Effect of Magnetic Resonance Imaging on Acute Surgical Treatment of Pregnant Patients: A Single Institution Study

Jonathan Abraham Demma MD[1]*, Lisandro Luques MD PhD[1]*, Lior Cohen MD[1], Uri P. Dior MD[2], Gad Marom MD[1], Asaf Kedar MD[1], Naama Lev Cohain MD[3], Alon Pikarsky MD[1], Gidon Almogy MD[1], and Liat Appelbaum MD[3]

Departments of [1]General Surgery and Traumatology, [2]Obstetrics and Gynecology, and [3]Radiology, Hadassah Medical Organization and Faculty of Medicine, Hebrew University of Jerusalem, Israel

ABSTRACT **Background:** Abdominal pathology in pregnant patients is a frequent challenge for emergency department physicians. Ultrasound is the imaging modality of choice but is inconclusive in approximately one-third of cases. Magnetic resonance imaging (MRI) is becoming increasingly available, even in acute settings. Multiple studies have defined the sensitivity and specificity of MRI in this population.

Objectives: To evaluate the use of MRI findings in pregnant patients presenting with acute abdominal complaints to the emergency department.

Methods: This retrospective cohort study was conducted at a single institution. Data were collected on pregnant patients who underwent an MRI for acute abdominal complaints between 2010 and 2019 at a university center. Patient demographics, diagnosis at admission, ultrasound and MRI findings, and discharge diagnosis were recorded and evaluated.

Results: In total, 203 pregnant patients underwent an MRI for acute abdominal complaints during the study period. MRI was found without pathology in 138 cases (68%). In 65 cases (32%), the MRI showed findings that could explain the patient's clinical presentation. Patients presenting with long-standing abdominal pain (> 24 hours), fever, leukocytosis, or elevated C-reactive protein values were at a significantly increased risk of having an acute pathology. In 46 patients (22.6%), MRI findings changed the primary diagnosis and management while in 45 patients (22.1%) MRI findings improved characterization of the suspected pathology.

Conclusions: MRI is helpful when clinical and sonographic findings are inconclusive, leading to changes in patient management in more than one-fifth of patients.

IMAJ 2023; 25: 392–397

KEY WORDS: acute abdomen, emergency department (ED), magnetic resonance imaging (MRI), pregnancy

*These authors contributed equally to this study

Diagnosis of acute surgical and non-surgical conditions in pregnant patients should be prompt and effectively addressed since both delay in diagnosis and performance of unnecessary procedures (i.e., negative laparoscopy) carry a high rate of maternal and obstetric complications, including preterm labor and abortion [1,2]. However, as clinical and laboratory analysis are greatly altered in pregnancy and imaging studies are often limited, acute abdomen in pregnant patients remains a clinical challenge for emergency department (ED) physicians [3,4]. Since acute appendicitis (AA) is the most common surgical emergency in pregnant women, diagnostic algorithms were widely investigated [4]. Preterm labor following a negative appendectomy was reported to be as high as 33%. It is unclear whether this high incidence is due to surgery alone or the combination of surgery and a non-surgical ongoing condition. Similar numbers are reported in cases of perforated appendicitis due to the ongoing abdominal infectious process [5]. The accuracy of ultrasound in the diagnosis of AA in this population was studied and reports are conflicting. While some authors claim that ultrasound is satisfactory for the diagnosis of AA, others have shown that ultrasound alone could lead to misdiagnosis, unnecessary surgical intervention, and complications. In the different studies, the sensitivity was reported between 30 and 100% [6-8]. Computed tomography (CT) scan is the modality of choice for the diagnosis of AA in non-pregnant adults. However, although CT was recently shown to be safe throughout most pregnancy stages [9,10], most ED physicians prefer to avoid ionizing radiation during pregnancy. According to the American College of Radiology, magnetic resonance imaging (MRI) may be used in pregnant women if other nonionizing forms of diagnostic imaging are inadequate [11]. During recent years, MRI has become available in many tertiary medical centers, and its role in the diagnosis of AA has been widely evaluated [12-15]. However, beyond AA, the role of MRI in assessing pregnant patients in the ED with an equivocal clinical picture has not been evaluated.

The primary aim of this study was to evaluate our experience with MRI in pregnant women presenting to the ED with acute abdominal complaints and to analyze the clinical impact of MRI on the management of these patients.

PATIENTS AND METHODS

We conducted a retrospective cohort study of pregnant women who underwent an MRI for suspected acute abdominal patholo-

gy between 2010 and 2019 at a tertiary medical center in Jerusalem, Israel. Ethics approval was obtained from the committee of ethics and medical research of our hospital. Data were extracted from medical records and included patient demographics, medical history, symptoms, vital signs, abdominal examination findings such as tenderness and peritoneal signs, laboratory results (including complete blood count [CBC], blood chemistry, and C-reactive protein [CRP]), imaging reports, intraoperative findings, and surgical findings. Inclusion criteria included a positive urine or blood pregnancy test and/or a visible pregnancy on ultrasound scanning at the time of the MRI. Exclusion criteria included non-emergency MRIs and MRIs performed for suspected bile duct pathology. We excluded magnetic resonance cholangiopancreatography (MRCP) from our study because patients with biliary-origin pathology usually have distinct clinical presentation with elevated liver function test and bilirubin. MRCP for those patients is performed to prevent pregnant women from undergoing endoscopic retrograde cholangiopancreatography, which includes radiation and elevated risk for complications.

Our institutional protocol for pregnant patients presenting with abdominal complaints includes an assessment by the gynecological and general surgery teams. Gynecological ultrasound by a gynecologist and abdominal ultrasound by a radiologist are performed for all pregnant patients. When clinical and ultrasound findings are uncertain or contradictory, an MRI is performed. All MRI studies were performed on our 1.5T, MRI scanner (Siemens Healthcare, Germany). The protocol includesd single-excitation half-Fourier T2-weighted sequences in two planes axial and coronal, as well as with fat saturation. T1-weighted dual-echo sequence for both in-phase and out-of-phase images in axial plane were acquired as well. We did not inject intravenous contrast agent. Studies were interpreted by an attending radiologist with expertise in abdominal MRI.

Positive MRI findings in this study were defined as the presence of acute abdominal pathology that may explain the patient's clinical presentation. Negative findings were defined as studies showing no acute abdominal pathology. False positive and false negative MRI examinations were defined as studies showing findings not matching the final diagnosis. Diagnosis at discharge was considered the final diagnosis. Patient characteristics were compared between women with positive and negative MRI findings. Patient characteristics of women in whom the post-MRI diagnosis differed from the pre-MRI diagnosis and those in whom the diagnosis remained unchanged after MRI were also compared. Fever was considered as a body temperature > 37.4°C [16]. Leukocytosis was defined as white blood cell count (WBC) > 11.0 × 10^9/L. Elevated neutrophil percentage was defined as neutrophils > 70% and a positive CRP > 5 mg/L. The comparison of quantitative variables between two independent groups was conducted using the two-sample *t*-test as well as the non-parametric Mann-Whitney test. Comparison of quantitative variables between four independent groups was performed by using a one-way ANOVA test with post hoc tests (with the Dunnett correction for multiple pairwise comparisons) or the Kruskal-Wallis non-parametric test. Non-parametric tests were applied for variables that were not normally distributed. The chi-square test and the Fisher's exact test were used for testing the association between two categorical variables. To simultaneously assess the effect of several variables on a dependent dichotomous variable, the logistic regression multivariate model was used, using the stepwise, forward, likelihood ration method. All statistical tests were two-tailed, and a *P*-value ≤ 0.05 was considered statistically significant.

RESULTS

DEMOGRAPHICS

In total, 226 pregnant women with acute abdominal disease underwent an MRI between 2010 and 2019 at our institution; 23 cases were excluded (non-urgent, MRCP, or lack of data); hence, 203 patients were included in our analysis. The median age was 28 years (range 17–42). Forty-one patients (20.2%) arrived at the ED during their first trimester (1–14 weeks), 117 (57.6%) during their second trimester (15–27 weeks), and 45 (22.2%) during their third trimester (28-42 weeks).

CLINICAL PRESENTATION

The clinical presentation of patients varied widely. The most common complaint was right abdominal pain (n=124, 61.1%), followed by low abdominal or diffuse pain (n=28, 13.8% in both cases). Only 10% presented with flank, epigastric, or left abdominal pain. A minority of patients presented with peritoneal signs or fever (n=37, 18.2%, and n=17, 8.3%, respectively). Most patients presented with complaints lasting between 6 and 24 hours (n=110, 54.2%), 39 (19.2%) presented earlier (< 6 hours), and 34 (16.7%) presented more than 24 hours after their symptoms commenced. CBC was available for all patients. Nearly half of the patients (n=98, 48.3%) presented with leukocytosis, while elevated neutrophil percentage was observed in 156 patients (75.4%). CRP was measured in 136 patients (67%) and found to be elevated (> 5 mg/L) in 99 patients (72.7%).

MRI FINDINGS

In our cohort, 131 MRI examinations were reported to be within normal limits, while pathological conditions were reported in 72 cases [Table 1]. Incidental findings unrelated to the acute presentation were reported in seven patients. For further analysis, incidental findings were considered as within normal limits (n=138). Acute surgical pathology was found in 31 cases. Obstetric and gynecological pathologies were found in 16 and 6 patients, respectively, and other medical conditions were reported in 12 patients. In six patients, the MRI findings were compatible with uncomplicated AA (n=1), ovarian torsion (n=1), ovarian cyst (n=2),

Table 1. Summary of MRI findings

MRI diagnosis		Number of patients
No pathology		**131**
Medical condition		**12**
	Enteritis	1
	Colitis	2
	Terminal ileitis	3
	Hydronephrosis	2
	Pyelonephritis	3
	Nephrolithiasis	1
Surgical condition		**31**
	Acute appendicitis	20
	Periappendicular abscess	3
	Malignancy	2
	SBO	2
	Internal hernia	1
	Incarcerated umbilical hernia	1
	Other abdominal abscess	2
Gynecological condition		**16**
	Ovarian cyst	9
	Ovarian torsion	3
	Myoma	2
	SOL of ovary	1
	Inflammatory process in RLQ	1
Obstetric condition		**6**
	Placenta previa	2
	Placenta accrete	3
	Chorionic hematoma	1
Incidental abdominal findings		**7**
	Cholelithiasis	5
	Echinococcal cyst in spleen	1
	FNH in liver	1

FNH = focal nodular hyperplasia, MRI = magnetic resonance imaging, RLQ = right lower quadrant, SBO = small bowel obstruction, SOL = space occupying lesion

hydronephrosis (n=1), and chorionic hematoma (n=1). However, the suspected pathology was ruled out later by clinical follow-up and additional imaging studies such as Doppler ultrasound. In 22 cases, despite a normal MRI study as interpreted by the surgical and radiology teams, an abdominal pathology was later diagnosed and treated accordingly. This group consists of one surgical condition (AA), four gynecological conditions (ovarian vein thrombosis, ovarian cyst, ovarian torsion, and hemorrhagic corpus luteum), five obstetrical conditions (labor [n=3], chorioamnionitis [n=1], preeclampsia [n=1]), ten urological conditions (urinary tract infection [n=8], nephrolithiasis [n=2]), and two other medical conditions (fever of unknown origin and bacteremia). Patients in whom MRI findings were not confirmed, such as false positives (n=6), and patients with pathologies that were not observed on MRI, including false negatives (n=22), were excluded from the analysis. Patient age, clinical presentation, and parameters related to pregnancy such as number of pregnancies, trimester of pregnancy and pregnancy by in vitro fertilization (IVF), were unrelated to positive MRI findings.

ASSOCIATION BETWEEN DEMOGRAPHICS, CLINICAL PRESENTATION, LABORATORY TESTS, AND A POSITIVE MRI

A total of 175 patients were analyzed. The group included 109 patients (62.3%) with a normal MRI who were eventually discharged without further evaluation and 66 (37.7%) with a diagnostic MRI who were treated accordingly. Data for these patients are summarized in Table 2 and Table 3. Age of the patient and trimester of pregnancy were unrelated to MRI findings. The onset of pain was significantly different between groups. The hazard ratio (HR) for positive MRI findings increased with duration of pain: the longer the pain persisted, the higher the HR for positive MRI findings (HR 0.33 for < 6 hours, HR 1.44 for >24 hours; $P = 0.015$). Fever ≥ 37.5°C was found to be significantly associated with positive MRI findings. Seven of 9 patients (77.8%) who presented with fever were diagnosed with acute pathology on MRI [Table 2].

Data were lacking for some patients. The final number of patients in each group was specified for each variable. The presence of leukocytosis (defined as WBC > 11×10^9/L) and elevated neutrophil percentage (> 70%) were associated with an increased risk of having abdominal pathology on MRI. No differences were found between groups when CRP threshold was set at 5 mg/L. It has been previously shown that a fourfold to eightfold increase in CRP is associated with an elevated risk of AA [17,18]. When the CRP threshold was set at 40 mg/L (8 times of normal) a significant difference between groups was found ($P < 0.01$) [Table 3].

ASSOCIATION BETWEEN PRE-MRI DIAGNOSIS AND MRI FINDINGS

In 46 patients MRI findings changed the diagnosis and management. In 18 of these patients (39.1%) the MRI demonstrated no pathology or a different pathology than the suspected diagnosis based on clinical presentation, laboratory tests, and ultrasound results [Table 4]. In the remaining 28 patients (60.9%), MRI demonstrated acute abdominal pathology that was not previously diagnosed. Twelve patients were diagnosed with surgical conditions including AA (n=9), small bowel obstruction (n=1), cecal inflammation (n=1), and post-surgical abscess (n=1). There were 12 patients with gynecological conditions including ovarian torsion (n=8), hemorrhagic corpus luteum (n=1), pelvic inflammatory disease (n=1), chorionic hematoma (n=1), and myoma torsion (n=1). Four patients were diagnosed with other medical

Table 2. Correlation of demographics, clinical data, and magnetic resonance imaging findings

	Age of pregnancy	Negative		Positive		*P*-value
			n		n	
Age of patient, in years#		27.9 ± 5.2	109	29.0 ± 6.2	66	0.33
In vitro fertilization		2/92	2	1/53	1	1
Twin		5/96	2	2/59	1	0.6
Gravidity (Mean ± standard deviation)		2.44 ± 1.74		2.95 ± 2.12		0.34
Age of pregnancy*			109		66	0.48
	1st trimester	17.4% (19)		27.3% (18)		
	2nd trimester	58.7% (64)		54.5% (36)		
	3rd trimester	22.9% (25)		18.2% (12)		
Onset of pain (days)*			101		57	**0.015**
	< 6 hours	24.8% (25)		12.3% (7)		0.33
	> 6 hours	65.3% (66)		57.9% (33)		0.47
	> 24 hours	9.9% (10)		29.8% (17)		0.02
Fever*	> 37.4°C	1.9% (2)	108	12.5% (8)	64	**< 0.01**

*Percentage and number

#Mean ± standard deviation

P-values were calculated by chi-square test for categorical values and *t*-test for non-categorical values

Bold signifies significance

Table 3. Correlation between laboratory data and magnetic resonance imaging findings

	Magnetic resonance imaging findings	N	Mean ± standard deviation	% above threshold* (n)	*P*-value
Leukocytes (10^9/L)					**0.010**
	Positive	66	12.6 ± 3.7	66.6% (44)	
	Negative	109	11.2 ± 3.8	39.6% (43)	
Neutrophils (%)					**0.018**
	Positive	66	80.1 ± 8.7	87.9% (58)	
	Negative	109	75.3 ± 9.4	70% (77)	
C-reactive protein (mg/L)					**0.006**
	Positive	36	49 ± 66	39.0% (14)	
	Negative	79	19 ± 22	11.4% (9)	

*Threshold: leukocytosis (> 11 K), high neutrophil percentage (> 70%), C-reactive protein (> 40 mg/L)

Bold signifies significance

Table 4. MRI finding that changed the pre-MRI diagnosis

	Pre-MRI diagnosis	MRI findings
Surgical	Post-surgical abscess	Terminal ileitis
	Acute appendicitis	No pathology
	Acute appendicitis	No pathology
	Acute appendicitis	No pathology
	Acute appendicitis	Ovarian cyst
	Internal hernia	SBO without internal hernia
Gynecological/ obstetrical	Ovarian vein thrombosis	No pathology
	Ovarian vein thrombosis	No pathology
	Preterm labor	Acute appendicitis
	Pelvic congestive syndrome	Placenta previa
Urological	Urinary tract infection	Periappendicular abscess
	Nephrolithiasis	Chorioamnionitis
	Nephrolithiasis	Torsion of myoma
	Hydronephrosis	Acute appendicitis
	Hydronephrosis	No pathology
	Hydronephrosis	No pathology
Others	Colitis	Terminal ileitis
	Portal hypertension	No pathology

MRI = magnetic resonance imaging, SBO = small bowel obstruction

conditions (enteritis, pyelonephritis) and treated accordingly. In 45 patients, MRI findings confirmed or better characterized the previously suspected pathology such as internal hernia (n=1), AA (n=9), pyelonephritis (n=3), space occupying lesion (n=3). Age, pregnancy trimester, time of onset of pain, presence of fever, leukocytosis, and CRP levels were not associated with changes in diagnosis due to MRI findings (data not shown).

DISCUSSION

We found that MRI may change management in up to one-fourth of pregnant patients presenting to the ED with acute abdominal complaints. MRI was also shown to be useful to avoid unnecessary procedures and treatments. In our cohort of patients, MRI allowed prompt treatment with obvious benefits for both patient and fetus. Even when the correct pathology was suspected before the MRI was conducted, the findings on MRI assisted with better characterize the pathology and its se-

verity. For example, MRI findings precisely defined the severity and extent of colitis that was suspected on ultrasound in a patient who presented with abdominal pain and diarrhea. The diagnosis of colitis and its severity helped with prompt and adequate management, which varied between supportive care such as adequate hydration, admission, and sometimes even antibiotic treatment.

There are scarce data on the impact MRI has on clinical decisions in the setting of suspected acute abdominal pathology in pregnant patients. Previous studies focused more on the specificity and sensitivity of MRI and less on the effect of MRI on the clinical management of pregnant patients who arrive in the ED with suspected acute abdomen [19,20]. Most of the patients with normal MRIs were admitted for observation and discharged without further treatment or investigation. The remaining patients were eventually diagnosed with conditions that are not usually seen or diagnosed on MRI (i.e., urosepsis, UTI [urinary tract infection], chorioamnionitis, preterm or term labor). Interestingly in this group, the lack of findings on MRI led to the correct diagnosis or prompted a more detailed investigation, which eventually led to the correct diagnosis. A previous study [21] showed that MRI in pregnant patients with suspected appendicitis does not affect clinical outcomes or hospital charges but allows for safe discharge from the ED and improves resource use. In our study, prolonged pain (> 24 hours) prior to ED admission significantly increased the likelihood of a positive MRI. Previous studies that included all pregnant patients who came to an ED with suspected appendicitis showed that physical examination on presentation is the most reliable diagnostic tool [22]. This difference may be explained due to patients with a classical presentation being treated surgically. Only the equivocal case underwent an MRI. Patient age and parameters related to pregnancy such as number of pregnancies, trimester of pregnancy, and pregnancy by IVF were unrelated to positive MRI findings. Fever ≥ 37.5°C was found to be significantly associated with positive MRI findings. Leukocytosis and elevated neutrophil percentage were present in about half of the patients. There was a significant difference between groups when leukocytosis (WBC > 11 K) or elevated neutrophil percentage (> 70%) were analyzed as categorical variables. These results did not seem to be clinical important in our study since two-thirds of the patients without acute pathology presented with elevated neutrophil percentage. A previous study that assessed the risk factor of positive MRI in suspected acute appendicitis in pregnancy showed the same results [23]. CRP was elevated in both groups, but CRP was significantly higher in patients with pathological findings on MRI (1.94 vs. 4.72 mg/L, $P < 0.05$). At a threshold of 5 no differences were observed between groups. Patients with CRP > 40 mg/L (8-times threshold) were 4.6 times more likely to have positive findings on MRI ($P < 0.01$). Likewise, almost half of the patients with a positive MRI presented with CRP > 40 mg/L. Our data suggest that patients with CRP higher than eightfold the normal should be considered for an early MRI. An earlier study showed that lower threshold (> 20 mg/L) is sufficient to dictate an MRI in suspected appendicitis [23].

The sensitivity of MRI in our study for acute appendicitis was 94% while sensitivity for acute surgical pathology was 96%. These findings concur with previous reports [13,24,25]. In 22 patients (10.8%) an MRI report was within normal limits, but the patients were eventually diagnosed with abdominal pathology and treated accordingly. Besides an isolated case of AA, this group did not represent a true false negative since MRI is not sensitive for the diagnosed pathologies. For analysis of sensitivity, we also included as false negative four gynecological conditions that can be diagnosed by MRI even if it is not the gold standard for diagnosis. The remaining 18 cases in which the pathology was not shown by MRI were excluded from the analysis since the final pathologies were medical or obstetrical conditions (i.e., abortion, UTI, bacteremia). In six patients, the MRI findings suggested a pathology that was subsequently ruled out by clinical course and additional imaging modalities.

There are several limitations to this study. They include the retrospective nature of data collection at a single institution and the lack of a non-MRI control group for comparison. We excluded patients who had false positive (n=6) and false negative (n=22) MRI studies from the statistical analysis to look for predictive signs and symptoms of abdominal pathology and define patients who could benefit from early MRI. We decided on this protocol because patients with abdominal pathologies that cannot be seen on MRI (false negative group) cannot be considered as healthy, even if no finding were found on MRI. Similarly, healthy patients with suspected findings on MRI who were eventually discharged cannot be considered as unhealthy patients. Including the false positive and false negative examinations had no effect on the results. Our population included only pregnant patients who underwent MRI but not all pregnant patients who presented to the ED with abdominal complaints. According to our data, over a 10-year period only 20 patients were diagnosed with AA following an MRI. We assumed that most of the pregnant patients with AA were diagnosed by conventional means and without MRI. More studies, preferably prospective, are needed to define the optimal algorithm in pregnant women with the suspicion of an acute abdomen.

CONCLUSIONS

The early use of MRI may be useful in the ED workup of pregnant patients with abdominal complaints, especially in patients presenting with equivocal or unclear findings, prolonged onset of pain (> 24 hours), fever, or high CRP values. In our cohort of patients, the prompt utilization of MRI at the ED allowed for an earlier and more accurate diagnosis, leading to swift and correct treatment.

Correspondence
Dr. J.A. Demma
Dept. of General Surgery and Traumatology Department, Hadassah Medical Organization and Faculty of Medicine, Hebrew University of Jerusalem 91120, Israel
Phone: (972-2) 677-9500
Email: yonatand@hadassah.org.il

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Life has no meaning a priori. It is up to you to give it a meaning, and value is nothing but the meaning that you choose.
Jean-Paul Sartre (1905–1980), writer and philosopher

Capsule

Observational study of patients hospitalized with neurologic events after SARS-CoV-2 vaccination, December 2020–June 2021

Kim et al. prospectively identified patients hospitalized for prespecified neurologic conditions who received mRNA or adenovirus COVID-19 vaccines and assessed cases for potential risk factors and alternative etiologies of the adverse event. Among 3830 individuals screened for COVID-19 vaccination status and neurologic conditions, 138 cases (3.6%) were included in this study (126 after mRNA and 6 after Janssen vaccines). The four most prevalent neurologic syndromes included ischemic stroke (52, 37.7%), encephalopathy (45, 32.6%), seizure (22, 15.9%), and intracranial hemorrhage (13, 9.4%). All 138 cases (100%) had one or more risk factors and/or evidence for established causes. Metabolic derangement was the most common etiology for seizures (24, 53.3%) and encephalopathy (5, 22.7%) while hypertension was the most significant risk factor in ischemic stroke (45, 86.5%) and intracranial hemorrhage (4, 30.8%).

Neurol Clin Practice 2023; 13 (4): e200166.
Eitan Israeli