Sonography: First-Line Modality in the Diagnosis of Acute Colonic Diverticulitis?

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Invited paper

The Sound Judgment Series consists of invited articles highlighting the clinical value of using ultrasound first in specific clinical diagnoses where ultrasound has shown comparative or superior value. The series is meant to serve as an educational tool for medical and sonography students and clinical practitioners and may help integrate ultrasound into clinical practice.

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Abbreviations

ACD, acute colonic diverticulitis; CT, computed tomography

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Diverticulosis is caused by outpouchings of the colon, some of which are acquired herniations (pseudodiverticula) of the submucosa and mucosa into the colon's muscular layer and others that are congenital herniations (true diverticula) containing all layers of the bowel wall.[1] Diverticula of the right side of the colon tend to be true congenital diverticula in the majority of cases and invariably have a favorable course with no perforation or large abscess formation in comparison to left-sided diverticula.[2] The incidence and prevalence of diverticulosis increase with advancing age and vary according to the patient age group under assessment.[3] It is present in 10% of the general population younger than 40 years and 60% of the population older than 80 years.[4] Most patients with diverticular disease are asymptomatic; however, inflammatory and ischemic complications often lead to acute-onset abdominal pain, the most common presenting sign in these patients. Acute colonic diverticulitis (ACD) develops in 10% to 20% of patients with diverticulosis[5] and is the second leading cause of abdominal pain, leading to approximately 130,000 annual hospital admissions in the United States.[3,6] It has been estimated that roughly one-third of patients are clinically missed as having ACD on clinical presentation,[7] hence the important role of imaging, in combination with clinical presentation, to enhance our diagnostic accuracy.

Over the past 4 decades, several imaging modalities have been used to improve the diagnostic accuracy of complicated diverticular disease in order to optimize patient treatment and outcomes. The primary modalities that have been used include radiography, endoscopy, barium contrast enemas, computed tomography (CT), sonography, and magnetic resonance imaging.[8,9] Although the barium contrast enema is one of the most sensitive modalities, it is of limited value in pericolonic disease,[10,11] and its safety in acute disease has been questioned, leading to the recommendation of using water-soluble agents in the acute setting.[12] These limitations have led to a decline in the use of the barium contrast enema as a first-line modality for ACD, in contrast to the rising use of both CT and sonography as the primary imaging modalities in these cases.[13]

In contrast to the United States, sonography is used as the first-line imaging modality in some European countries[14,15] and most developing countries.[16] With the recent technological advances of the sonographic machines that are available today, the ever-improving

resolution, and the ability to visualize the various characteristics of echo architecture that accompany spreading transmural inflammation, sonography is emerging as a premier modality for the imaging of the gastrointestinal tract.[13]

Sonographic Approach to Evaluating the Abdomen

In scanning the gastrointestinal tract, the graded compression procedure[3,17] is used. The examination is performed with a curvilinear 3.5–5.0-MHz probe, which is used in the majority of cases. However a high-frequency linear 5–12-MHz probe may also be used, primarily in the pediatric patient, the thin patient, and the elderly patient who has decreased muscular mass, allowing for enhanced penetrability. This probe leads to improved image resolution and is most helpful in the evaluation of superficial disease affecting the left colon as well as the sigmoid colon. In addition, an endocavitary (transrectal or tranvaginal) probe may be used when indicated for the evaluation of difficult-to-access areas such as the sigmoid colon, keeping in mind that this approach is more invasive, requires additional examination time, and may be a source of discomfort, particularly to the elderly patient.[15]

Before commencing the systemic evaluation of the abdomen, it is critical to focus on the patient's most painful area. It is precisely this ability to communicate with the patient and to perform a focused evaluation in real time that distinguishes sonography from all other diagnostic modalities and renders it an invaluable extension of the physical examination.

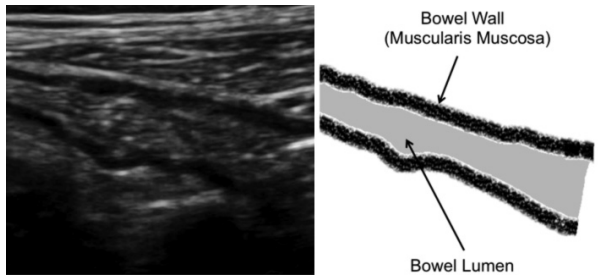
Subsequently, it is recommended to perform a systemic evaluation of the abdomen by commencing in the right upper quadrant with the ascending colon, with its characteristic haustra in its constant anatomic location. From there, the right lower quadrant is evaluated, reaching the blind-ending loop of bowel, the cecum. The terminal ileum and the appendix are then evaluated, followed by the transverse and descending portions of the colon. It is recommended to follow the sigmoid colon into the pelvis and to attempt visualizing the rectum with the bladder as an acoustic window. Optimal visualization may be attained with a half-full bladder. The small bowel is then scanned and recognized by its valvulae conniventes, while paying attention to the perienteric soft tissue and fat.[18] The normal colon is seldom recognized on sonography, and its wall thickness is less than 3 mm (Figure 1). As such, whenever the colonic wall measures greater than 5 mm, underlying disease must be suspected (Figures 2–6).[19] Although bowel gas and peristalsis may hinder a proper sonographic evaluation of the normal gastrointestinal tract, with underlying disease there tends to be a thickened wall, a narrowed lumen, and decreased peristalsis, all of which facilitate the sonographic evaluation.[18] The key to differentiating the sigmoid colon from the small bowel lies in identifying its stable location, visualizing the colonic lumen that lacks vulvulae conniventes, and ascertaining the absence of peristalsis that is normally pathognomonic for the small bowel.[19,20]

Sonographic Features of ACD

Several key sonographic features have been described in ACD:

1. A thick hypoechoic wall with a central hyperechoic center (target phenomena), which is seen in up to 40% of cases.[20,21] This structure is known as the Parulekar pseudokidney (Figure 3). Although it was one of the initial sonographic signs described for the diagnosis of ACD, later studies have found it to be nonspecific.[22] Thus, the primary emphasis is placed on a thickened hypoechoic wall.
2. Diverticula, which are seen in up to 50% of cases (Figures 2, 3, and 7).[21]
3. Changes in pericolic fat. This sign is usually seen as a rigid hyperechoic zone surrounding the colon, representing omental or pericolic fat that is encasing the inflammation (Figures 3, 5, and 7).[14,19]
4. Enlarged fluid-filled loops of bowel.
5. Air-containing diverticula manifesting as hyperechoic areas within the lumen where there is acoustic shadowing as a result of air residue (Figure 2).[14]
6. An abscess presenting primarily as a cystic mass with hyperechoic debris.[13]
7. Local pain and tenderness on compression.[23]

Figure 1. Transabdominal sonogram obtained with a 10-MHz linear probe. It shows normal bowel at the level of the sigmoid colon. The hypoechoic muscularis mucosa and the hyperechoic bowel lumen are depicted.



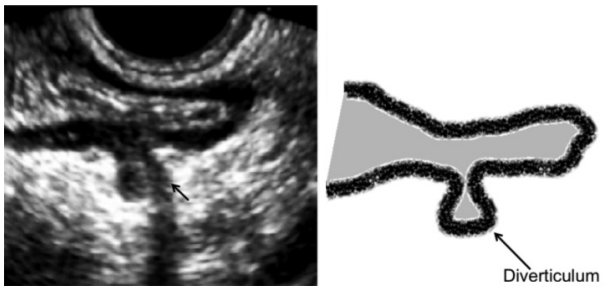


Figure 2. Transvaginal sonogram obtained with a 9-MHz endocavitary probe. It shows an uncomplicated diverticulum at the level of the sigmoid colon with adjacent acoustic shadowing (short arrow) secondary to the presence of a fecolith or air.

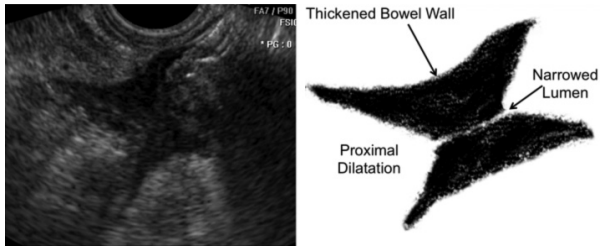


Figure 4. Transvaginal sonogram obtained with a 9-MHz endocavitary probe. It shows substantial circumferential thickening of the wall of the sigmoid colon with near-complete narrowing of the lumen and proximal bowel dilatation. The circumferential thickening in this case raises the possibility of underlying colon cancer.

Sonography has been found to be of great utility in patients who are not too obese, especially in early benign uncomplicated disease, as there tends to be a predictable evolutionary sonographic pattern in diverticulitis. While initially the colon wall is thickened, the ability to visualize its layers on sonography is maintained, and there may be either a fecolith or air visualized within the diverticulum (Figures 2 and 7). The fecolith eventually becomes evacuated into the lumen within 1 to 2 days (Figure 7). In addition, sonography is helpful in right-sided diverticula, as these tend to have larger fecoliths with a wider diverticular neck, and there is no concomitant hypertrophy of the right colonic wall.[2]

It should be noted that sonography has an important diagnostic role in differentiating alternative underlying causes of ACD such as carcinoma of the sigmoid and gynecologic causes, in addition to epiploic appendagitis, a self-limited condition that may closely mimic ACD but has a distinguishing sonographic trait: it appears as an isolated pericolic fatty inflammation without bowel wall thickening.[24]

Evidence in Support of Sonography First

Sonography is safe, widely available, easily accessible, portable, and affordable, and it enables the visualization of the entire alimentary and genitourinary tracts. Not only does it allow for the evaluation of specific sonographic features of ACD, but it also allows immediate assessment of peristalsis as well as blood flow on color Doppler imaging in the evaluation of key structures and vessels.[3] In addition, with the simultaneous, instantaneous ability to interpret both clinical and sonographic findings, it enables rapid and accurate diagnoses in trained hands.

One of the earliest studies on the accuracy of sonography in diverticular disease was conducted by Parulekar[20] in 1985. In 1990, Wilson and Toi[25] concluded that sonography was a valuable initial imaging modality in 54 patients with ACD. Subsequent studies have been conducted and have provided ample evidence in support of sonography,[14,26,27] demonstrating similar accuracy of sonography and CT of approximately 94%.[28–31] In a recent meta-analysis by Laméris et al,[32] comparing the diagnostic accu-

Figure 3. Transabdominal sonogram obtained with a 10-MHz linear probe in a case of ACD. It shows a thickened hypoechoic bowel wall with a hyperechoic center. Note the hyperechoic surrounding pericolic fat.

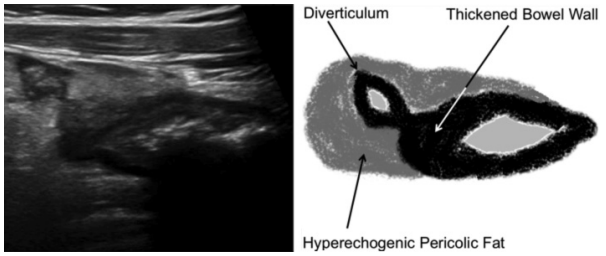
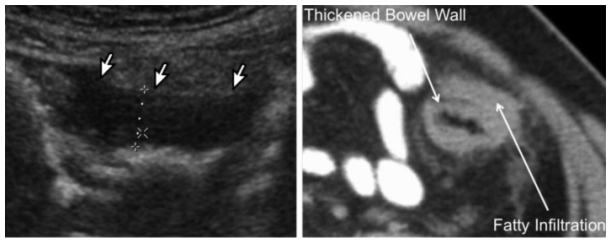


Figure 5. Transabdominal sonogram obtained with a 5-MHz curvilinear probe and corresponding CT. It shows thickening of the wall of the left colon (short arrows) with surrounding fatty infiltration. This appearance may be due to underlying ACD or colon cancer.



racy of CT and sonography in the diagnosis of diverticulitis on a total of 630 patients evaluated by sonography and 684 patients evaluated by CT, there was no statistically significant difference in the sensitivity of sonography (92%) versus CT (94%) with $P = .65$ (Table 1). In addition, Table 2 summarizes the results of the largest studies in the literature pertaining to the sensitivity and specificity of sonography in the diagnosis of ACD.

There are certain limitations to the use of sonography in ACD, where first and foremost, the area under question may be obscured by overlying gas. In addition, obesity is a limiting factor, as with the diagnosis of other conditions, and disease that is confined to the distal colon may be more difficult to visualize, as the bladder and other pelvic structure may limit accessibility.[13] This situation is where transrectal or transvaginal sonography, using an endocavitary probe, may prove to be of utility (Figures 2, 4, and 6),[15] keeping in mind that it is more invasive, requires additional time, and is a source of discomfort to the patient. However, the greatest limiting factor for the use of sonography in ACD, as in other areas of the body, is that it is highly operator dependent, with considerable variations in skill levels, leading to variable interpretations and discrepant sensitivities. This limitation was shown in a study by van Randen et al,[35] in which there was a statistically significant difference in the detection of ACD in the hands of operators who had done less than 500 scans versus those who had done in excess of 500 scans. On the other hand, CT, being relatively objective and operator independent, is the primary modality used for ACD in the United States.[15,25,26]

Computed tomography has been considered the reference standard for the diagnosis of ACD, especially in cases of disease affecting the left colon, in cases in which there is clinical suspicion but negative sonographic findings, in cases of complicated ACD, and to properly stage the patient before the initiation of treatment.[3,7] In addition, CT is the best modality for diagnosing intraperitoneal air.[3] Nonetheless, even with nearly a doubling of the rate of CT scans performed on patients presenting to emergency departments with abdominal pain in the United States from 2001 to 2005, there was no increase in the detection rates for diagnosing gallbladder disease, ACD, or appendicitis, nor was there a decline in the number of hospital admissions.[36] In addition, we must keep in mind that CT is more costly, is less available, may require contrast (required for complicated disease or to rule out other potential underlying conditions), and exposes the patient to radiation.[37] Also, with ACD being a recurrent disease, these patients require repetitive imaging with each episode of recurrent disease, and this repeated exposure to ionizing radiation becomes a major concern,[38] where it has been estimated that roughly 29,000 cancers could be attributed to CT scans performed in the United States in 2007, with the largest contribution, 14,000 cases, attributed to CT of the pelvis.[39,40] This scenario is precisely where the role of sonography, with its safety and effectiveness, becomes paramount in the surveillance and follow-up of these patients.

Figure 6. Transvaginal sonogram obtained with a 9-MHz endocavitary probe. It shows asymmetrical wall thickening with a hypoechoic collection in the left iliac fossa at the level of the sigmoid colon, suggestive of complicated ACD.

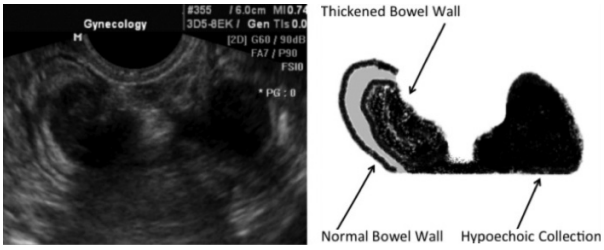
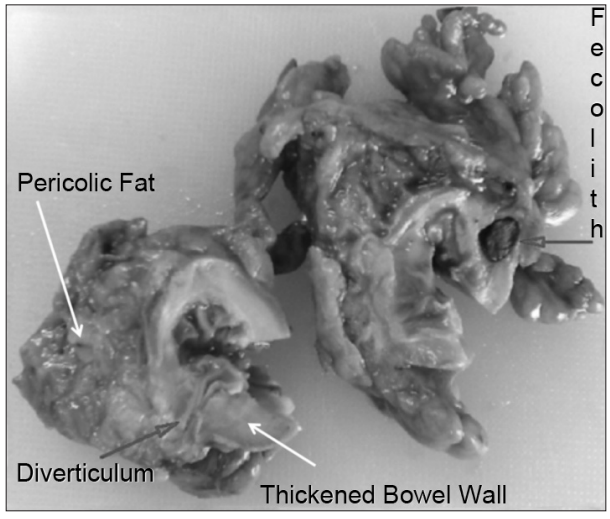


Figure 7. Pathologic specimen showing a thickened bowel wall, pericolic fat, and outpouchings of the colon (gray arrows), one of which contains a fecolith.



Conclusions

Sonography is safe, widely available, easily accessible, portable, and affordable, and it enables the visualization of the entire gastrointestinal tract. In addition, with the simultaneous, instantaneous ability to interpret both clinical and sonographic findings, it facilitates rapid and accurate diagnoses in trained hands. As such, and with the application of "sound judgment," sonography becomes the first-line modality for the diagnosis of diverticulitis. As Parente et al[34] so elegantly stated: "the availability of dedicated bowel sonographers is therefore advisable in all gastrointestinal referral centers in which large numbers of patients are seen, and the technique should be regarded as a natural extension of the physical examination."

Table 1. Test Accuracy of Ultrasound Studies

	Patients With Diverticulitis		Patients Without Diverticulitis					
Study, Year	**TP**	**FN**	**TN**	**FP**	**Sensitivity[a]**	**Specificity[a]**	**Positive Likelihood Ratio[a]**	**Negative Likelihood Ratio[a]**
Ultrasound								
Verbanck, 1989[30]	44	8	57	14	0.85 (44/52)	0.80 (57/71)	4.3 (0.85/0.20)	0.19 (0.15/0.80)
Schwerk, 1993[29]	73	1	84	3	0.99 (73/74)	0.97 (84/87)	28.6 (0.99/0.03)	0.01 (0.01/0.97)
Zielke, 1997[31]	62	12	64	5	0.84 (62/74)	0.93 (64/69)	11.6 (0.84/0.07)	0.17 (0.16/0.93)
Pradel, 1997[32]	28	5	26	5	0.85 (28/33)	0.84 (26/31)	5.3 (0.85/0.16)	0.18 (0.15/0.84)
Garcia-Aguayo, 2002[34]	42	10	19	5	0.81 (42/52)	0.79 (42/52)	3.9 (0.81/0.20)	0.24 (0.19/0.79)
Farag Soliman, 2004[33]	43	0	20	0	1.00 (43/43)	1.00 (43/43)	NA	NA
Summary estimate (95% CI)[b]					**0.92 (80–97)**	**0.90 (82–95)**		
Summary likelihood ratio (95% CI)[b]							**9.6 (5.0–18.6)**	**0.09 (0.04–0.23)**
Computed tomography								
Cho, 1990[35]	25	2	29	0	0.93 (25/27)	1.00 (29/29)	NA	0.07 (0.07/1.00)
Doringer, 1990[36]	20	1	9	3	0.95 (20/21)	0.75 (9/12)	3.8 (0.95/0.25)	0.06 (0.05/0.75)
Pradel, 1997[32]	30	3	24	7	0.91 (30/33)	0.77 (24/31)	4.0 (0.91/0.23)	0.12 (0.09/0.77)
Stefansson, 1997[37]	36	16	36	0	0.69 (36/52)	1.00 (36/36)	NA	0.31 (0.31/1.00)
Rao, 1998[38]	62	2	86	0	0.97 (62/64)	1.00 (86/86)	NA	0.03 (0.03/1.00)
Werner, 2003[39]	65	2	52	1	0.97 (65/67)	0.98 (52/53)	51.4 (0.97/0.02)	0.03 (0.03/0.98)
Farag Soliman, 2004[33]	42	1	20	0	0.98 (42/43)	1.00 (20/20)	NA	0.02 (0.02/1.00)
Tack, 2005[40]	36	3	70	1	0.92 (36/39)	0.99 (70/71)	65.5 (0.92/0.01)	0.08 (0.08/0.99)
Summary estimate (95% CI)[b]					**0.94 (87–97)**	**0.99 (90–100)**		
Summary likelihood ratio (95% CI)[b]							**78.4 (8.7–706.6)**	**0.06 (0.03–0.13)**

Reproduced with permission from Laméris et al[32]; reference citations indicate references therein, CI indicates confidence interval; FN, false negative; FP, false positive; NA, not available; TN, true negative; and TP, true positive.

[a]Individual study sensitivity, specificity, and the likelihood ratios were calculated from the raw data of the individual studies.

[b]Mean summary estimates of sensitivity, specificity, and the summary likelihood ratios were calculated from the results of bivariate random effects analysis.

Table 2. Sensitivity and Specificity of Sonography in ACD

Study	Year	Cases, n	Sensitivity, %	Specificity, %
Verbanck et al[26]	1989	123	85	80
Wilson and Toi[25]	1990	54	85	—
Hollerweger et al[15]	2000	102	77	99
Moll et al[33]	2002	247	76	97
Ripollés et al[30]	2003	203	94	98
Parente et al[34]	2003	336	85	95
Laméris et al[32]	2008	630	92	90

References

1. Vijayaraghavan SB. High-resolution sonographic spectrum of diverticulosis, diverticulitis, and their complications. *J Ultrasound Med* 2006; 25:75–85.
2. Puylaert JB. Ultrasound of colon diverticulitis. *Dig Dis* 2012; 30:56–59.
3. Stoker J, van Randen A, Laméris W, Boermeester M. Imaging patients with acute abdominal pain. *Radiology* 2009; 253:31–46.
4. Ferzoco LB, Raptopoulos V, Silen W. Acute diverticulitis. *N Engl J Med* 1998; 338:1521–1526.
5. Stollman N, Raskin JB. Diverticular disease of the colon. *Lancet* 2004; 363:631–639.
6. Jacobs DO. Clinical practice: diverticulitis. *N Engl J Med* 2007; 357:2057–2066.
7. Laurell H, Hansson LE, Gunnarsson U. Acute diverticulitis: clinical presentation and differential diagnostics. *Colorectal Dis* 2007; 9:496–501.
8. Freeman SR, McNally PR. Diverticulitis. *Med Clin North Am* 1993; 77:1149–1167.
9. Heverhagen JT, Zielke A, Ishaque N, Bohrer T, El-Sheik M, Klose KJ. Acute colonic diverticulitis: visualization in magnetic resonance imaging. *Magn Reson Imaging* 2001; 19:1275–1277.
10. Ambrosetti P, Jenny A, Becker C, Terrier F, Morel P. Acute left colonic diverticulitis—compared performance of computed tomography and water-soluble contrast enema: prospective evaluation of 420 patients. *Dis Colon Rectum* 2000; 43:1363–1367.
11. Birnbaum BA, Balthazar EJ. CT of appendicitis and diverticulitis. *Radiol Clin North Am* 1994; 32:885–898.
12. Veidenheimer MC, Berman I, Castro AF, Gallagher DM, Hale HW Jr, Salvati EP. Surgical management of diverticulitis. *Dis Colon Rectum* 1981; 24:65–72.
13. Snyder MJ. Imaging of colonic diverticular disease. *Clin Colon Rectal Surg* 2004; 17:155–162.
14. Schwerk WB, Schwarz S, Rothmund M. Sonography in acute colonic diverticulitis: a prospective study. *Dis Colon Rectum* 1992; 35:1077–1084.
15. Hollerweger A, Rettenbacher T, Macheiner P, Brunner W, Gritzmann N. Sigmoid diverticulitis: value of transrectal sonography in addition to transabdominal sonography. *AJR Am J Roentgenol* 2000; 175:1155–1160.
16. Chaubal N, Dighe M, Shah M, Chaubal J. Sonography of the gastrointestinal tract. *J Ultrasound Med* 2006; 25:87–97.
17. Puylaert JB, Rutgers PH, Lalisang RI, et al. A prospective study of ultrasonography in the diagnosis of appendicitis. *N Engl J Med* 1987; 317:666–669.
18. O'Malley ME, Wilson SR. US of gastrointestinal tract abnormalities with CT correlation. *Radiographics* 2003; 23:59–72.
19. Fleischer AC, Muhletaler CA, James AE Jr. Sonographic assessment of the bowel wall. *AJR Am J Roentgenol* 1981; 136:887–891.
20. Parulekar SG. Sonography of colonic diverticulitis. *J Ultrasound Med* 1985; 4:659–666.
21. Zielke A, Hasse C, Bandorski T, et al. Diagnostic ultrasound of acute colonic diverticulitis by surgical residents. *Surg Endosc* 1997; 11:1194–1197.
22. Anderson DR. The pseudokidney sign. *Radiology* 1999; 211:395–397.
23. Schwerk WB, Wichtrup B, Rothmund M, Rüschoff J. Ultrasonography in the diagnosis of acute appendicitis: a prospective study. *Gastroenterology* 1989; 97:630–639.
24. Pereira JM, Sirlin CB, Pinto PS, Jeffrey RB, Stella DL, Casola G. Disproportionate fat stranding: a helpful CT sign in patients with acute abdominal pain. *Radiographics* 2004; 24:703–715.
25. Wilson SR, Toi A. The value of sonography in the diagnosis of acute diverticulitis of the colon. *AJR Am J Roentgenol* 1990; 154:1199–1202.
26. Verbanck J, Lambrecht S, Rutgeerts L, et al. Can sonography diagnose acute colonic diverticulitis in patients with acute intestinal inflammation? A prospective study. *J Clin Ultrasound* 1989; 17:661–666.
27. Pradel JA, Adell JF, Taourel P, Djafari M, Monnin-Delhom E, Bruel JM. Acute colonic diverticulitis: prospective comparative evaluation with US and CT. *Radiology* 1997; 205:503–512.
28. Ambrosetti P, Grossholz M, Becker C, Terrier F, Morel P. Computed tomography in acute left colonic diverticulitis. *Br J Surg* 1997; 84:532–534.
29. Rao PM, Rhea JT, Novelline RA, et al. Helical CT with only colonic contrast material for diagnosing diverticulitis: prospective evaluation of 150 patients. *AJR Am J Roentgenol* 1998; 170:1445–1449.
30. Ripollés T, Agramunt M, Martinez MJ, Costa S, Gómez-Abril SA, Richart J. The role of ultrasound in the diagnosis, management and evolutive prognosis of acute left-sided colonic diverticulitis: a review of 208 patients. *Eur Radiol* 2003; 13:2587–2595.
31. Hollerweger A, Macheiner P, Rettenbacher T, Brunner W, Gritzmann N. Colonic diverticulitis: diagnostic value and appearance of inflamed diverticula—sonographic evaluation. E*ur Radiol* 2001; 11:1956–1963.
32. Laméris W, van Randen A, Bipat S, Bossuyt PM, Boermeester MA, Stoker J. Graded compression ultrasonography and computed tomography in acute colonic diverticulitis: meta-analysis of test accuracy. *Eur Radiol* 2008; 18:2498–2511.
33. Moll R, Mittelkötter U, Reith HB, Schindler G, Thiede A. Which imaging in case of sigmoid diverticulitis? The value of ultrasound (conventional B-mode in combination with hydrocolon sonography and colour flow Doppler) in comparison to the well-established modalities like contrast enema and helical computer tomography [in German]. *Zentralbl Chir* 2002; 127:279–301.
34. Parente F, Greco S, Molteni M, et al. Role of early ultrasound in detecting inflammatory intestinal disorders and identifying their anatomical location within the bowel. *Ailment Pharmacol Ther* 2003; 18:1009–1016.
35. van Randen A, Laméris W, van Es HW, et al. A comparison of the accuracy of ultrasound and computed tomography in common diagnoses causing acute abdominal pain. *Eur Radiol* 2011; 21:1535–1545.
36. Pines JM. Trends in the rates of radiography use and important diagnoses in emergency department patients with abdominal pain. *Med Care* 2009; 47:782–786.
37. Brenner DJ, Hall EJ. Computed tomography: an increasing source of radiation exposure. *N Engl J Med* 2007; 357:2277–2284.
38. Destigter KK, Keating DP. Imaging update: acute colonic diverticulitis. *Clin Colon Rectal Surg* 2009; 22:147–155.
39. Benacerraf BR. Why has computed tomography won and ultrasound lost the market share of imaging for acute pelvic imaging in the female patient? *J Ultrasound Med* 2010; 29:327–328.
40. Berrington de González A, Mahesh M, Kim KP, et al. Projected cancer risks from computed tomographic scans performed in the United States in 2007. *Arch Intern Med* 2009; 169:2071–2077.