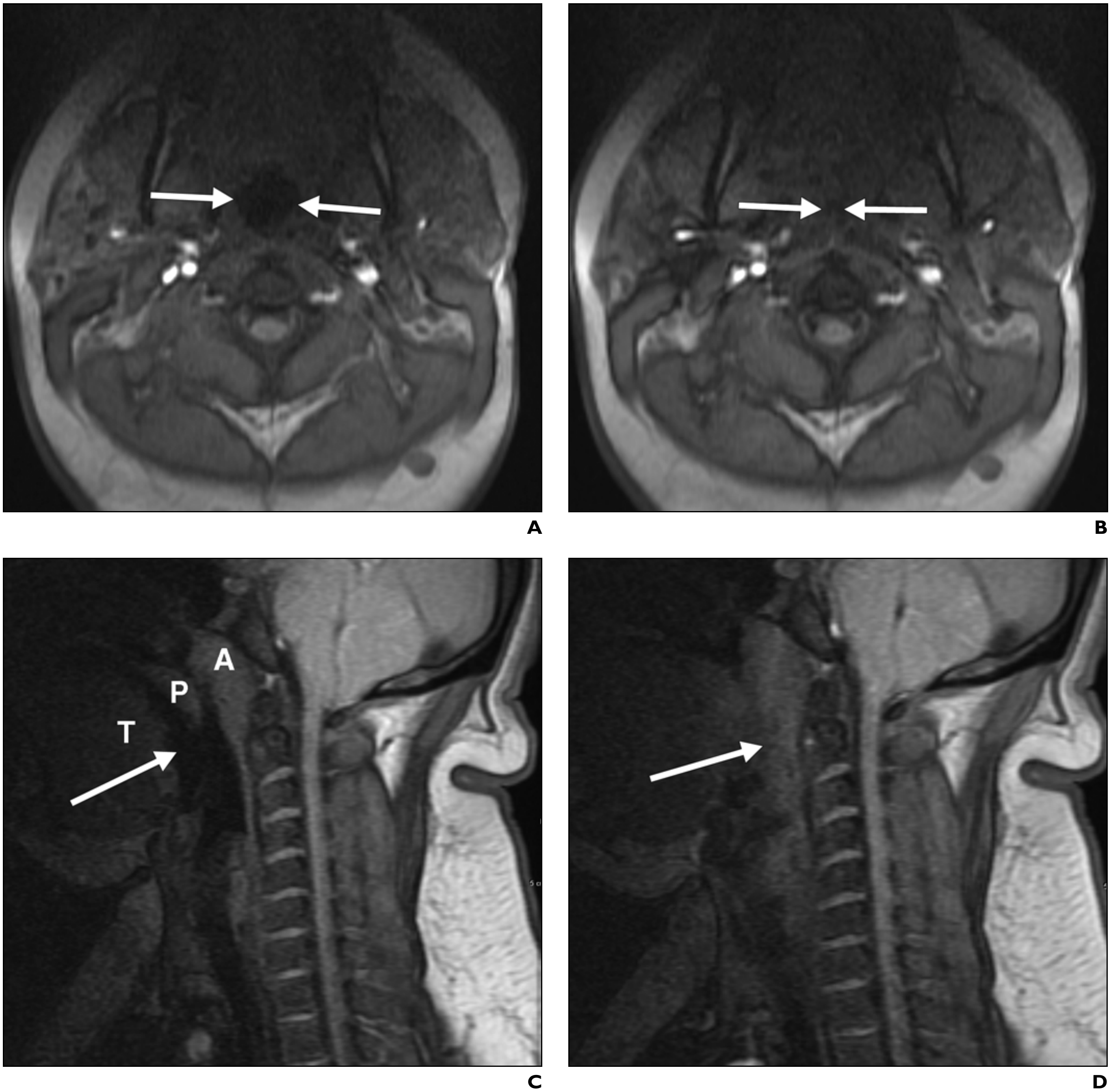


Fig. 3—Airway obstruction in 18-year-old boy.
A, Axial T1-weighted image obtained during sleep apnea evaluation shows excessive soft tissue, indicative of obesity. Arrows indicate open airways.
B, Axial T1-weighted cine MR image shows complete obstruction at level of hypopharynx (*arrows*).
C, Sagittal T1-weighted image reveals excessive soft tissue and enlargement of adenoids (A). Arrow indicates open airways. P = palatine tonsil, T = tongue.
D, Sagittal T1-weighted cine MR image also shows complete obstruction at level of hypopharynx (*arrow*).

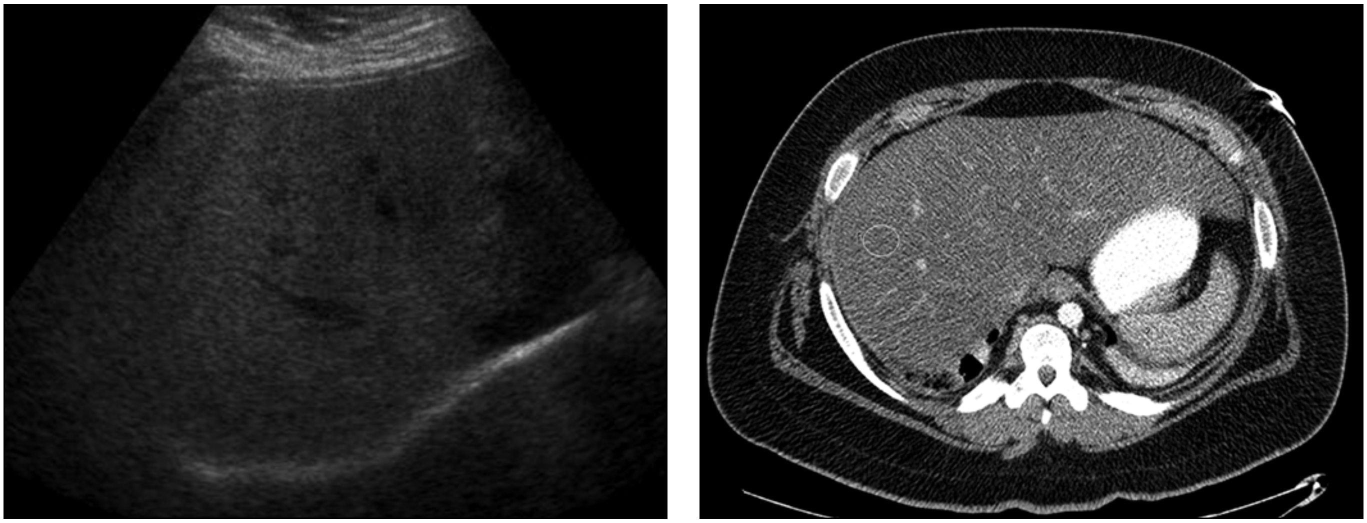


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Fig. 4—Nonalcoholic fatty liver disease in 14-year-old boy.
A, Transverse sonogram shows echogenic liver and poor visualization of portal triads.
B, Axial CT scan through abdomen shows low attenuation throughout liver. Density of liver measures 28 H; of spleen, 91 H.

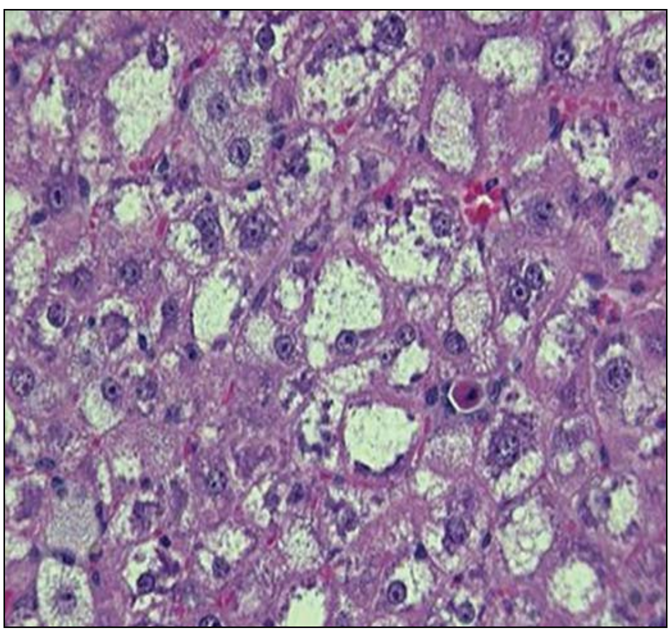
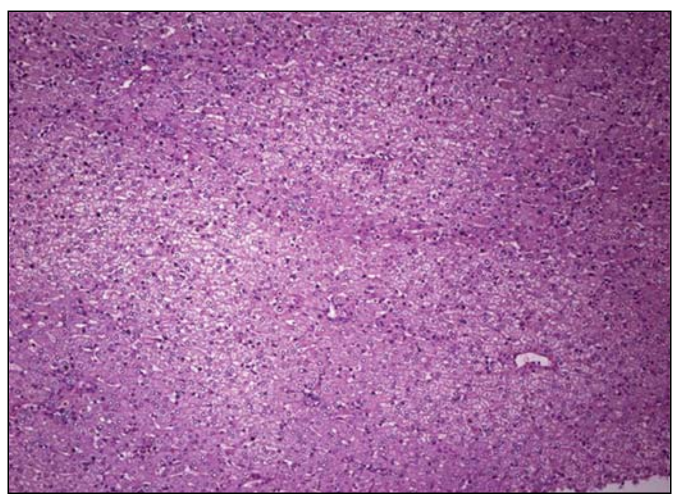


Fig. 5—Nonalcoholic steatohepatitis in children.
A, Biopsy specimen shows fatty infiltration, ballooning degeneration of hepatocytes, and pericellular fibrosis.
B, Compare with normal specimen from liver biopsy.



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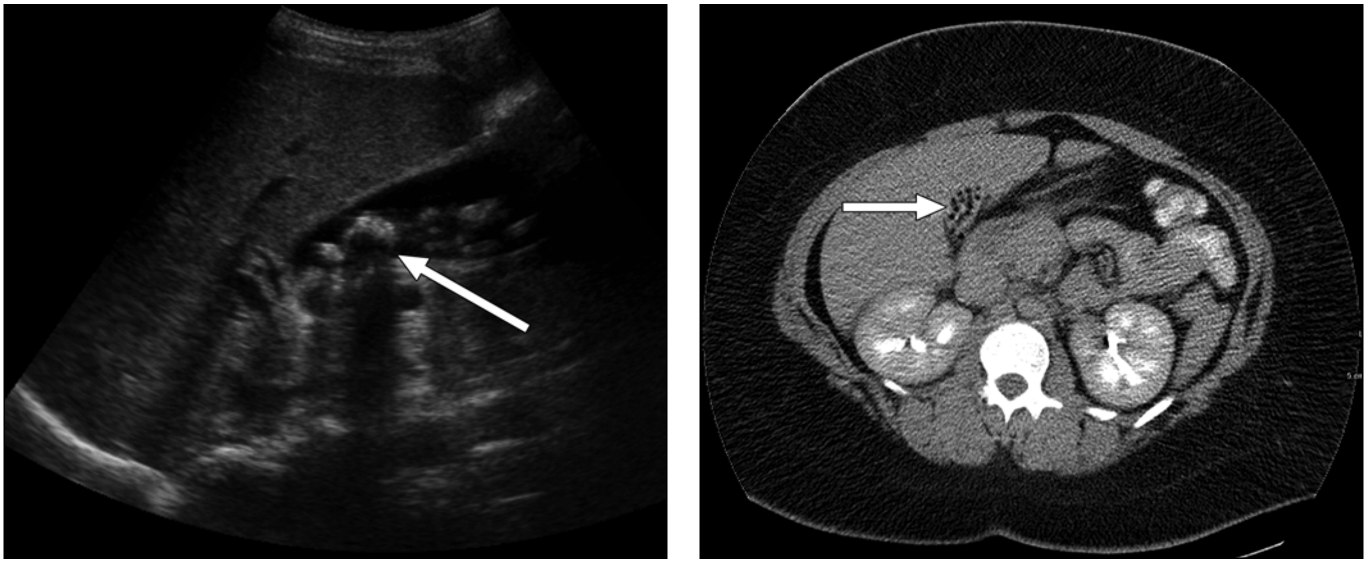

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Fig. 6—Cholelithiasis in 12-year-old girl.
A, Longitudinal sonogram of gallbladder shows echogenic foci (*arrow*) and acoustic shadowing indicative of gallstones.
B, Axial CT scan of abdomen shows multiple cholesterol gallstones (*arrow*) that typically have low attenuation.

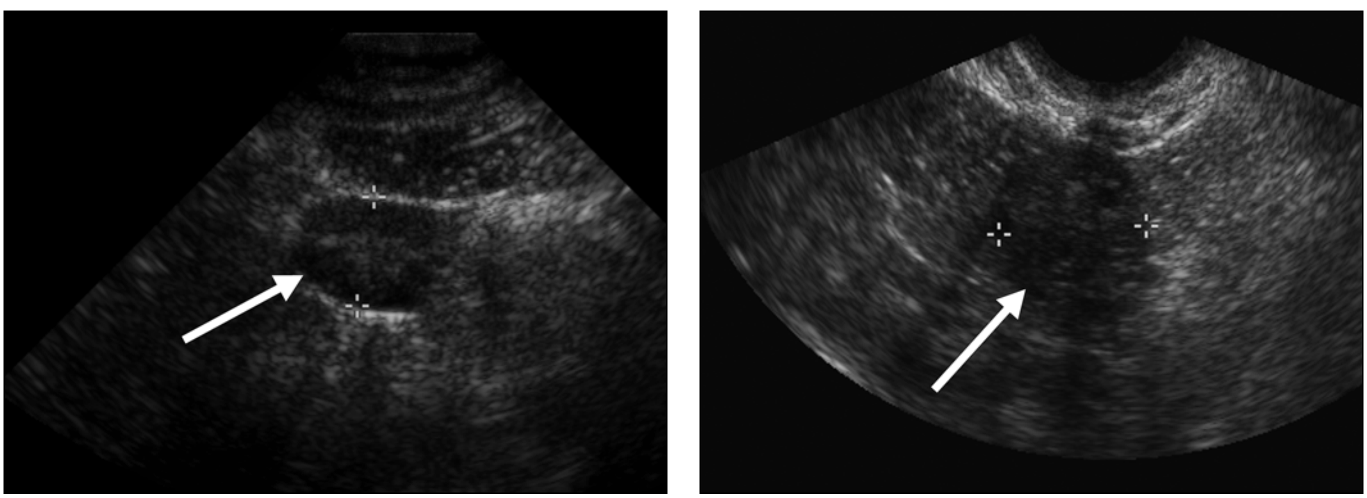

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Fig. 7—Polycystic ovarian syndrome in 14-year-old girl.
A, Transabdominal sonogram shows enlarged right ovary (*arrow*). Sonography was difficult to perform because of large body habitus.
B, Transvaginal sonogram shows large left ovary with multiple cysts (*arrow*), suggestive of polycystic ovarian syndrome.

Fig. 8—14-year-old boy with advanced skeletal age. Single radiograph of hand shows excessive soft tissue (obesity) and advanced skeletal age of 17 years.

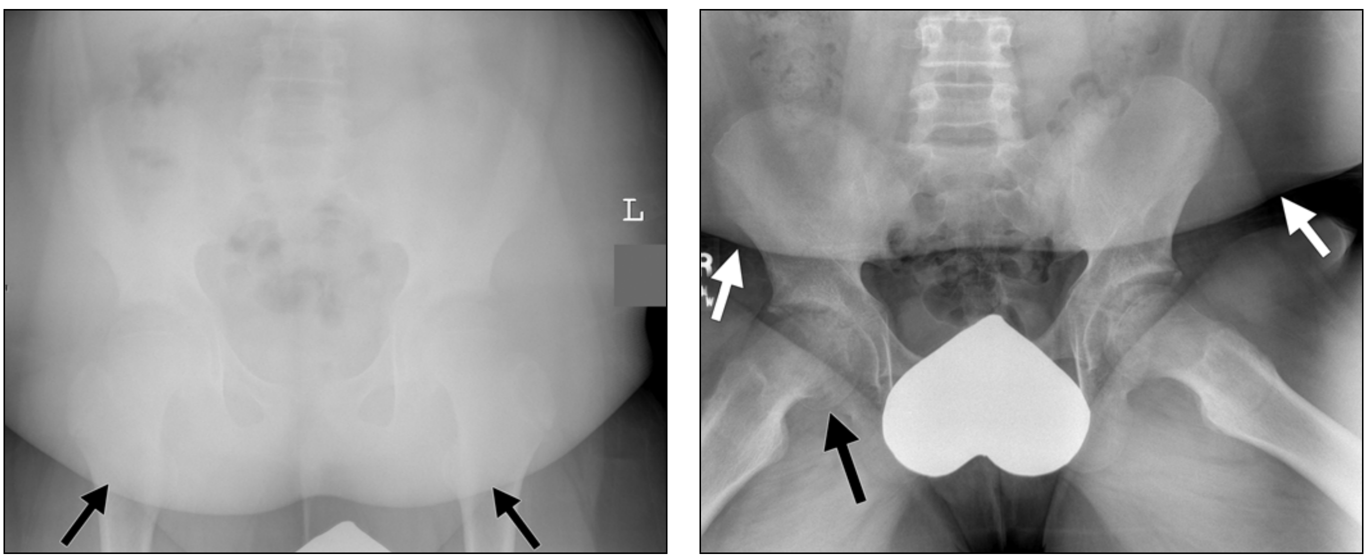

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Fig. 9—Slipped capital femoral epiphysis in 11-year-old boy.
A, Anteroposterior radiograph of hip shows obesity (*arrows*) that degrades imaging of hip joint.
B, Frogleg lateral radiograph of hip shows obesity (*white arrows*) and right slipped capital femoral epiphysis (*black arrow*).

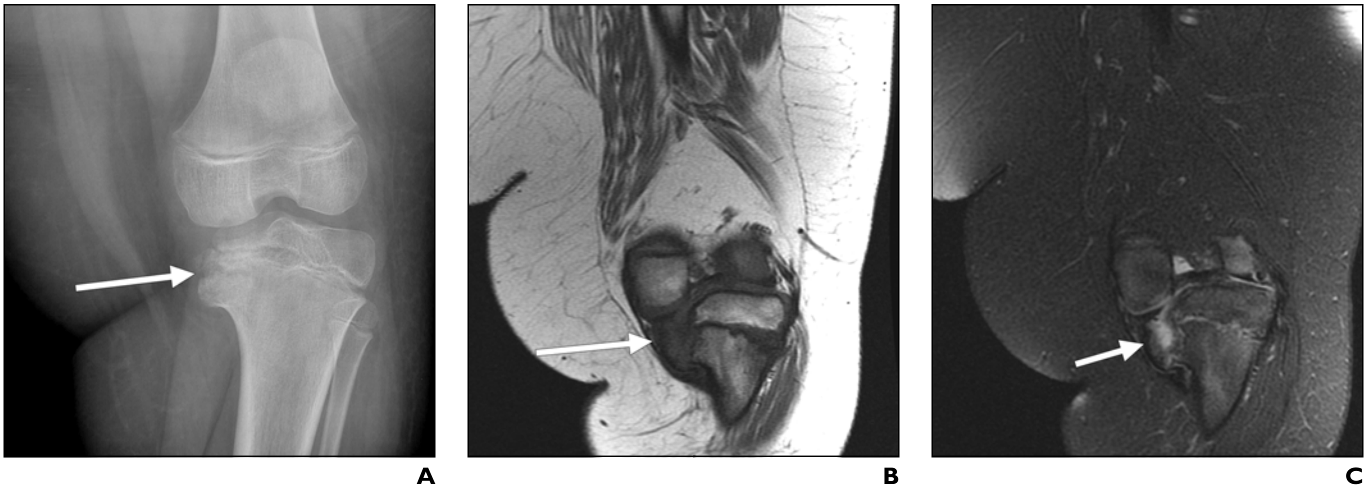


Fig. 10—Blount disease (tibia vara) in two girls.
A, In 11-year-old obese girl, radiograph with patient standing shows loss of height of medial tibial epiphysis and slanting (tibia vara) (*arrow*).
B and **C,** In 4-year-old obese girl, coronal T1-weighted MR image (**B**) shows irregular, widening depression of medial growth plate; unossified medial epiphysis (*arrow*); and hypertrophy of medial meniscus. Coronal T2-weighted fast spin-echo image (**C**) illustrates edema of medial epiphysis and irregularity of growth plate cartilage (*arrow*) that extends medially and inferiorly.

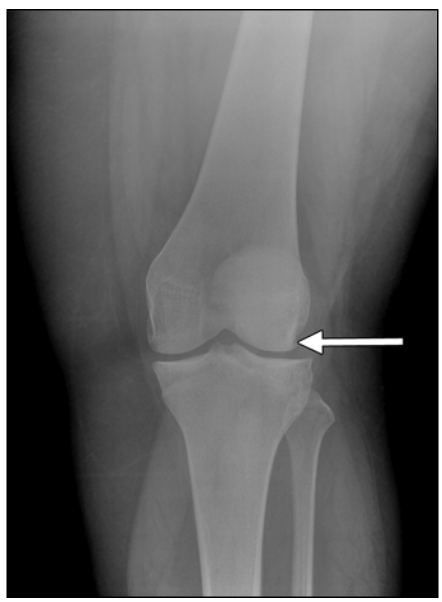
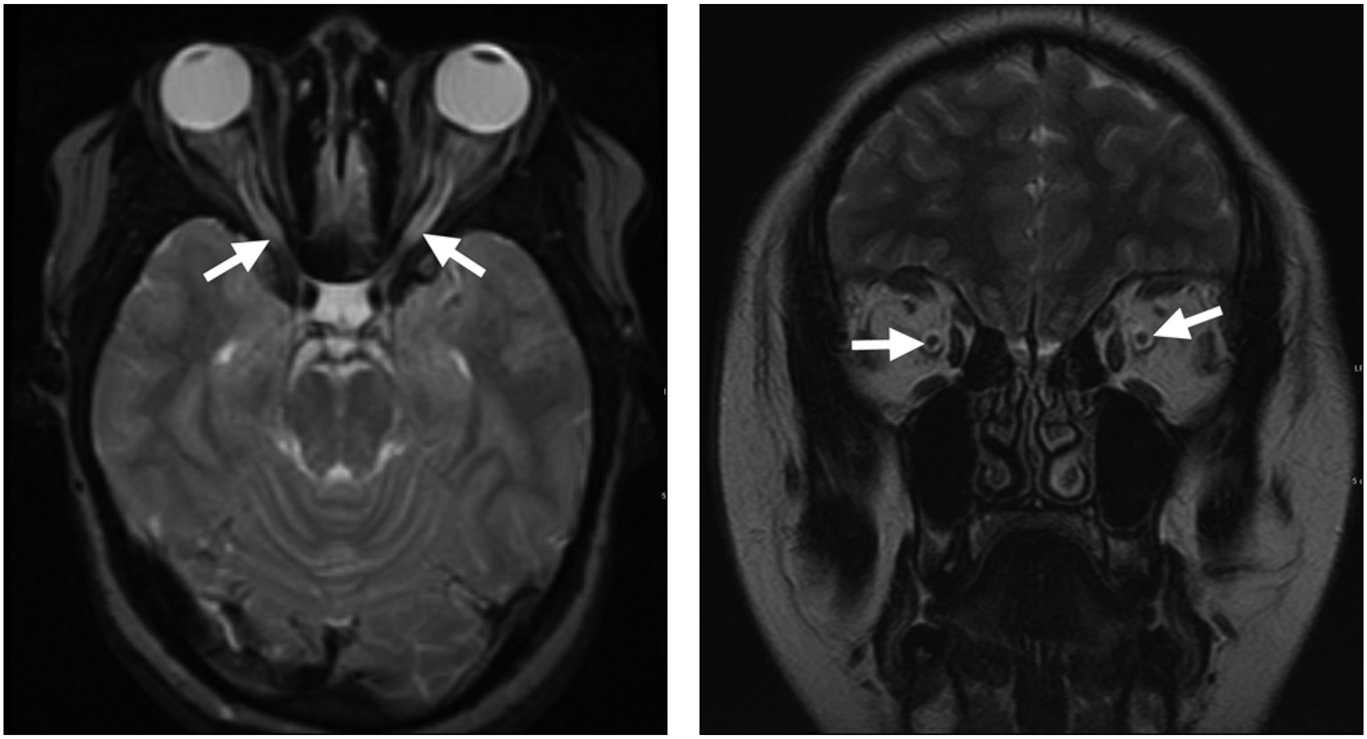


Fig. 11—Osteoarthritis of knee joint in 16-year-old girl with chronic knee pain. Anteroposterior radiograph of knee joint shows obesity, loss of height of medial component, and small osteophyte (*arrow*).



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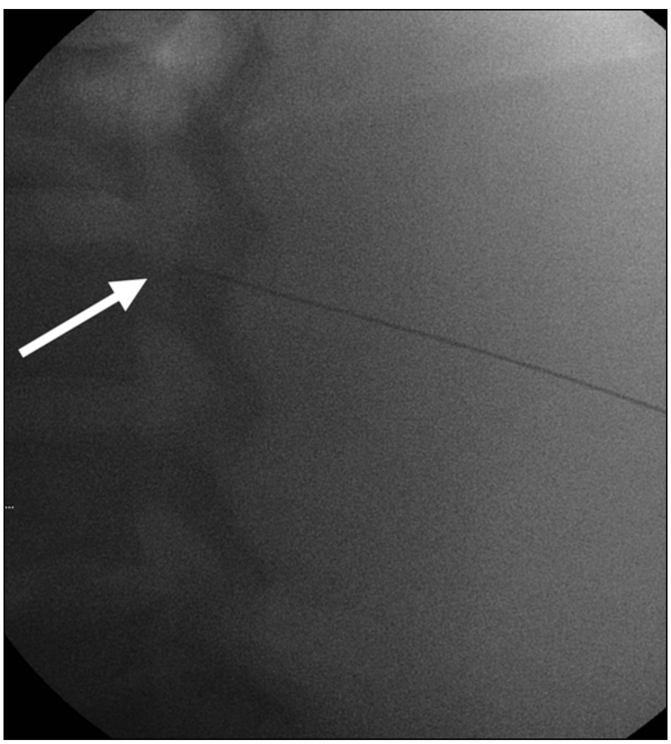


C

Fig. 12—Pseudotumor cerebri in 19-year-old girl who presented with visual loss and papilledema on ophthalmologic examination.
A and **B,** T2-weighted axial (**A**) and coronal (**B**) MR images show increased fluid in optic sheath (*arrows*) surrounding optic nerve. Brain was otherwise normal, and no dural sinus thrombosis was seen.
C, Because of obesity, interventional imaging was used for lumbar puncture. Arrow indicates needle tip.

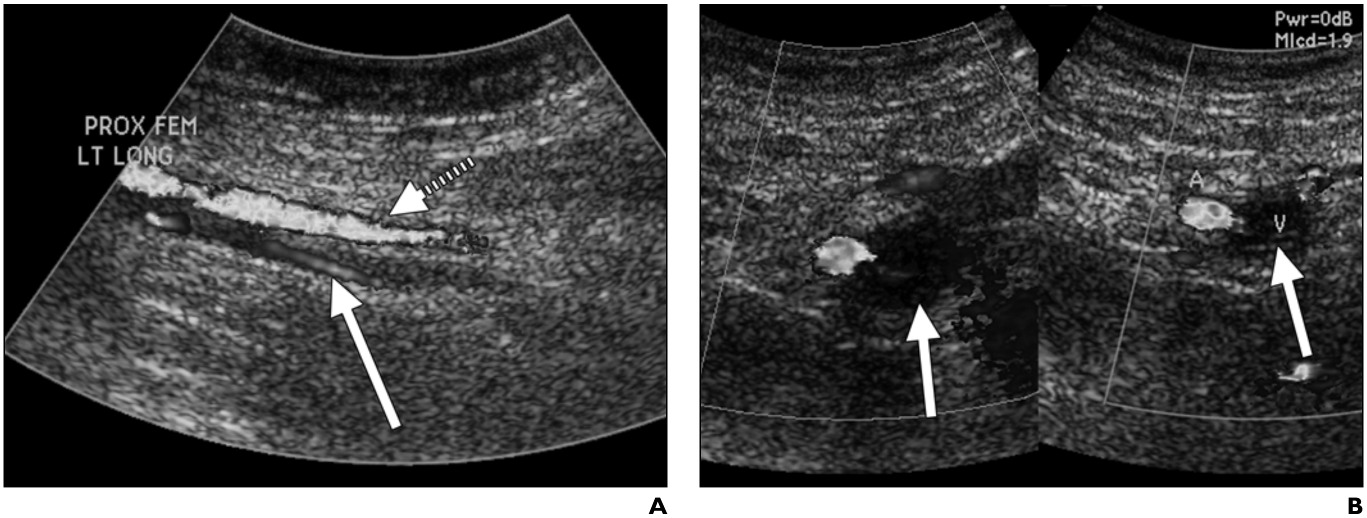


Fig. 13—Deep venous thrombosis in 15-year-old obese girl.
A, Longitudinal sonogram using 4-MHZ probe shows clot (*solid arrow*) in proximal femoral vein. Normal flow is seen in patent left proximal femoral artery (*dashed arrow*).
B, Transverse sonograms without (*right*) and with (*left*) compression show occluding clot and noncompressible vein (*arrows*). Femoral artery (A) is adjacent to vein (V).

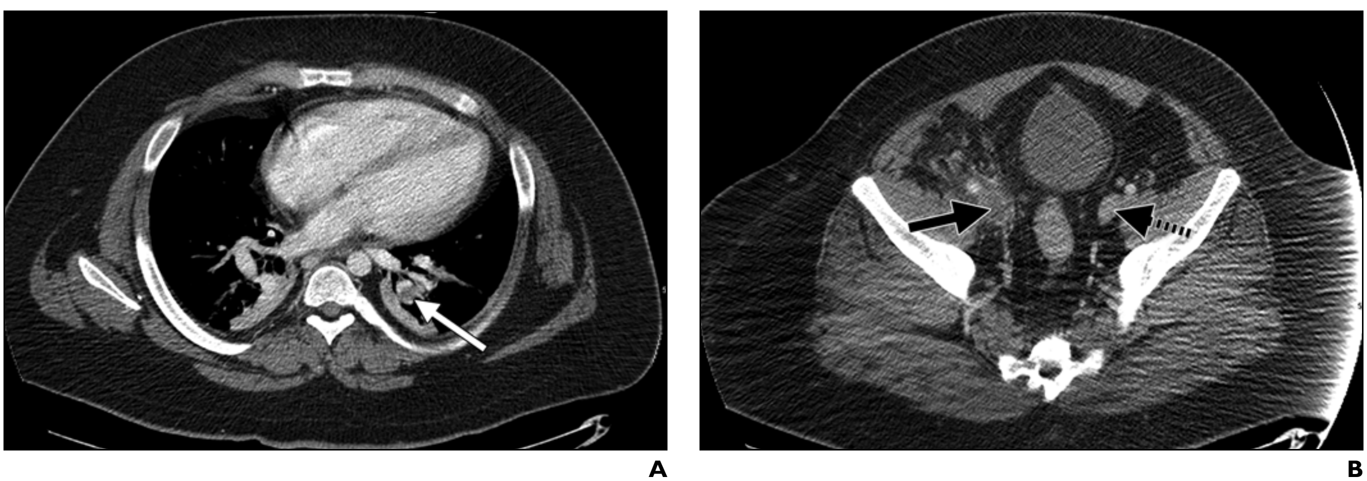
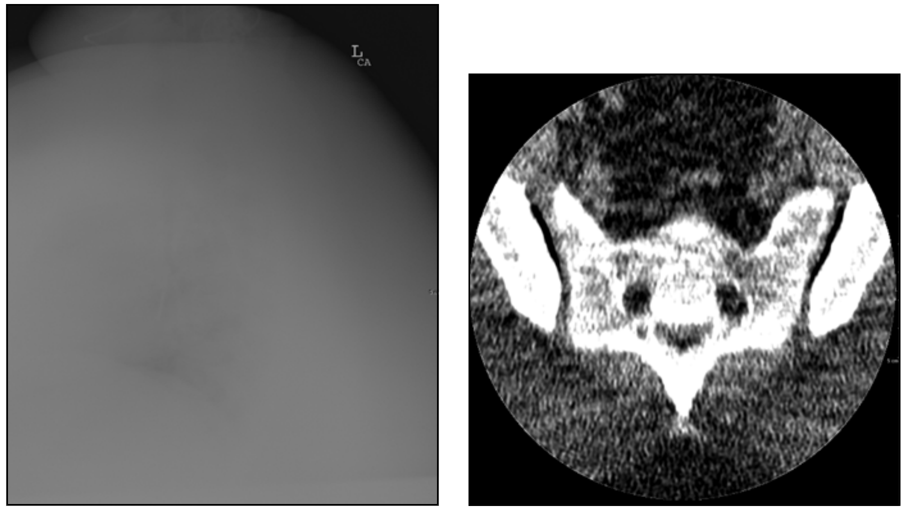


Fig. 14—Pulmonary artery embolism in 14-year-old obese boy who presented with chest pain.
A, Axial pulmonary CT angiogram shows filling defect in inferior left pulmonary artery (*arrow*).
B, Axial CT scan of pelvis shows dilatation of right iliac vein and occlusive clot (*solid arrow*). Dotted arrow shows normal left iliac vein. Note soft-tissue obesity.

Fig. 15—Technical challenges in imaging obese patients.
A, Lateral chest radiograph in10-year-old boy is nondiagnostic because of excessive soft tissue, even with optimum exposure factors.
B, Axial CT scan in 11-year-old boy was obtained because of trauma and shows poor resolution of bones despite adjustment of exposure factors.



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