Radiology

ORIGINAL RESEARCH ■ GASTROINTESTINAL IMAGING

Pregnant Patients Suspected of Having Acute Appendicitis: Effect of MR Imaging on Negative Laparotomy Rate and Appendiceal Perforation Rate[1]

Ivan Pedrosa, MD
Michelle Lafornara, MD
Pari V. Pandharipande, MD
Jeffrey D. Goldsmith, MD
Neil M. Rofsky, MD

Purpose: To investigate the effect of magnetic resonance (MR) imaging on the negative laparotomy rate (NLR) and the perforation rate (PR) in pregnant patients suspected of having acute appendicitis (AA) and to assess the need for computed tomography (CT) in this setting.

Materials and Methods: The data of 148 consecutive pregnant patients (mean age, 29 years; age range, 15–42 years; mean gestational age, 20 weeks; gestational age range, 4–37 weeks) who were clinically suspected of having AA and examined with MR imaging between March 2002 and August 2007 were retrospectively analyzed in an institutional review board–approved HIPAA-compliant protocol. One hundred forty patients underwent ultrasonography (US) before MR imaging. The clinical and laboratory data and the findings of the initial US and MR image interpretations were recorded and analyzed at Student *t* and Fisher exact testing. The NLR and PR were calculated.

Results: Fourteen (10%) patients had AA, and perforation occurred in three (21%) of them. US results were positive for AA in five (36%) patients with proved AA. MR results were positive in all 14 patients with AA. MR results were negative in 125 of the 134 patients without AA; there were nine false-positive cases (two positive, seven inconclusive). Among the patients without AA, the normal appendix could be visualized on US images in less than 2% (two of 126) of cases and on MR images in 87% (116 of 134) of cases ($P < .0001$). Twenty-seven (18%) patients underwent surgical exploration, and eight of them had negative laparotomy results, yielding an NLR of 30% and a PR of 21% (three of 14 patients). Only four (3%) patients underwent CT.

Conclusion: For pregnant patients clinically suspected of having AA, use of MR imaging yields favorable combinations of NLR and PR compared with previously reported values. The radiation exposure associated with CT examination can be avoided in most cases.

© RSNA, 2009

[1] From the Departments of Radiology (I.P., N.M.R.), Obstetrics and Gynecology (M.L.), and Pathology (J.D.G.), Beth Israel Deaconess Medical Center, Harvard Medical School, One Deaconess Road, Boston, MA 02215; and Department of Radiology, Massachusetts General Hospital, Harvard Medical School, Boston, Mass (P.V.P.). Received June 18, 2008; revision requested July 18; revision received August 11; accepted September 26; final version accepted October 6. **Address correspondence to** I.P. (e-mail: *ipedrosa@bidmc.harvard.edu*).

The differential diagnosis of abdominal pain in pregnant patients is broad and includes surgery-requiring and non–surgery-requiring conditions (1). During pregnancy, acute appendicitis (AA) is the most common cause of abdominal pain necessitating surgical treatment; however, it has a relatively low prevalence—similar to that in the general population: 0.02%–0.07% (2–4). Differentiating AA from other, non–surgery-requiring conditions may be very challenging and can lead to delayed treatment with associated complications (3,5).

Negative laparotomy rate (NLR) and perforation rate (PR) are commonly accepted outcome indicators in the setting of clinically suspected AA. Prior to the imaging era, an NLR of nearly 20% in nonpregnant patients had been advocated to avoid an unacceptably high PR (6–8). Computed tomography (CT) can have a favorable effect on the NLR without the sacrifice of an increased PR, particularly in the more challenging population of patients of childbearing age (8–11). However, the radiation exposure is undesirable.

The accepted NLR and PR for pregnant patients are higher than those for the general population owing to the lack of specificity of the signs and symptoms of appendicitis in these patients, which hinders the accurate preoperative diagnosis (5,11,12).

Because of its wide availability and lack of ionizing radiation, ultrasonography (US) performed with a graded compression technique has been favored for examining pregnant patients with abdominal pain (13). However, the limitations of this technique include difficulty compressing the cecum with the US probe, particularly in the third trimester of pregnancy (13), and limited visualization of the normal appendix (in 0%–4% of cases, even in nonpregnant patients) (14–16). Despite the wide acceptance of US, to our knowledge, there are limited data on the effects of US on the surgical outcomes of pregnant patients suspected of having AA. Furthermore, a recent report did not reveal a lower NLR in pregnant patients who were examined with US compared with that in pregnant patients who underwent clinical examination only (11).

CT is often performed for evaluation of AA in nonpregnant and nonpediatric patients (17). The use of CT in pregnant patients is variable and usually reserved for those with inconclusive US results (11,18). Abdominal and pelvic CT is frequently avoided during pregnancy because of the associated risk of radiation to the mother and the fetus.

Magnetic resonance (MR) imaging has been advocated as an alternative to CT for examining pregnant patients clinically suspected of having AA (19–21). The sensitivity, specificity, and negative predictive values of MR imaging reported in a small series of pregnant patients with right-sided abdominal pain support the use of MR imaging to accurately rule out AA (21). However, to our knowledge, the effects of MR imaging on the surgical outcomes in a large series of pregnant patients have not been reported. Thus, the aim of our study was to assess the effects of MR imaging in the examination of a relatively large series of pregnant patients clinically suspected of having AA by using the NLR and the PR as objective measures of outcome and to assess the need for CT in this setting.

Advances in Knowledge

- In the pregnant patients without acute appendicitis (AA), the rate of visualization of the normal appendix at MR imaging (87%) was significantly higher than that at US (<2%) ($P < .0001$).
- For pregnant patients suspected of having AA, unnecessary laparotomies can be avoided when the normal appendix is identified at MR imaging.

Implications for Patient Care

- MR imaging has the potential to help reduce the negative laparotomy rate while maintaining an acceptable perforation rate in pregnant patients clinically suspected of having AA.
- CT-associated radiation exposure can be markedly reduced by using MR imaging for examinations in this patient population.

Materials and Methods

Study Patients

We searched the radiology and surgery databases of the Department of Obstetrics and Gynecology, Beth Israel Deaconess Medical Center, to identify all pregnant patients who underwent MR imaging for clinically suspected AA between April 2002 and June 2007. This search yielded 152 records, which were retrospectively reviewed by one of the authors (M.L.); 49 of these cases were previously reported (21). Three patients whose clinical charts were not available and one patient who prematurely stopped participating in the study were excluded. Therefore, a total of 148 patients formed the final study group. This Health Insurance Portability and Accountability Act–compliant study was approved by the Committee on Clinical Investigations of Beth Israel Deaconess Medical Center. The requirement for informed patient consent was waived owing to the retrospective nature of the study.

Imaging Protocols

One hundred forty of the 148 patients underwent US before undergoing MR imaging. An abdominal imaging attend-

Published online
10.1148/radiol.2503081078

Radiology 2009; 250:749–757

Abbreviations:
AA = acute appendicitis
NLR = negative laparotomy rate
PR = perforation rate

Author contributions:
Guarantors of integrity of entire study, I.P., N.M.R.; study concepts/study design or data acquisition or data analysis/interpretation, all authors; manuscript drafting or manuscript revision for important intellectual content, all authors; manuscript final version approval, all authors; literature research, I.P., N.M.R.; clinical studies, I.P., M.L., J.D.G., N.M.R.; experimental studies, M.L.; statistical analysis, I.P., P.V.P.; and manuscript editing, I.P., P.V.P., J.D.G., N.M.R.

Authors stated no financial relationship to disclose.

ing or on-call radiology resident performed the US examinations by using the graded compression technique (22). US results were documented as positive, negative, or inconclusive for AA on the basis of information gleaned from the prospectively interpreted initial report. The number of US examinations at which the appendix was identified was tabulated. Four patients underwent abdominopelvic CT before (n = 1) or after (n = 3) MR imaging at admission for assessment of the appendiceal abnormality.

As part of standard clinical practice, informed consent was obtained from all patients before they underwent MR imaging. MR imaging was performed with the patient in the supine position and by using 1.5-T systems (Siemens Vision, Siemens Medical Systems, Iselin, NJ; Excite TwinSpeed, GE Medical Systems, Waukesha, Wis) and a surface phased-array coil. The MR protocol included the acquisition of axial, coronal, and sagittal T2-weighted half-Fourier single-shot fast spin-echo images (800–1100/60 [repetition time msec/echo time msec], 4-mm section thickness with 1-mm intersection gap, matrix of 192 × 256, 130°–155° flip angle, 62.5-kHz bandwidth, 35–40-cm field of view); axial T2-weighted single-shot fast spin-echo images obtained by using the parameters applied for half-Fourier imaging but with frequency-selective fat saturation; axial time-of-flight T2*-weighted images (30/minimum full, 45° flip angle, 3-mm section thickness with 1-mm intersection gap, matrix of 256 × 128, 31-kHz bandwidth, 35-cm field of view); and axial T1-weighted in-phase and opposed-phase images (205/2.2 or 4.5, 80° flip angle, 5-mm section thickness with 2-mm intersection gap, matrix of 160 × 256, 35-cm field of view). A radiologist monitored the examinations during the time of image acquisition to ensure adequate coverage of the area of interest. The entire MR protocol took approximately 30–45 minutes to complete.

To mark the bowel lumen with low-signal-intensity material, an oral contrast agent preparation consisting of a combination of 450 mL of ferumoxsil (Gastromark; Mallinckrodt Medical, St Louis, Mo) and 300 mL of a 2% barium sulfate suspension (Readi-Cat 2; E-Z-Em Canada, Westbury, NY) was administered 1.0–1.5 hours before MR imaging. To visualize the oral contrast agent in the cecum, the monitoring radiologist performed delayed repeat imaging in three patients. In one patient, rectal air was instilled to distend the cecum in an attempt to fill the appendix. Intravenous contrast material was not administered.

MR Image Interpretation

The initial MR image interpretations were performed by any of five MR fellowship-trained attending radiologists (including I.P. and N.M.R.), who had 1–25 years experience interpreting abdominal MR images. In general, the appendix was considered normal when its diameter was equal to or less than 6 mm and/or it was filled with oral contrast material and/or air. The appendix was considered normal in the absence of intraluminal fluid and in the presence of a blooming effect throughout its length, which was caused by magnetic susceptibility on T2*-weighted images and representing air and/or oral contrast material (21,23). Variations in the size and appearance of the normal appendix are not uncommon (24), and appendicitis can manifest in normal-sized appendices (25). Thus, the radiologist rendered a diagnosis on the basis of the described guidelines and a subjective interpretation of the MR imaging findings.

A dilated appendix (>7 mm in diameter) with high-signal-intensity fluid seen filling its lumen on T2-weighted MR images was considered positive for appendicitis. Periappendiceal fat stranding, seen as thin linear collections of high-signal-intensity fluid within the periappendiceal fat on single-shot fast spin-echo MR images was considered to be indicative of AA. A 6–7-mm-diameter appendix without evidence of oral contrast material or air in its lumen was considered an indeterminate finding; in such cases, the presence or absence of ancillary findings—for example, periappendiceal fat stranding and/or abscess—was used to render a diagnosis.

MR Data Recording

The initial diagnosis used to plan patient care was prospectively recorded as positive, negative, or inconclusive for appendicitis. Early in the series, inconclusive diagnoses were rendered in those patients in whom the appendix was not visualized and in those in whom inflammatory changes were absent. Later in the series, as radiologic experience increased, this constellation of findings was interpreted as negative for appendicitis (26,27). The number of pregnant patients in whom the appendix was visualized on MR images was tabulated. MR-based diagnoses of alternative surgery-requiring abnormalities were also recorded.

Data Collection

The demographic, physical examination, and laboratory data obtained at presentation (ie, location of abdominal pain, white blood cell count, percentage of polymorphonuclear leukocytes, and body temperature) (Tables 1, 2); the initial interpretations of the MR findings; and the surgical, pathologic, and clinical follow-up findings were collected by two authors (M.L., I.P.).

The reference standards for the final diagnosis of AA in 14 patients were surgical and pathologic findings in 13 cases and confirmatory CT results in one case—that of a patient with tip appendicitis that improved after antibiotic therapy. The reference standards for the final diagnosis in 120 of the 134 patients without appendicitis were clinical follow-up findings in 112 cases and surgical and/or pathologic findings in eight. The median clinical follow-up period for the 112 patients who did not undergo surgery was 7 days (range, 2 days to 15 months). The medical records of all of these patients were reviewed to obtain follow-up information on additional visits, possible readmission for similar signs and symptoms, and/or surgery performed outside our institution. Fourteen patients were discharged within the first 24 hours after admission owing to improved symptoms, and no further follow-up data were available.

Pathologic Analysis

A single gastrointestinal pathologist (J.D.G.) who had 6 years experience in gastrointestinal pathology and was unaware of the MR findings retrospectively reviewed all of the pathologic data and assigned each appendix specimen to one of the following categories: *(a)* normal, *(b)* AA limited to the wall of the appendix, *(c)* AA with periappendicitis, *(d)* severe transmural AA with periappendicitis, *(e)* gangrenous AA, or *(f)* AA with abscess formation. The presence of gangrenous AA and/or AA with abscess formation was considered positive for appendiceal perforation.

Statistical Analyses

We assessed the patient demographic and clinical data, including maternal age, gestational age, white blood cell count, percentage of polymorphonuclear leukocytes, and body temperature, by computing the mean values (with standard deviations) for the patients with and those without appendicitis and comparing these values between the two patient groups at Student *t* testing. The test performance characteristics (ie, sensitivity, specificity, and positive and negative predictive values) of US and MR imaging in the diagnosis of AA were calculated. The rates of visualization of the normal appendix at US and MR imaging in the patients without AA were compared by using the Fisher exact test. Statistical analyses were performed by using Statistical Analysis System, version 9.1.3, software (SAS Institute, Cary, NC). $P < .05$ was considered to indicate a significant difference.

Results

Of the 148 pregnant patients who were clinically suspected of having AA and underwent abdominal MR imaging during the study period, 14 had AA and 134 did not. The demographic and laboratory data for both the patients with and those without AA are presented in Table 1.

Differences in mean values for maternal age, gestational age, body temperature, and white blood cell count between the patients with and those without AA were not significant ($P > .05$) (Table 1). The mean percentage of polymorphonuclear leukocytes in the patients with AA (83.8%) was significantly higher than that in the patients without AA (78.3%) ($P = .002$).

The right lower quadrant was the most common location of the abdominal pain (in 65 [44%] patients) (Table 2). The classic manifestation of periumbilical pain that later radiated to the right lower quadrant was associated with AA in only four (40%) of the 10 patients who presented with this symptom.

Values of the diagnostic performance of US and MR imaging are shown in Table 3. One hundred forty patients underwent US before undergoing MR imaging. US findings were positive for AA in five (36%) of the 14 patients with proved AA. In seven (50%) of the 14 patients with AA, the US findings were interpreted as normal. In the remaining two patients, the appendix was seen on the US images but deemed to be inconclusive for the diagnosis of AA. Indeterminate US findings were recorded as false-negative.

Four (3%) patients underwent abdominopelvic CT at admission to assist in the evaluation for AA. One patient, who underwent MR imaging 2 hours after CT owing to persistent pain, had false-negative CT findings. A diagnosis of AA was made on the basis of the MR results and was subsequently confirmed at surgery and pathologic analysis. CT findings confirmed the tip AA initially seen at MR imaging in one patient, who subsequently showed clinical improvement following antibiotic therapy. MR findings were positive for AA in one patient with atypical abdominal pain; this diagnosis was confirmed at CT and pathologic analysis. The fourth patient, who did not have AA, underwent CT after MR imaging yielded negative results, and the results were negative for AA.

The MR images of all 14 patients proved to have AA were interpreted as positive for the disease (Fig 1). Among nine patients without appendicitis, the MR findings were interpreted as positive for AA in two and as inconclusive in seven patients. These nine (6%) patients were recorded as having false-positive MR findings. The inconclusive

Table 1

Patient Demographic and Laboratory Results

Characteristic	All Patients (n = 148)*	Patients with AA (n = 14)*	Patients without AA (n = 134)*	*P* Value
Age (y)	29 ± 5.9	30.1 ± 4.3	28.9 ± 6	.47
Gestational age (wk)	19.8 ± 8.7	21.9 ± 8.1	19.6 ± 8.7	.34
WBC ($10^3/\mu L$)†	12.7 ± 4.4	14.6 ± 4.2	12.5 ± 4.4	.09
Percentage of PMLs‡	78.9 ± 9.9	83.8 ± 4.9	78.3 ± 10.2	.002§
Body temperature (degrees)‖	98.5 ± 1.1	98.8 ± 1.1	98.5 ± 1.1	.33

* Mean ± the standard deviation.

† White blood cell count (WBC) was taken in 144 of the 148 patients: all 14 patients with AA and 130 of the 134 patients without AA.

‡ Percentage of polymorphonuclear leukocytes (PMLs) was determined in 136 of the 148 patients: all 14 patients with AA and 122 of the 134 patients without AA.

§ Difference between AA and no AA groups was significant.

‖ Body temperature was measured in 146 of the 148 patients: all 14 patients with AA and 132 of the 134 patients without AA.

Table 2

Locations of Abdominal Pain

Location of Pain	AA (n = 14)	No AA (n = 134)
Right lower quadrant	6	59
Periumbilical, radiating to right lower quadrant	4	6
Right side	2	28
Right upper quadrant	2	9
Pelvic	0	18
Diffuse	0	9
Left lower quadrant	0	3
Epigastric	0	2

Note.—Data are numbers of patients.

Table 3

Diagnostic Accuracy of US and MR Imaging

Findings	Patients with AA ($n = 14$)*	Patients without AA ($n = 134$)*	Sensitivity†	Specificity†	PPV†	NPV†
US			36 (5/14)	99 (125/126)	83 (5/6)	93 (126/135)
Positive for AA	5	1	. . .	. . .	. . .	. . .
Negative for AA	9	125	. . .	. . .	. . .	. . .
MR			100 (14/14)	93 (125/134)	61 (14/23)	100 (125/125)
Positive for AA	14	9	. . .	. . .	. . .	. . .
Negative for AA	0	125	. . .	. . .	. . .	. . .

Note.—US was performed in 140 patients, and MR imaging was performed in all 148 patients. NPV = negative predictive value, PPV = positive predictive value.

* Data are numbers of patients.

† Data are percentages. The numbers used to calculate the percentages are in parentheses.

Figure 1

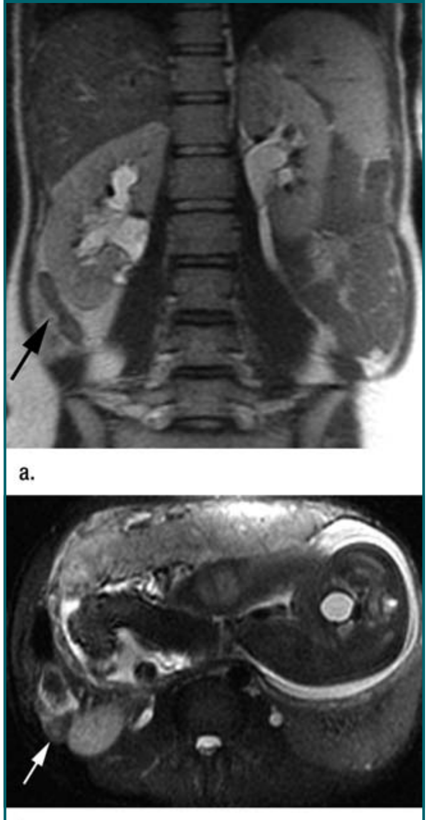


Figure 1: **(a)** Coronal and **(b)** fat-saturated axial MR images (T2-weighted single-shot fast spin-echo sequence, 1100/60, 130° flip angle, 40-cm [coronal] or 35-cm [axial] field of view) in 28-year-old woman at 32 weeks gestation who presented with right upper quadrant pain and fever show enlarged fluid-filled appendix (arrow) consistent with AA, which was confirmed at surgery and pathologic analysis. Note the superior displacement of the appendix, which is immediately lateral to the lower pole of the right kidney. Findings on right lower quadrant US image acquired before MR imaging were normal.

cases consisted of four cases of a borderline enlarged (ie, 6–7-mm) appendix, two cases of a normal-sized (ie, <6 mm) fluid-filled appendix (none with periappendiceal inflammation), and one case of an appendix that could not be visualized. One patient with positive MR results and five with indeterminate MR findings (Fig 2) were treated conservatively because their symptoms improved shortly after they underwent MR imaging.

There were no false-negative MR findings, although a radiology attending physician initially interpreted the MR findings in one patient with AA as negative. When the MR images were additionally reviewed by a more experienced attending physician because of persistent symptoms, a positive diagnosis was rendered 10 hours after the initial review and prompted the surgical exploration. Perforated AA was confirmed at surgery and pathologic analysis.

An appendix was seen at US in nine (6%) of 140 patients: seven with and two without AA (one erroneously deemed to have AA). An appendix was seen at MR imaging in 130 (88%) of 148 patients: 14 with and 116 without AA. Overall, the rate of visualization of a normal appendix in patients without AA at MR imaging (87% [116 of 134 patients]) was significantly higher than that at US (<2% [two of 126 patients]) ($P < .0001$) (Fig 3).

Twenty-eight (19%) of the 148 patients underwent surgery. In one patient, a prolapsed ureterocele was seen at US and MR imaging and was subsequently excised at cystoscopy. Twenty-seven patients underwent exploratory laparotomy ($n = 13$) or laparoscopy ($n = 14$) (Table 4), and AA was confirmed in 13 (48%) of them. In four patients, the MR findings were reported as suspicious for ovarian torsion, which was confirmed at surgery in all of these patients. In one patient, the MR findings were consistent with ectopic pregnancy, which was confirmed at laparoscopy. MR imaging failed to depict the appendix in one patient with appendiceal endometriosis (without appendicitis) at pathologic analysis.

Overall, eight of 27 patients underwent surgical exploration that yielded negative results, yielding an NLR of 30%. The MR findings were reported as positive for AA in one of these patients and as indeterminate in two (one patient with a borderline enlarged appendix and one with a nonvisualized appendix and no inflammatory changes). In the remaining five patients, the results of surgical exploration, performed despite negative MR findings because of continued clinical suspicion, were negative. The MR report for three of these patients indicated a normal appendix.

Pathologic evaluation revealed uncomplicated AA in seven patients, AA with periappendicitis in three patients, gangrenous AA in two patients, and AA with abscess formation in one patient. Thus, with inclusion of the patient with tip appendicitis who was treated with antibiotics, the PR was 21% (three of 14 patients).

If the decision to avoid exploratory laparotomy had been based on negative MR findings (ie, normal appendix seen or appendix not visualized, with no inflammatory changes), then the NLR would have been 7% (two of 27 patients), while the PR would have remained 21%.

Discussion

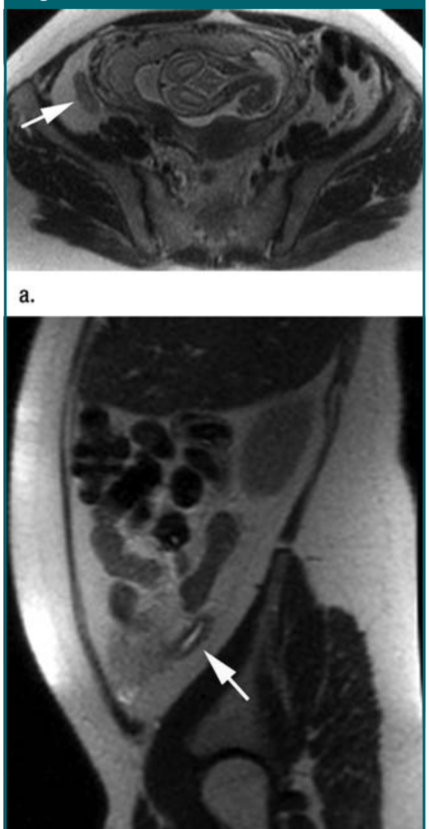
For all patients suspected of having AA, the uncertainties in making a correct diagnosis must be balanced with the imperative for early treatment to minimize morbidity and mortality. This balance has necessitated a tolerance for surgeries that yield negative results (6,8). The circumstances of pregnant patients in this clinical scenario are further complicated by physiologic and pathologic considerations that reduce the specificity of the presenting signs and symptoms (1,28). For example, we noted the classic pain symptoms in 10 patients, only four of whom were found to have appendicitis. Despite the significant difference in the percentage of polymorphonuclear leukocytes observed between patients with and those without AA, the substantial elevation and overlap of values in the two groups remain problematic (2,5). Furthermore, the welfare of the fetus—particularly in terms of the increased mortality associated with maternal appendiceal perforation—represents a vital concern (5,28). Together, these complicating factors have resulted in accepted NLRs and PRs as high as 25%–50% (2,5) and 22%–57% (8,12,28,29), respectively, in this patient population.

The NLR of 30% that we achieved by using MR imaging in pregnant patients was higher than the NLR of 8.3% achieved by Balthazar et al (8) by using CT in nonpregnant patients of childbearing age. It is important to point out that if the decision not to perform surgical exploration had been based on negative MR findings, then our adjusted NLR would have been 7%, which is almost equivalent to the NLR reported by Balthazar et al. This NLR is also close to that achieved by Tracey and Fletcher (5%) (12). However, our PR of 21% is quite favorable compared with the PR of 55% reported by Tracey and Fletcher and close to the PR of 19% reported by Balthazar et al (8).

In addition to facilitating an accurate diagnosis of appendicitis in the general population (8,10,30), CT can assist in the diagnosis of appendicitis in patients of childbearing age (8,31) and pregnant patients (11,18). However, a foremost concern for the pregnant patient is the radiation exposure to the mother and the fetus, with the associated small but pertinent risk of malignancy (32,33). The radiation dose to the fetus from a routine abdominopelvic CT examination is approximately 25 mGy (34). Although the risk from radiation doses of less than 50 mGy (5 rads) has been reported to be negligible (34,35), the increase over background incidence for organ malformation and development of childhood cancer associated with doses of 100 mGy or higher is 1% (34). The radiation-exposed fetus has substantial time for radiation-induced cancer to develop (32). Thus, it seems prudent to provide alternative imaging strategies for pregnant patients suspected of having AA.

US has had variable results in the diagnosis of AA in pregnant patients (12,13,19,36), which are probably reflective of the operator-dependent na-

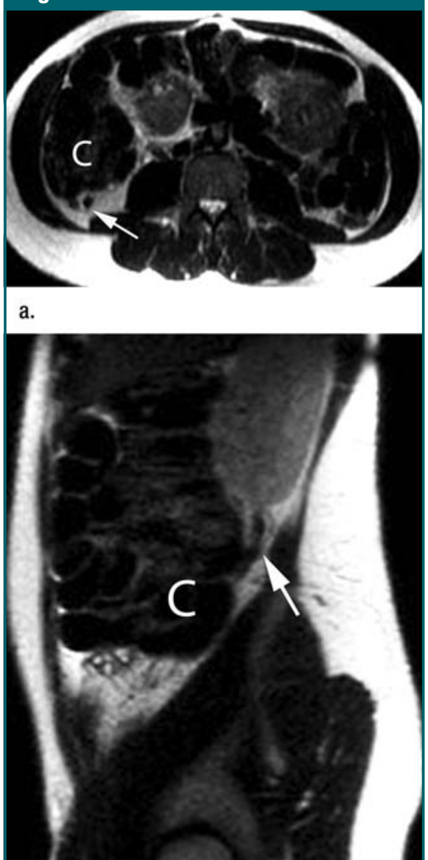
Figure 2



a. b.

Figure 2: **(a)** Axial and **(b)** sagittal T2-weighted single-shot fast spin-echo MR images (1100/60, 130° flip angle, 35-cm [axial] or 40-cm [sagittal] field of view) in 36-year-old woman at 19 weeks gestation with right lower quadrant pain show an abnormal thick-walled and enlarged (10-mm) distal appendix (arrow) without periappendiceal inflammation. **(b)** More proximally, the appendix is fluid filled and thick walled, but the periappendiceal fat is normal. These findings were interpreted as inconclusive for AA. Patient's symptoms improved shortly after the MR examination, without surgical intervention.

Figure 3



a. b.

Figure 3: **(a)** Axial and **(b)** sagittal T2-weighted single-shot fast spin-echo MR images (1100/60, 130° flip angle, 35-cm [axial] or 40-cm [sagittal] field of view) in 34-year-old woman at 18 weeks gestation with nausea, vomiting, and right lower quadrant pain show normal-sized (5-mm) retrocecal appendix (arrow). Prior US findings were normal, although the appendix was not visualized. Patient's symptoms improved with conservative treatment. *C* = cecum.

ture of this procedure. Furthermore, the negative predictive value of a nonvisualized appendix at US is, at best, 90% (13,37). Further limitations to the negative predictive value of US are related to the restricted capability of this examination to depict the normal appendix (11,22,38), even when it is performed by expert sonographers (19). This limits the clinically relevant negative predictive value. A negative US image interpretation is based predominantly on the absence of findings positive for appendicitis rather than on the identification of a normal appendix. This can leave the surgeon with an ambiguous result on which to base treatment decisions.

In our study, a normal appendix was seen at US in fewer than 2% of the patients without AA; in contrast, the rate of visualization of the normal appendix at MR imaging in this group was 87%. These rates are similar to previously reported rates of visualization of the normal appendix with US (14–16) and MR imaging (39) and extend the reported experiences with our initial cohort of 51 patients (21). The improved visualization of the normal appendix with MR imaging is a major attribute that assists in clinical decision making.

The visualization of a normal appendix on MR images virtually excludes the diagnosis of appendicitis. In our series, three of the eight negative-result laparotomies were performed in patients in whom a normal appendix was identified at MR imaging. We expect further decreases in the NLR as surgeons and obstetricians become more aware of the negative predictive value of a normal appendix visualized at MR imaging and gain confidence in the diagnostic usefulness of this finding.

The administration of oral contrast material facilitates identification of the normal appendix and reduces the number of false-positive CT image interpretations (40). The time required for CT imaging, however, has been critiqued as a potential cause of delayed diagnoses and increased complications (41,42). However, despite the lengthened stay in the emergency department with use of oral and intravenous contrast material–enhanced CT, Riesenman et al reported no adverse effect on PRs in nonpregnant patients suspected of having AA (43). Similarly, the PR that we reported with use of an oral MR contrast agent should mitigate such concern.

MR imaging without oral contrast material enhancement has been used successfully to evaluate AA in pregnancy (19,20,44–46). In a recent study in which the normal appendix was visualized at MR imaging without oral contrast material enhancement in 52% of cases, the potential benefits of using this procedure were recognized (46).

Early in our series, the nonvisualized appendix without inflammatory changes in one patient was considered inconclusive. This patient underwent

Table 4

Findings at Surgical Abdominal Exploration in 27 Patients

Patient No.	US Finding(s)	MR Finding(s)	Surgery Performed	Surgical Finding(s)
1	Not performed	Right ovarian enlargement	Laparotomy	Right ovarian torsion
2*	AA	AA	Laparotomy	AA with abscess
3	Normal	Normal appendix	Laparoscopy	Negative
4	Normal	AA	Laparoscopy	AA
5	AA	AA	Laparoscopy	AA with periappendicitis
6	Normal	Ectopic pregnancy	Laparoscopy	Ectopic pregnancy
7	Normal	Inconclusive, appendix not seen	Laparotomy	Negative
8	Normal	Bilateral ovarian enlargement (hyperstimulation) with asymmetric right ovarian edema	Laparotomy	Right ovarian torsion
9	Normal	AA	Laparotomy	AA
10	Normal	Right ovarian enlargement and edema	Laparoscopy converted to laparotomy	Right ovarian torsion
11	AA	AA	Laparotomy	AA
12	Normal	AA	Laparoscopy	AA
13	Normal	AA	Laparotomy	AA
14	AA	AA	Laparoscopy	AA
15	Normal	AA	Laparoscopy	Negative
16	Right ovarian enlargement	Right ovarian enlargement and edema	Laparoscopy	Ovarian torsion
17	Normal	Inconclusive, appendix borderline enlarged	Laparoscopy	Negative
18	Normal	AA	Laparoscopy	AA with periappendicitis
19	Normal	Normal appendix	Laparotomy	Negative
20	Indeterminate, possible abnormal appendix	AA	Laparoscopy	Gangrenous AA
21	Indeterminate, possible abnormal appendix	AA	Laparoscopy	AA
22†	Normal	AA	Laparotomy	Gangrenous AA
23	AA	AA	Laparotomy	AA with periappendicitis
24	Normal	Normal, appendix not seen	Laparotomy	Negative
25	Normal	Normal appendix	Laparoscopy	Negative
26	Normal	Normal, appendix not seen	Laparoscopy	Negative
27	Normal	Normal, appendix not seen	Laparotomy	Appendiceal endometriosis

* At initial presentation, patient was at 27 weeks gestation and had right lower quadrant phlegmon. Patient was treated with antibiotics, and laparotomy for appendectomy and cesarean section was performed at 32 weeks gestation.

† Initial MR image interpretation was normal. The MR findings were reviewed again 10 hours later owing to persistent abdominal pain and were interpreted as AA, which prompted surgical exploration.

laparotomy, which yielded negative results. Owing to increasing experience, our strategy has been modified such that we no longer interpret such cases as inconclusive; this is similar to the approach used with CT results (26,27). Given the relatively small numbers of laparotomies that yielded negative results in our series, had this one case been handled with use of our current approach, the NLR would have been reduced by 4%.

Patient tolerance of the MR imaging environment represents an additional concern in terms of successful implementation. Reflective of the feasibility of MR imaging in the emergency setting, only one patient in our series refused to complete the MR protocol. MR imaging involves the use of a static magnetic field, pulsed radiofrequency fields, and time-varying gradient electromagnetic fields to generate images. During the 20 years of experience gained in using MR imaging to evaluate maternal and fetal disorders, there have been, to our knowledge, no reported incidents of harmful effects to the fetus (47,48). Pertinent to our study is the potential for heating effects induced by single-shot fast spin-echo MR imaging. However, the amniotic fluid temperatures in pregnant pigs did not change significantly when the animals were examined with a single-shot fast spin-echo MR imaging protocol similar to ours (49).

Our study had several limitations, including the small number of patients with AA. In addition, the 24-hour, 7-day-a-week availability of the MR system at our facility is not uniform across centers. Such availability is essential for the clinical implementation of MR imaging in the setting of appendicitis. We also recognize the potential for bias that is inherent to any retrospective study. Some US images were acquired and interpreted after hours by residents on call, while all of the MR images were interpreted by attending radiologists; this difference may have led to more favorable MR results. It is also conceivable that some of the 14 patients with negative MR findings and limited clinical follow-up data may have been admitted to other institutions after they were discharged from our hospital. We did not contact patients by phone to inquire about subsequent admissions. The clinical symptoms of all 14 patients had improved or resolved before they were discharged.

In conclusion, when examining pregnant patients for clinically suspected AA, the use of MR imaging yields favorable combinations of the NLR and the PR compared with values previously reported in the literature. With use of MR imaging, the radiation exposure associated with CT examinations can be minimized and in many cases avoided.

References

1. Mayer IE, Hussain H. Abdominal pain during pregnancy. Gastroenterol Clin North Am 1998;27:1–36.

2. Hee P, Viktrup L. The diagnosis of appendicitis during pregnancy and maternal and fetal outcome after appendectomy. Int J Gynaecol Obstet 1999;65:129–135.

3. Mourad J, Elliott JP, Erickson L, Lisboa L. Appendicitis in pregnancy: new information that contradicts long-held clinical beliefs. Am J Obstet Gynecol 2000;182:1027–1029.

4. Bailey LE, Finley RK Jr, Miller SF, Jones LM. Acute appendicitis during pregnancy. Am Surg 1986;52:218–221.

5. Andersen B, Nielsen TF. Appendicitis in pregnancy: diagnosis, management and complications. Acta Obstet Gynecol Scand 1999;78:758–762.

6. Velanovich V, Satava R. Balancing the normal appendectomy rate with the perforated appendicitis rate: implications for quality assurance. Am Surg 1992;58:264–269.

7. Berry J Jr, Malt RA. Appendicitis near its centenary. Ann Surg 1984;200:567–575.

8. Balthazar EJ, Rofsky NM, Zucker R. Appendicitis: the impact of computed tomography imaging on negative appendectomy and perforation rates. Am J Gastroenterol 1998;93:768–771.

9. Bendeck SE, Nino-Murcia M, Berry GJ, Jeffrey RB Jr. Imaging for suspected appendicitis: negative appendectomy and perforation rates. Radiology 2002;225:131–136.

10. Togawa A, Kimura F, Chiku T, Sano W, Tashiro T, Miyazaki M. Simple way to improve accuracy in diagnosis of quadrant inflammatory disease: how to avoid adverse laparotomy by using plain CT. Hepatogastroenterology 2005;52:135–138.

11. Wallace CA, Petrov MS, Soybel DI, Ferzoco SJ, Ashley SW, Tavakkolizadeh A. Influence of imaging on the negative appendectomy rate in pregnancy. J Gastrointest Surg 2008;12:46–50.

12. Tracey M, Fletcher HS. Appendicitis in pregnancy. Am Surg 2000;66:555–559.

13. Lim HK, Bae SH, Seo GS. Diagnosis of acute appendicitis in pregnant women: value of sonography. AJR Am J Roentgenol 1992;159:539–542.

14. Birnbaum BA, Wilson SR. Appendicitis at the millennium. Radiology 2000;215:337–348.

15. Jeffrey RB Jr, Laing FC, Townsend RR. Acute appendicitis: sonographic criteria based on 250 cases. Radiology 1988;167:327–329.

16. 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.

17. Ralls PW, Balfe DM, Bree RL, et al. Evaluation of acute right lower quadrant pain: American College of Radiology—ACR appropriateness criteria. Radiology 2000;215(suppl):159–166.

18. Lazarus E, Mayo-Smith WW, Mainiero MB, Spencer PK. CT in the evaluation of nontraumatic abdominal pain in pregnant women. Radiology 2007;244:784–790.

19. Cobben LP, Groot I, Haans L, Blickman JG, Puylaert J. MRI for clinically suspected appendicitis during pregnancy. AJR Am J Roentgenol 2004;183:671–675.

20. Oto A, Ernst RD, Shah R, et al. Right-lower-quadrant pain and suspected appendicitis in pregnant women: evaluation with MR imaging—initial experience. Radiology 2005;234:445–451.

21. Pedrosa I, Levine D, Eyvazzadeh AD, Siewert B, Ngo L, Rofsky NM. MR imaging evaluation of acute appendicitis in pregnancy. Radiology 2006;238:891–899.

22. Puylaert JB. Acute appendicitis: US evaluation using graded compression. Radiology 1986;158:355–360.

23. Pedrosa I, Zeikus EA, Levine D, Rofsky NM. MR imaging of acute right lower quadrant pain in pregnant and nonpregnant patients. RadioGraphics 2007;27:721–743.

24. Gwynn LK. Appendiceal enlargement as a criterion for clinical diagnosis of acute appendicitis: is it reliable and valid? J Emerg Med 2002;23:9–14.

25. Daly CP, Cohan RH, Francis IR, Caoili EM, Ellis JH, Nan B. Incidence of acute appendi-

citis in patients with equivocal CT findings. AJR Am J Roentgenol 2005;184:1813–1820.

26. Ganguli S, Raptopoulos V, Komlos F, Siewert B, Kruskal JB. Right lower quadrant pain: value of the nonvisualized appendix in patients at multidetector CT. Radiology 2006;241:175–180.

27. Nikolaidis P, Hwang CM, Miller FH, Papanicolaou N. The nonvisualized appendix: incidence of acute appendicitis when secondary inflammatory changes are absent. AJR Am J Roentgenol 2004;183:889–892.

28. McGory ML, Zingmond DS, Tillou A, Hiatt JR, Ko CY, Cryer HM. Negative appendectomy in pregnant women is associated with a substantial risk of fetal loss. J Am Coll Surg 2007;205:534–540.

29. Flum DR, Morris A, Koepsell T, Dellinger EP. Has misdiagnosis of appendicitis decreased over time? a population-based analysis. JAMA 2001;286:1748–1753.

30. in't Hof KH, van Lankeren W, Krestin GP, et al. Surgical validation of unenhanced helical computed tomography in acute appendicitis. Br J Surg 2004;91:1641–1645.

31. Antevil J, Rivera L, Langenberg B, Brown CV. The influence of age and gender on the utility of computed tomography to diagnose acute appendicitis. Am Surg 2004;70:850–853.

32. Brenner DJ, Hall EJ. Computed tomography: an increasing source of radiation exposure. N Engl J Med 2007;357:2277–2284.

33. Hurwitz LM, Yoshizumi T, Reiman RE, et al. Radiation dose to the fetus from body MDCT during early gestation. AJR Am J Roentgenol 2006;186:871–876.

34. McCollough CH, Schueler BA, Atwell TD, et al. Radiation exposure and pregnancy: when should we be concerned? RadioGraphics 2007;27:909–917.

35. ACOG Committee on Obstetric Practice. ACOG Committee opinion: number 299, September 2004 (replaces no. 158, September 1995)—guidelines for diagnostic imaging during pregnancy. Obstet Gynecol 2004;104:647–651.

36. Barloon TJ, Brown BP, Abu-Yousef MM, Warnock N, Berbaum KS. Sonography of acute appendicitis in pregnancy. Abdom Imaging 1995;20:149–151.

37. Kessler N, Cyteval C, Gallix B, et al. Appendicitis: evaluation of sensitivity, specificity, and predictive values of US, Doppler US, and laboratory findings. Radiology 2004;230:472–478.

38. Johansson EP, Rydh A, Riklund KA. Ultrasound, computed tomography, and laboratory findings in the diagnosis of appendicitis. Acta Radiol 2007;48:267–273.

39. Oto A, Srinivasan PN, Ernst RD, et al. Revisiting MRI for appendix location during pregnancy. AJR Am J Roentgenol 2006;186:883–887.

40. Balthazar EJ, Megibow AJ, Siegel SE, Birnbaum BA. Appendicitis: prospective evaluation with high-resolution CT. Radiology 1991;180:21–24.

41. Bickell NA, Aufses AH Jr, Rojas M, Bodian C. How time affects the risk of rupture in appendicitis. J Am Coll Surg 2006;202:401–406.

42. Lee SL, Walsh AJ, Ho HS. Computed tomography and ultrasonography do not improve and may delay the diagnosis and treatment of acute appendicitis. Arch Surg 2001;136:556–562.

43. Riesenman PJ, Riesenman KP, Stone TJ, Beidler SK, Douillet CD, Rich PB. Nonfocused enhanced CT evaluation of acute appendicitis increases length of stay in the emergency department but does not increase perforation rate. Am Surg 2008;74:488–492.

44. Birchard KR, Brown MA, Hyslop WB, Firat Z, Semelka RC. MRI of acute abdominal and pelvic pain in pregnant patients. AJR Am J Roentgenol 2005;184:452–458.

45. Oto A, Ernst RD, Ghulmiyyah LM, et al. MR imaging in the triage of pregnant patients with acute abdominal and pelvic pain. Abdom Imaging doi:10.1007/s00261-008-9381-y. Published online March 11, 2008. Accessed August 11, 2008.

46. Israel GM, Malguria N, McCarthy S, Copel J, Weinreb J. MRI vs ultrasound for suspected appendicitis during pregnancy. J Magn Reson Imaging 2008;28:428–433.

47. Kanal E. Pregnancy and the safety of magnetic resonance imaging. Magn Reson Imaging Clin N Am 1994;2:309–317.

48. De Wilde JP, Rivers AW, Price DL. A review of the current use of magnetic resonance imaging in pregnancy and safety implications for the fetus. Prog Biophys Mol Biol 2005;87:335–353.

49. Levine D, Zuo C, Faro CB, Chen Q. Potential heating effect in the gravid uterus during MR HASTE imaging. J Magn Reson Imaging 2001;13:856–861.