ELSEVIER
SAUNDERS

Radiol Clin N Am 42 (2004) 445–456

RADIOLOGIC
CLINICS
of North America

Ultrasound evaluation of acute abdominal emergencies in infants and children

Pauravi Vasavada, MD

Department of Pediatric Radiology, University Hospitals of Cleveland, 11100 Euclid Avenue, Cleveland, OH 44106, USA

Ultrasonography is an essential component in the evaluation of acute abdominal pain and vomiting in children. Radiation exposure is a prime consideration in the pediatric population. Ultrasonography, unlike CT or fluoroscopy, allows the radiologist to acquire diagnostic information without the use of ionizing radiation. Ultrasound (US) can be performed in any imaging plane, which is advantageous when evaluating such structures as the pylorus and appendix, which may not be fixed in their orientation. Small children with abdominal pain often are not able to lie down quietly for a CT or MR image without the use of sedation. US, however, is able to obtain diagnostic images in nonsedated children. It is also cost effective, being far less expensive than CT or MR imaging. Real-time ultrasonography can be performed in the radiology department or at bedside in the emergency department [1,2].

Hypertrophic pyloric stenosis

Hypertrophic pyloric stenosis (HPS) is the most common surgical disorder producing emesis in infancy [1,3]. The incidence of HPS is approximately 2 to 5 per 1000 births per year and it varies with the geographic area. HPS is less common in India, and among black and Asian population, with a frequency that is one third to one fifth compared with that in the white population [3]. Boys are four times more likely to be affected than girls, with the incidence significantly higher in first-born boys [2–4]. Although it's etiology remains unknown, there is a familial predisposition. Close to 7% of children with HPS have parents with the same condition [2,4].

Hypertrophic pyloric stenosis is characterized by a defect in contractility or relaxation of the circular muscle of the pylorus that results in hypertrophy of the pyloric circular muscle and narrowing of the pyloric channel [3,4]. This leads to stomach dilation and gastric outlet obstruction of variable severity. Pyloric stenosis should be suspected in neonates 3 to 6 weeks old with postprandial nonbilious vomiting. Symptoms, however, can be present in the first week of life or as late as 5 months of age. The patient classically presents with nonbilious vomiting that is projectile secondary to the pressures generated by the hypertrophied gastric muscles [5]. Persistent vomiting results in large losses of gastric secretions. Because only gastric secretions are lost, prolonged vomiting leads to hypokalemic, hypochloremic metabolic alkalosis. If uncorrected the condition can lead to malnutrition, weight loss, dehydration, and death. More recent evidence suggests, however, that more than 90% of infants with HPS present without any metabolic disorders. This lower incidence has been linked to proper diagnosis before protracted vomiting is allowed to occur, and it has been suggested that easy access to ultrasonography may be contributing to earlier diagnosis [6]. Nonbilious vomiting can present in several other conditions including gastroesophageal reflux disease and pylorospasm [4].

The clinical diagnosis of HPS has traditionally been made by palpation of an olive-shaped mass in the epigastrium representing the hypertrophic pyloric muscle. Palpation of a tumor-like mass in the right upper quadrant by an experienced examiner is usually considered specific and diagnostic without further testing [3,4,7]. In those infants in whom a mass is

E-mail address: vasavada@uhrad.com

doi:10.1016/j.rcl.2004.01.003

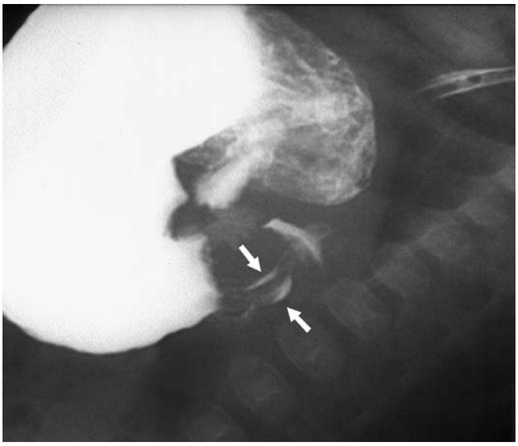

Fig. 1. Fluoroscopic image from an upper gastrointestinal study in a patient with HPS. The double track sign (*arrows*) is formed by contrast material coming through the mucosal interstices of the canal.

not palpated unequivocally, an imaging examination is required. The diagnosis of HPS can be established by imaging upper gastrointestinal tract with the help of a radiographic contrast, such as barium, or by sonography. An upper gastrointestinal tract reveals a beak or a ‘‘string‘‘ sign because of the narrow opening of the pylorus or the double tract sign (Fig. 1) [2]. In patients with pyloric stenosis the muscle is hypertrophied and the intervening mucosa is crowded and thickened and protrudes into the distended portion of the antrum resulting in the nipple sign. The upper gastrointestinal tract provides indirect information about the status of the pyloric channel based on the morphology of the canal lumen as outlined by contrast material. Secondary to this fact, failure of relaxation of the pyloric channel, known as ‘‘pylorospasm,’’ may be confused with pyloric stenosis. Upper gastrointestinal tract can be time consuming, because the radiologist has to wait for contrast to pass through the high-grade obstruction. Fluoroscopy time and radiation exposure may be prolonged. Upper gastrointestinal tract sensitivity rate has been reported to be approximately 95% but error rate as high as 11% has also been reported [3,7].

Sonography has become the modality of choice for the diagnosis of HPS. Sonography is documented to be a highly sensitive (90%–96%) and specific modality for the diagnosis of HPS [4]. US avoids radiation and allows direct visualization of the pyloric muscle as opposed to the upper gastrointestinal tract where the morphology of the muscle is inferred by the thinness and length of the barium through the area [1–3]. The sonographic examination is typically performed with a 5- to 7.5-MHz linear array transducer. A transducer up to 10 MHz can be used adjusted to the size of the infant and the depth of the pylorus [3,4]. The patient is placed in the right posterior oblique position, which allows fluid in the stomach to distend the antrum and pyloric region.

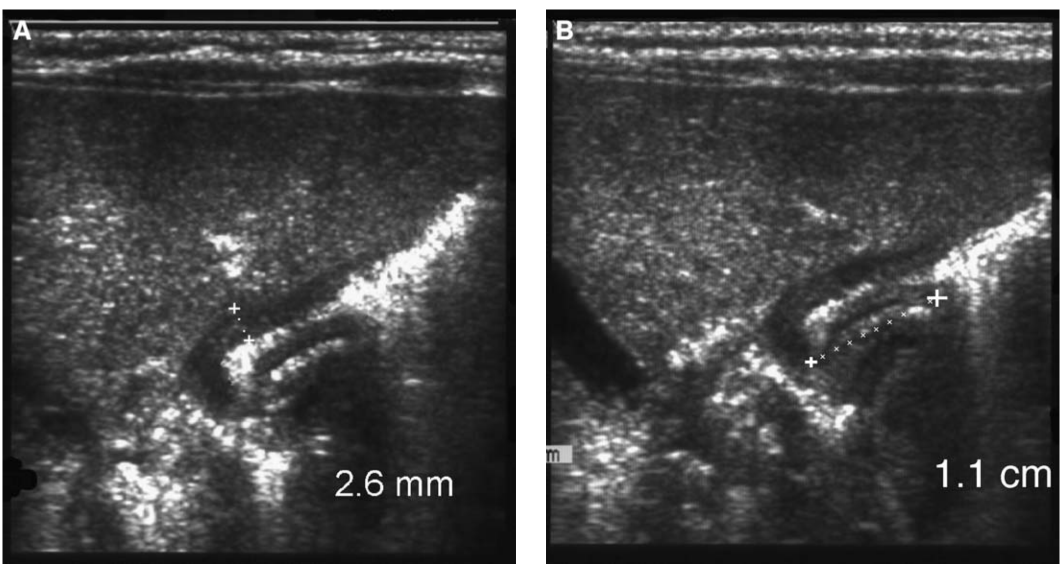

Fig. 2. (*A,B*) Sonograms in a patient with a normal pylorus. Longitudinal views demonstrate normal measurement of the pyloric muscle. The pyloric channel is not elongated measuring 1.1 cm, and the muscle wall is not thickened measuring 2.6 mm.

Because the stomach in infants with pyloric stenosis is normally distended it is usually not necessary to introduce more fluid. If the antrum does not contain adequate fluid, a glucose solution or water can be given orally or through a nasogastric tube [3,4,7]. Occasionally, the stomach may become so distended and displace the duodenal cap caudally and medially rendering the pylorus difficult to visualize. In these cases, if the patient is placed in the supine or left posterior oblique (LPO) position, the pylorus is able to rise anteriorly for more optimal evaluation.

The pylorus is viewed in longitudinal and transverse planes. The examination begins by placing the transducer in the transverse plane, beginning at the gastroesophageal junction and following the contour of the stomach to its antrum. The duodenal cap is recognized by its arrowhead shape. By positively identifying the gastric antrum and the duodenal cap, the interposed pyloric channel can be imaged [7]. A negative study hinges on the diagnosis of a normal pyloric ring and a distensible pyloric portion of the stomach (Fig. 2) [3,7].

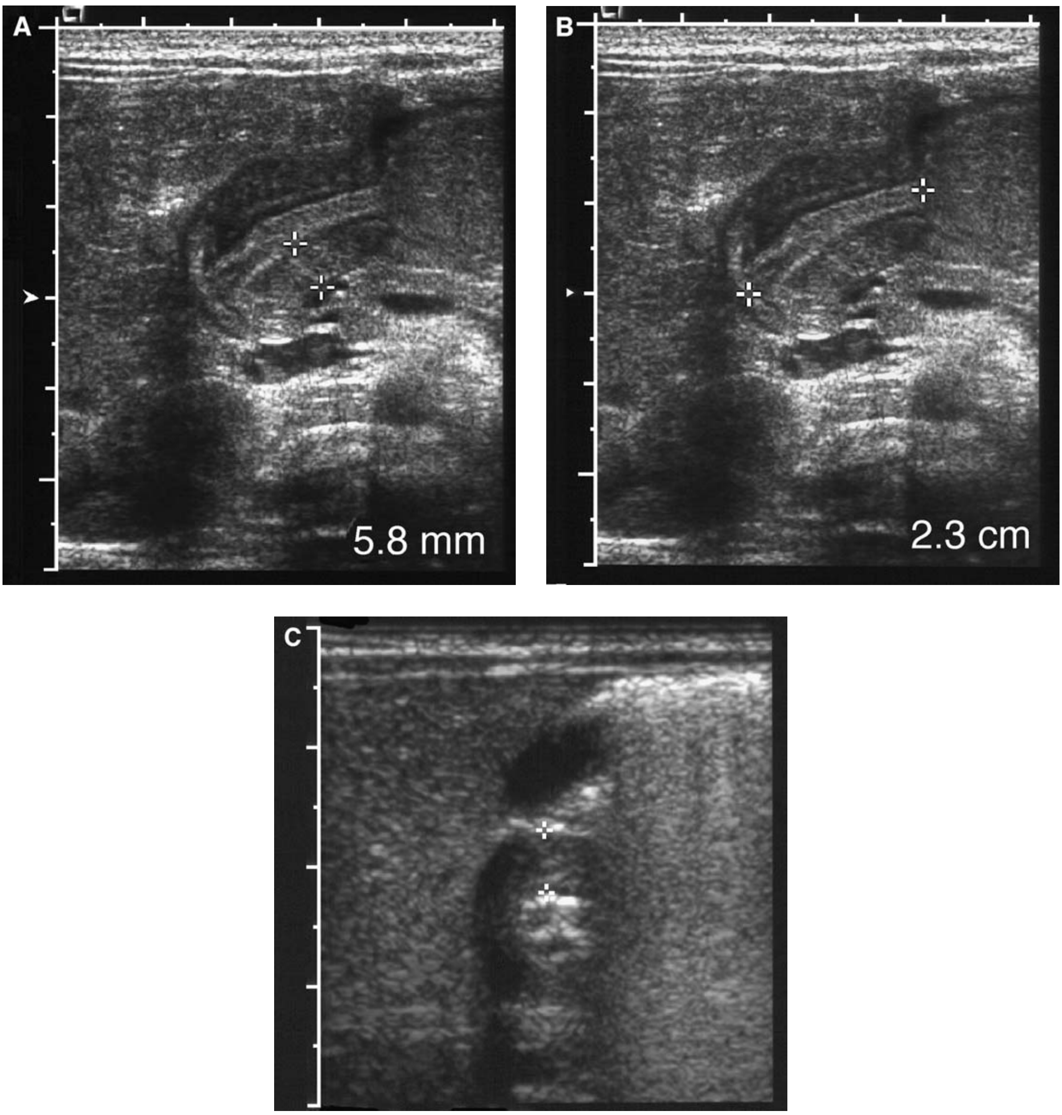

Fig. 3. Hypertrophic pyloric stenosis. (*A,B*) Longitudinal sonographic views demonstrate the hypertrophied pyloric muscle measuring 5.8 mm. The pyloric channel is elongated measuring 23 mm. (*C*) Cross-sectional view shows the thickened hypoechoic muscle surrounding the echogenic mucosa.

On longitudinal views the muscle has a uniformly hypoechoic appearance. In the short axis view, the hypertrophic pyloric muscle has a target or bull's eye appearance reflecting the thickened hypoechoic muscle surrounding the echogenic mucosa. The sonographic hallmark of HPS is the thickened pyloric muscle (Fig. 3). The numeric value for the diagnostic muscle thickness has varied greatly. The exact recommended measurement includes a range of numbers with a broad range of sensitivities and specifications [8]. Controversy persists regarding the significance of muscle thickness between 3 and 4 mm. Some authors consider 3 mm as diagnostic, whereas others believe that this diagnosis cannot be made reliably until a muscle thickness of 3.5 to 4 mm has been attained [3,8]. The length of the hypertrophic canal is variable and may range from as little as 14 mm to more than 20 mm. Despite this variability in numbers in the literature, a patient with HPS has an examination and overall morphology of the pylorus that is characteristic of pyloric stenosis. The muscle thickness is at least 3 mm or more during the examination and the intervening lumen is filled with crowded or redundant mucosa through the center of the canal. Additionally, gastric peristaltic activity fails to distend the preduodenal portion of the stomach [3].

In patients without HPS the muscle does not measure more than 3 mm at any given time. Thickening of the pyloric channel may be a transient phenomenon because of peristaltic activity or pylorospasm. During a normal examination, one can document the pyloric canal changing from a rigid linear morphology to a relaxed canal that permits pockets of fluid within the lumen. If the stomach is empty and the antrum is collapsed a small amount of fluid may be fed to the infant to document a normal fluid-filled antrum (Fig. 4). Patients in whom the pyloric canal relaxes to a normal morphology do not have pyloric stenosis. Patients in whom the muscle is 2 to 3 mm thick during the examination and does not relax warrant monitoring and follow-up examination. Because the cause and evolution of HPS are unknown, it is uncertain whether a young infant in whom the canal fails to relax completely will go on to develop HPS requiring surgery or whether the changes will be arrested and resolve with sequelae [3].

Potential causes of errors in the diagnosis of HPS are overdistention of the stomach, which may lead to displacement of the pylorus posteriorly making identification and measurement of the pyloric thickness more difficult. Additionally, off-midline or tangential images can lead to erroneous diagnosis of a thickened muscle [3,4].

The treatment of HPS is pyloromyotomy in which the hypertrophic muscle is split longitudinally. A study by Yoshizawa et al [9] showed that although

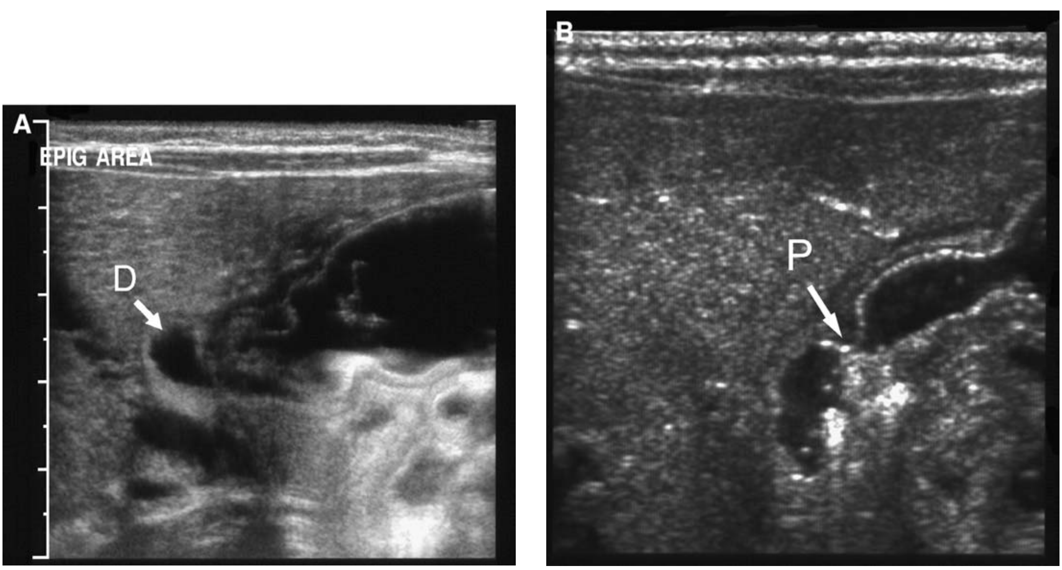

Fig. 4. (*A, B*) Sonographic images of the pylorus after the infant was given a small amount of fluid. Both images show fluid within the antrum passing through a normal pylorus (P, *arrow*) into the duodenum (D, *arrow*).

the pyloric muscle thickness remains abnormal after surgery, by 5 months the dimensions gradually return to less than or equal to normal values.

Intussusception

Intussusception is one of the most common causes of acute abdomen in infancy. The condition occurs when a segment of intestine (the intussusceptum) prolapses into a more caudal segment of intestine (the intussuscipiens). This condition usually occurs in children between 5 months to 2 years of age. In this age group most intussusceptions are idiopathic with no pathologic lead point demonstrated. More than 90% of intussusceptions are believed to be secondary to enlarged lymphoid follicles in the terminal ileum. Intussusception is more common in boys and the condition is rare in children younger than 3 months. The peak incidence is between 5 and 9 months of age. Lead points are noted in children younger than 3 months of age or greater than 2 years of age. Lead points include such entities as Meckel's diverticulum, duplication cysts, intestinal polyps, lymphoma, and intramural hematomas [4]. Transient intussusception is seen in patients with celiac disease (sprue).

Most intussusceptions involve the ileocolic region (75%), where the ileum becomes telescoped into the colon. This is followed in decreasing frequency by ileoileocolic, ileoileal, and colocolic intussusceptions.

The classic clinical triad of acute abdominal pain (colic), currant jelly stools or hematochezia, and a palpable abdominal mass is present in less than 50% of children with intussusception [10,11]. Up to 20% of patients may be pain free at presentation. Additionally, in some instances lethargy or convulsion is the predominant sign or symptom. This situation results in consideration of a neurologic disorder rather than intussusception. Given the uncertainty of achieving an accurate clinical diagnosis, imaging is required in most cases to achieve an early and quick diagnosis to reduce morbidity and mortality. Delay may be life-threatening because of the development of bowel necrosis and its complications [12].

Much controversy exists in the literature related to the diagnosis and management of intussusception. Realistically speaking children with intussusception can be managed successfully in a number of different ways. It is best to use diagnostic tools that are as benign as possible, however, to avoid potential harm to these children and to lessen the discomfort to the children who are not shown to have intussusception.

Conventional radiography and the contrast enema examination have been the principal methods used for the diagnosis and treatment of intussusception. Radiographs of the abdomen are useful and can suggest the diagnosis by showing a mass usually located in the right upper quadrant effacing the adjacent hepatic contour (Fig. 5). Other signs include reduced air in the small intestine, gasless abdomen, or obstruction of the small intestine [13–15]. Identification of a cecum filled with gas or feces in the normal location is the finding that allows exclusion of intussusception with most confidence [10,13]. In the presence of intussusception, plain radiography allows exclusion of bowel perforation, a major complication of intussusception. The accuracy of plain radiography in diagnosis on exclusion of intussusception ranges from 40% to 90% [13,16,17].

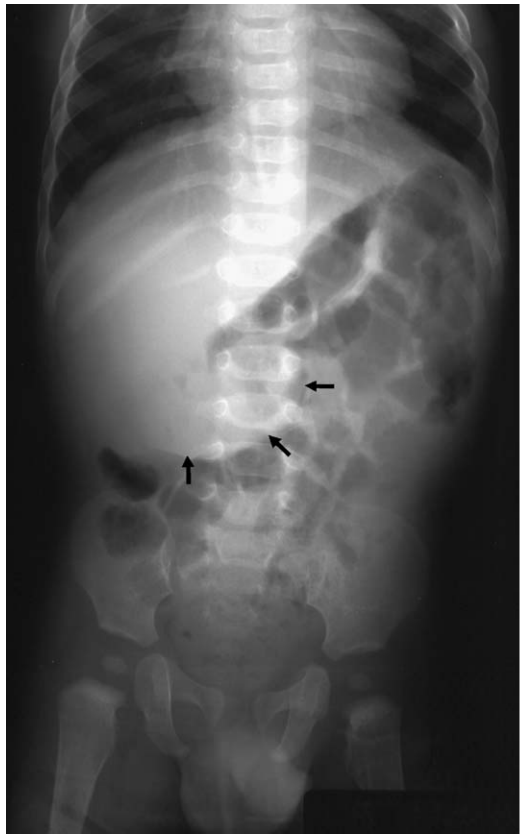

Fig. 5. Intussusception. Plain radiograph demonstrates a round soft tissue density mass (*arrows*) in the right upper quadrant protruding into the gas-filled transverse colon.

Barium enema examination has been the standard of reference for the diagnosis of intussusception for many years. At many institutions liquid enema or air enema examination is the principal diagnostic tool.

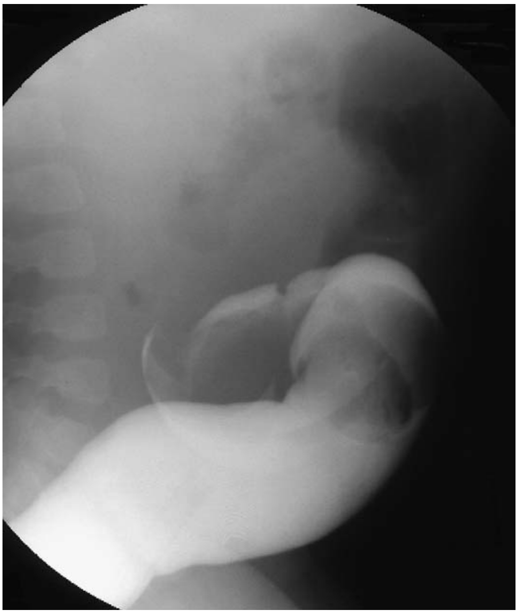

Fig. 6. Meniscus sign. Image from barium enema reduction shows the rounded apex of the intussusception protruding into the column of contrast material.

The classic signs of intussusception at enema examination are the meniscus sign and the coiled spring sign. The meniscus sign is produced by the rounded apex of the intussusception (the intussusceptum) protruding into the column of contrast material (Fig. 6). The coiled spring sign is produced when the edematous mucosal folds of the returning limb of the intussusception are outlined by contrast material in the lumen of the colon. The enema examination, however, can be a very unpleasant experience for both the parent and child and is also associated with radiation.

The role of sonography in the diagnosis of intussusception is well established with a sensitivity of 98% to 100% and a specificity of 88% to 100% [18]. It has been suggested that sonography should be the initial imaging modality and that the enema examination should only be performed for therapeutic reasons [11,18,19]. Sonography not only aids in the diagnosis of intussusception but it also allows the identification of patients who are candidates for therapeutic reduction. Sonography may also detect other abnormalities that are overlooked by the enema examination [4]. In addition, there is a high level of patient comfort and safety with US.

A technique of graded compression is used for the sonographic evaluation of suspected intussusception. Because deep penetration of the US beam is not necessary in small children, a linear high-resolution transducer, 5 to 10 MHz, can be used to improve the definition of the image. The abdomen and the pelvis should be scanned in both longitudinal and transverse planes [1]. The intussusception mass is a large structure, usually greater than 5 cm. Most intussusception occurs in the subhepatic region often displacing adjacent bowel loops (Fig. 7). Even inexperienced operators can readily identify the intussusception on sonography. An intussusception is a complex structure. The intussuscipiens (the receiving loop) contains the folded intussusceptum (the donor loop), which has two components: the entering limb and the returning limb. The attached mesentery is dragged between the entering and returning limbs. Sonographically, the intussusception may demonstrate an outer hypoechoic region surrounding an echogenic center, referred to as a "target" or "doughnut" appearance (Fig. 8) [20]. The hypoechoic outer ring seen on axial scans is formed by the everted returning limb, which is the thickest component of the intussusception and the thin intussuscipiens. The echogenic center of intussusception contains the central or entering limb, which is of normal thickness and is eccentrically surrounded by hyperechoic mesentery [20]. Another pattern of imaging that has been described is that of multiple con-

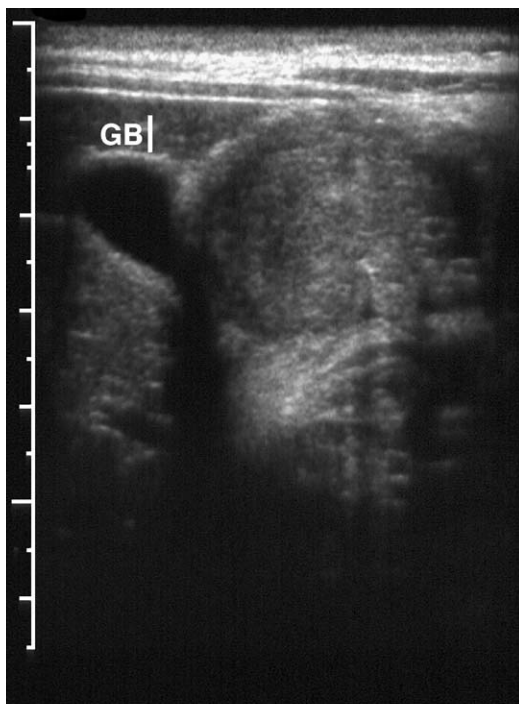

Fig. 7. Intestinal intussusception. Transverse sonographic image demonstrates a soft tissue mass in the right upper quadrant adjacent to the gallbladder (GB).

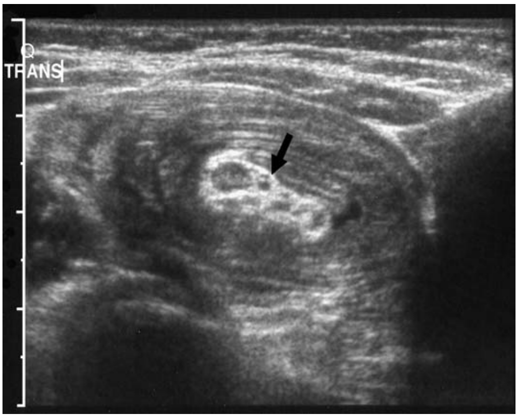

Fig. 8. Target appearance. Transverse sonographic view demonstrates the intussusception. The hypoechoic outer layer represents the intussuscipiens and the central echogenic layer represents the intussusceptum (*arrow*).

centric rings. Within the bowel wall the mucosa and submucosa are echogenic, whereas the muscularis layer is hypoechoic. Multiple hypoechoic and hyperechoic layers are identified when there is little bowel edema present. This represents the mucosa, submucosa, and muscularis layers of the intussusceptum and intussuscipiens. With increasing degrees of bowel edema, the hyperechoic mucosal and submucosal echoes are obliterated in the intussusceptum resulting in fewer layers. On long axis scans the hypoechoic layers on each side of the echogenic center may result in a reniform or pseudokidney appearance (Fig. 9).

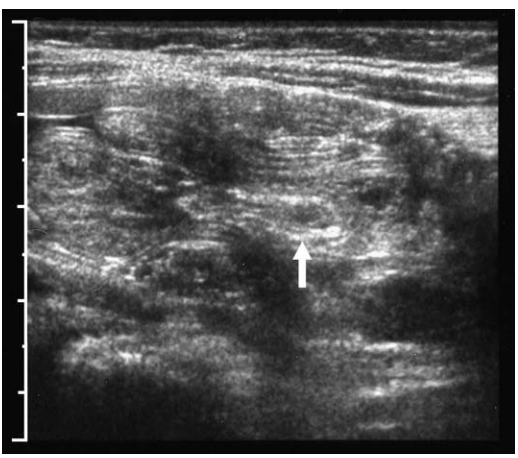

Fig. 9. Long-axis sonographic view shows an elongated appearance resulting in a pseudokidney appearance (*arrow*).

The pseudokidney sign is seen if the intussusception is curved or imaged obliquely [1].

Although the target and pseudokidney signs are the most common ultrasonographic signs used, they are not pathognomic because they have also been seen in normal or pathologic intestinal loops. Differential consideration for the US findings includes other causes of bowel wall thickening, such as neoplasm, edema, and hematomas. An inexperienced operator may mistake stool or psoas muscle for an intussusception.

In addition to diagnosing the intussusception US has other advantages. US may detect the presence of a lead point, which is present in approximately 5% of intussusception. Various sonographic findings have been reported to be predictive of success of hydrostatic reduction. A study by Koumanidou et al [18] shows that the sonographic presence of enlarged mesenteric lymph node in the intussusception is a prediction of hydrostatic irreducibility. Small amounts of free peritoneal fluid are seen in up to 50% of cases. The presence of trapped peritoneal fluid within an intussusception correlates significantly with ischemia and irreducibility, however, because it reflects vascular compromise of the everted limb.

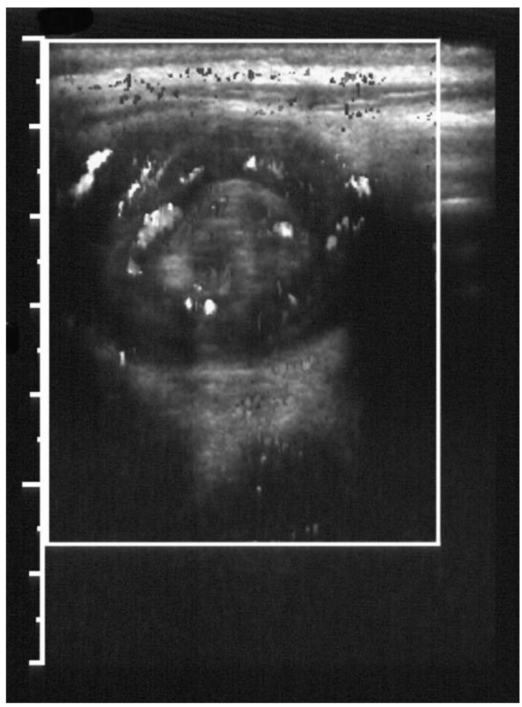

Fig. 10. Use of Doppler ultrasound to evaluate intussusception. Doppler ultrasound shows blood flow within the intussusception, suggesting its reducibility.

Additionally, the absence of flow within the intussusception on color Doppler sonography correlates with a decreased success of reduction and a higher likelihood of bowel ischemia [21–23], and presence of color flow within the intussusception correlates with higher success rate of its reduction (Fig. 10).

There are many different techniques used to reduce intussusception described in the literature. Water-soluble contrast material, barium, air enema guided by fluoroscopy, and physiologic saline solution combined with US have all been used [24,25]. The use of sonography to guide hydrostatic reduction has been predominately performed in the eastern hemisphere and is increasingly being used in Europe. The reduction rate is high (76%–95%), with only 1 perforation in 825 cases reported [25,26]. The procedure may be performed with water, saline solution, or Hartmann solution. The instilled fluid is followed as it courses through the large bowel until the intussusception is no longer visualized and the terminal ileum and distal small bowel are filled with fluid or air. There has been little experience with US-guided air enema therapy. Because air prevents the passage of the US beam, it may be difficult to visualize the ileocecal valve; therefore, small residual ileoileal intussusception can be observed. Additionally, it is difficult to detect perforation resulting in pneumoperitoneum [24].

Sonography has been shown to be highly successful in the diagnoses and reduction of intussusception. The appropriate use of US in children with suspected intussusception obviates the necessity for diagnostic enema, and the use of enema should be limited to therapeutic purposes [27].

Acute appendicitis

Acute appendicitis is one of the major causes of hospitalization in children and it is the most common condition requiring emergency abdominal surgery in the pediatric population. The condition typically develops in older children and young adults with the diagnosis being rare under the age of 2. Clinical signs and symptoms associated with acute appendicitis include crampy, periumbilical, or right lower quadrant pain; nausea; vomiting; point tenderness in the right lower quadrant; rebound tenderness; and leukocytosis with a left shift [28]. When the history and clinical findings are classic, the diagnosis of acute appendicitis is often straightforward [29]. Not only do one-third of children with acute appendicitis have atypical findings, however, but also the presenting signs and symptoms of many nonsurgical conditions may mimic those of acute appendicitis. Most children with acute abdominal pain have self-limited nonsurgical disease. Upper respiratory tract infections, pharyngitis, viral syndrome, gastroenteritis, and constipation are the most common associated conditions noted in these children. The actual prevalence of acute appendicitis in children presenting in the outpatient setting with acute abdominal pain ranges from 1% to 4% [28,30].

The delayed diagnosis of acute appendicitis can carry serious consequences. Perforation, abscess formation, peritonitis, wound infection, sepsis, infertility, adhesions, bowel obstruction, and death have been reported. Morbidity and mortality in acute appendicitis are related almost entirely to appendiceal perforation. The prevalence of appendiceal perforation in various pediatric series has ranged from 23% to 73%, with the perforation rate even higher in young children [28,31–33]. Up to half of children with perforated appendicitis may experience a complication, with nearly all deaths associated with perforated appendix [28]. For fear of missing the diagnosis and allowing the development of perforation, peritonitis, and sepsis, a low index of suspicion and early operative intervention have been recommended. As a result, negative laboratory rates as high as 20% have been reported with rates of 10% to 15% widely accepted [29,34,35]. Unnecessary appendectomy carries potentially major risks and substantial costs, however, prompting many to advocate increased efforts to avoid unnecessary appendectomy [36]. The goal of imaging in a child with suspected appendicitis should be to identify the presence of disease in patients with equivocal clinical findings. Used correctly, imaging should reduce the negative laparotomy and perforation rates and reduce the intensity and cost of care. The ideal diagnostic test should be fast, noninvasive, highly accurate, and readily available [37]. The primary imaging technique over the past decade for evaluating children with suspected appendicitis has been graded-compression US because it is widely available, noninvasive, and does not involve radiation [28,38–40].

The reported diagnostic accuracy of US in the diagnosis of acute appendicitis has varied greatly. The sensitivity of US has ranged from 44% to 94% and the specificity has ranged from 47% to 95% [28]. The clinical use of US lies primarily in the subgroup of children in whom the clinical findings are equivocal. Not only can it establish the diagnosis of appendicitis but also it can identify other abdominal and pelvic conditions, especially gynecologic, that present as right lower quadrant pain [28,41].

The graded-compression technique of US is performed with a high-resolution, linear-array transducer of 5 to 10 MHz. Graded-compression sonography primarily consists of anterior forced compression to reduce the distance between the pathologic process and the transducer and to displace or compress bowel structures to eliminate gas artifacts. Reducing the abdominal cavity by compression enables clear visualization of the retroperitoneal structures [42]. Anterior compression is considered adequate when the iliac vessels and psoas muscles are visualized because the appendix is anterior to these structures.

Scanning is performed in both longitudinal and transverse planes. The examination begins with the identification of the cecum and the terminal ileum. The ascending colon is a nonperistaltic structure containing gas and fluid. The terminal ileum is compressible easily and displays active peristalsis. The cecal tip where the appendix arises is approximately 1 to 2 cm below the terminal ileum. The examination can be expedited by asking the patient to point to the area of maximal tenderness. This can also aid in locating a retrocecal appendix [28].

In early nonperforated appendicitis, an inner echogenic lining representing submucosa can be identified. The inflamed, nonperforated appendix appears as a fluid-filled, noncompressible, blind-ending tubular structure on longitudinal US image. The maximal appendiceal diameter from outside wall to outside wall is greater than 6 mm in an inflamed appendix. A noncompressible enlarged appendix measuring greater than 6 mm in maximal diameter is the only US sign that is specific for appendicitis (Fig. 11). Other findings of appendicitis include an appendicolith, which appears as an echogenic focus with acoustic shadowing; pericecal or periappendiceal fluid; and enlarged mesenteric lymph nodes. On transverse imaging a target appearance is delineated. This is characterized by a fluid-filled appendiceal lumen, which is surrounded by the echogenic mucosa and submucosa and hypoechoic muscularis layer. The US features of perforation include loss of the echogenic submucosal layer and presence of a loculated periappendiceal or pelvic fluid collection or abscess (Fig. 12) [43,44]. The appendix is visible in 50% to 70% of patients with perforated appendicitis [44].

The use of color Doppler has also been described in the evaluation of appendicitis. Color Doppler US of nonperforated appendicitis demonstrates peripheral wall hyperemia reflecting inflammatory hyperperfusion. Color flow may be absent in gangrenous

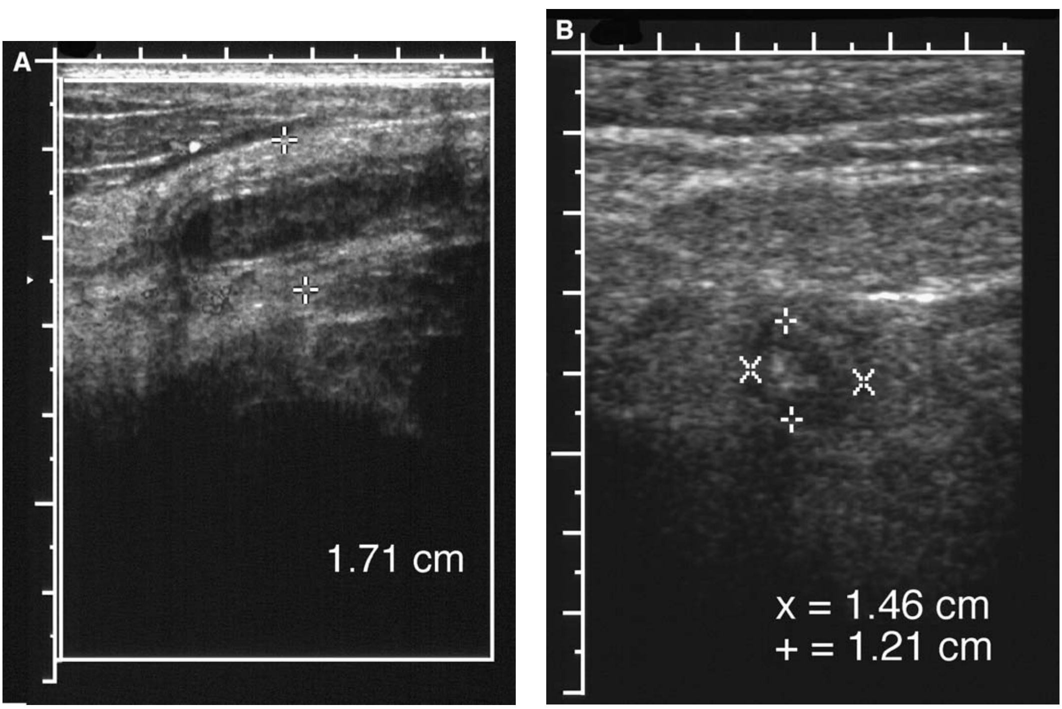

Fig. 11. Acute appendicitis. Longitudinal (*A*) and transverse (*B*) ultrasound images show an inflamed appendix (*between the calipers*), which is enlarged.

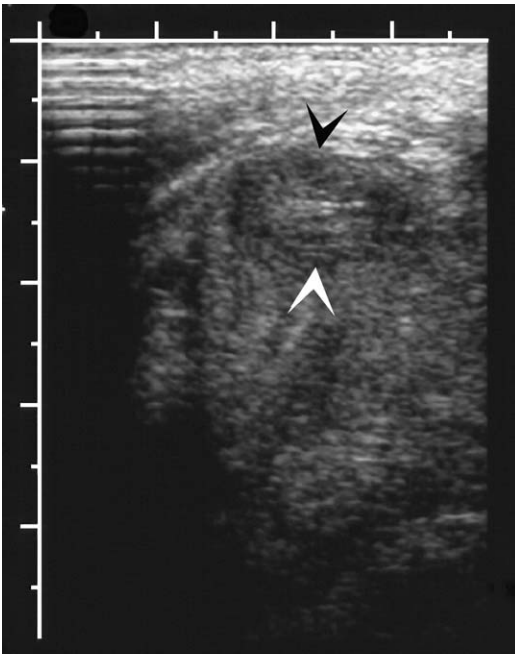

Fig. 12. Right lower quadrant abscess. Two-year-old girl presented with abdominal pain. A complex mass in the right lower quadrant consistent with an appendiceal abscess was demonstrated on ultrasound.

appendicitis or early inflammation [45]. Color Doppler findings of appendiceal perforation include hyperemia in the periappendiceal soft tissue or within a well-defined abscess [46]. Color Doppler US does not increase the sensitivity of the examination but it does make interpretation of the gray-scale US findings easier and can increase observer confidence in the diagnosis of acute appendicitis.

Most false-negative diagnosis results from failure to visualize the appendix. This may be secondary to operator dependency, inability to compress the right lower quadrant adequately, a retrocecal position of the appendix, or appendiceal perforation [37,42]. In patients with obesity the high-frequency transducer may fail to reach the necessary depth, which makes accurate diagnosis difficult because of decreased spatial resolution. Another pitfall is early inflammation limited to the appendiceal tip, which can be missed if only the proximal appendix is imaged [47,48].

False-positive diagnosis has also been reported. The normal appendix, which may be visible in 10% to 50% of children and adolescents, may be mistaken for appendicitis. The normal appendix measures 6 mm or less, is compressible, and lacks adjacent inflammatory changes. Periappendiceal changes may also be secondary to causes other than appendicitis, such as Crohn's disease or pelvic inflammatory disease. The use of US in patients with acute appendicitis is a subject of controversy in the literature [42]. Many studies have been performed to evaluate the use of US in the ultimate outcome of children with suspected appendicitis. Some studies have suggested that the use of US has not improved outcome in children with suspected appendicitis. A study by Roosevelt and Reynolds [49] showed no significant differences in the perforation rate or cost of care in children who underwent US compared with those who did not. A study by Lessin et al [29], however, suggests that the early and selective US in clinically equivocal cases could rapidly allow an accurate diagnosis, without the need for prolonged observation or hospitalization.

There are several other tests that have been used to facilitate the diagnosis of acute appendicitis but the advantage of ultrasonography is its low cost, lack of radiation exposure, easy availability, and noninvasive nature [38].

Summary

Ultrasound is extremely beneficial in the evaluation of acute pediatric abdominal disease, such as HPS, intussusception, and acute appendicitis. As techniques and equipment improve, its role in the evaluation of infants and children continues to increase.

References

[1] Mendelson KL. Emergency abdominal ultrasound in children: current concepts. Med Health 1999;82:198–201.
[2] Hudson PA, Promes SB. Abdominal ultrasonography. Emerg Med Clin North Am 1997;15:826–48.
[3] Hernanz-Schulman M. Infantile hypertrophic pyloric stenosis. Radiology 2003;227:319–31.
[4] Sivit CJ, Siegel MJ. Gastrointestinal tract. Pediatric Sonography 2002;3:337–83.
[5] Haider N, Spicer R, Grier D. Ultrasound diagnosis of infantile hypertrophic pyloric stenosis: determinants of pyloric length and the effect of prematurity. Clin Radiol 2002;57(2):136–9.
[6] Papadakis K, Chen EA, Luks FI, Lessin MS, Wesselhoeft Jr CW, DeLuca FG. The changing presentation of pyloric stenosis. Am J Emerg Med 1999;17:67–9.
[7] Hernanz-Schulman M, Sells LL, Ambrosino MM, Heller RM, Stein SM, Neblett III WW. Hypertrophic pyloric stenosis in the infant without a palpable olive: accuracy of sonographic diagnosis. Radiology 1994;193:771–6.
[8] Lowe LH, Banks WJ, Shyr Y. Pyloric ratio: efficacy

in the diagnosis of hypertrophic pyloric stenosis. J Ultrasound Med 1999;18:773–7.

[9] Yoshizawa J, Eto T, Higashimoto Y, Saitou T, Maie M. Ultrasonographic features of normalization of the pylorus after pyloromyotomy for hypertrophic pyloric stenosis. J Pediatr Surg 2001;36:582–6.

[10] del-Pozo G, Albillos JC, Tejedor D, Calero R, Rasero M, de-la-Calle U. Intussusception in children: current concepts in diagnosis and enema reduction. Radiographics 1999;19:299–319.

[11] Shanbhogue RL, Hussain SM, Meradji M, Robben SG, Vernooij JE, Molenaar JC. Ultrasonography is accurate enough for the diagnosis of intussusception. J Pediatr Surg 1994;29:324–8.

[12] Kim MC, Strouse PJ, Peh WC. Clinics in diagnostic imaging (80). Ileocolic intussusception. Singapore Med J 2002;43:645–8.

[13] Sargent MA, Babyn P, Alton DJ. Plain abdominal radiography in suspected intussusception: a reassessment. Pediatr Radiol 1994;24:17–20.

[14] Bisset III GS, Kirks DR. Intussusception in infants and children: diagnosis and therapy. Radiology 1988; 168:141–3.

[15] Ratcliffe JF, Fong S, Cheong I, O'Connell P. Plain film diagnoses of intussusception: prevalence of the target sign. AJR Am J Roentgenol 1992;158:619–21.

[16] Eklof O, Hartelius H. Reliability of the abdominal plain film diagnosis in pediatric patients with suspected intussusception. Pediatr Radiol 1980;9:199–206.

[17] Meradji M, Hussain SM, Robben SG, Hop WC. Plain film diagnosis in intussusception. Br J Radiol 1994;67: 147–9.

[18] Koumanidou C, Vakaki M, Pitsoulakis G, Kakavakis K, Mirilas P. Sonographic detection of lymph nodes in the intussusception of infants and young children: clinical evaluation and hydrostatic reduction. AJR Am J Roentgenol 2002;178:445–50.

[19] Verschelden P, Filiatrault D, Garel L, Grignon A, Perreault G, Boisvert J. Intussusception in children: reliability of US in diagnosis–a prospective study. Radiology 1992;184:741–4.

[20] del Pozo G, Albillos JC, Tejedor D. Intussusception: US findings with pathologic correlation-the crescent-in-doughnut sign. Radiology 1996;199:688–92.

[21] Lim HK, Bae SH, Lee KH, Seo GS, Yoon GS. Assessment of reducibility of ileocolic intussusception in children: usefulness of color Doppler sonography. Radiology 1994;191:781–5.

[22] Lam AH, Firman K. Value of sonography including color Doppler in the diagnosis and management of long standing intussusception. Pediatr Radiol 1992; 22:112–4.

[23] Lagalla R, Caruso G, Novara V, Derchi LE, Cardinale AE. Color Doppler ultrasonography in pediatric intussusception. J Ultrasound Med 1994;13:171–4.

[24] Rubi I, Vera R, Rubi SC, Torres EE, Luna A, Arcos J, et al. Air reduction of intussusception. Eur J Pediatr Surg 2002;12:387–90.

[25] Riebel TW, Nasir R, Weber K. US-guided hydrostatic reduction of intussusception in children. Radiology 1993;188:513–6.

[26] Rohrschneider WK, Troger J. Hydrostatic reduction of intussusception under US guidance. Pediatr Radiol 1995;25:530–4.

[27] Henrikson S, Blane CE, Koujok K, Strouse PJ, DiPietro MA, Goodsitt MM. The effect of screening sonography on the positive rate of enemas for intussusception. Pediatr Radiol 2003;33:190–3.

[28] Sivit CJ, Siegel MJ, Applegate KE, Newman KD. When appendicitis is suspected in children. Radiographics 2001;21:247–62.

[29] Lessin MS, Chan M, Catallozzi M, Gilchrist MF, Richards C, Manera L. Selective use of ultrasonography for acute appendicitis in children. Am J Surg 1999; 177:193–6.

[30] Scholer SJ, Pituch K, Orr DP, Dittus RS. Clinical outcomes of children with acute abdominal pain. Pediatrics 1996;98:680–5.

[31] Gamal R, Moore TC. Appendicitis in children aged 13 years and younger. Am J Surg 1990;159:589–92.

[32] Adolph VR, Fallerman KW. Appendicitis in children in the managed care era. J Pediatr Surg 1996;31: 164–9.

[33] Rao PM, Rhea JT, Rattmer DW, et al. Introduction of appendiceal CT: impact on negative appendectomy and appendiceal perforation rates. Ann Surg 1999; 229:344–9.

[34] Bell MJ, Bower RJ, Ternberg JL. Appendectomy in childhood: analysis of 105 negative exploration. Am J Surg 1982;144:335–7.

[35] Puylaert JB. Acute appendicitis: ultrasound evaluation using graded compression. Radiology 1986;158: 355–60.

[36] Bendeck SE, Nino-Murcia M, Berry GJ, Jeffrey Jr RB. Imaging for suspected appendicitis: negative appendectomy and perforation rates. Radiology 2002;225: 131–6.

[37] Sivit CJ, Applegate KE, Stallion A, Dudgeon DL, Salvator A, Schluchter M. Imaging evaluation of suspected appendicitis in a pediatric population: effectiveness of sonography versus CT . AJR Am J Roentgenol 2000;175:977–80.

[38] Pena BM, Taylor GA, Fishman SJ, Mandl KD. Cost and effectiveness of ultrasonography and limited computed tomography for diagnosing appendicitis in children. Pediatrics 2000;106:672–6.

[39] Pena BM, Taylor GA. Radiologists' confidence in interpretation of sonography and CT in suspected pediatric appendicitis. AJR Am J Roentgenol 2000;175: 71–4.

[40] Sivit CJ, Newman KD, Boenning DA, Nussbaum-Blask AR, Bulas DI, Bond SJ. Appendicitis: usefulness of US in diagnosis in a pediatric population. Radiology 1992;185:549–52.

[41] Even-Bendahan G, Lazar I, Erez I, Gullemacker M, Verner M, Konen O. Role of imaging in the diagnosis of acute appendicitis in children. Clin Pediatr (Phila) 2003;42:23–7.

[42] Lee JH, Jeong YK, Hwang JC, Ham SY, Yang SO. Graded compression sonography with adjuvant use of a posterior manual compression technique in the sonographic diagnosis of acute appendicitis. AJR Am J Roentgenol 2002;178:863–8.
[43] Quillin SP, Siegel MJ, Coffin CM. Acute appendicitis in children: value of sonography in detecting perforation. AJR Am J Roentgenol 1991;159:1265–8.
[44] Borushok KF, Jeffrey RB, Laing FC, Townsend RR. Sonographic diagnosis of perforation in patients with acute appendicitis. AJR Am J Roentgenol 1990;154: 275–8.
[45] Quillin SP, Siegel MJ. Appendicitis: efficacy of color Doppler sonography. Radiology 1994;191:557–60.
[46] Quillin SP, Siegel MJ. Diagnosis of appendiceal abscess in children with acute appendicitis: value of color Doppler sonography. AJR Am J Roentgenol 1995;164: 1251–4.
[47] Lim HK, Lee WJ, Lee SJ, Namgung S, Lim JH. Focal appendicitis confined to the tip: diagnosis at US. Radiology 1996;200:799–801.
[48] Sivit CJ. Diagnosis of acute appendicitis in children: spectrum of sonographic findings. AJR Am J Roentgenol 1993;161:147–52.
[49] Roosevelt GE, Reynolds SL. Does the use of ultrasonography improve the outcome of children with appendicitis? Acad Emerg Med 1998;5:1071–5.