Diagnostic Performance of Diffusion-Weighted MR Imaging in Detecting Acute appendicitis in Pediatric Patients: Comparison with Conventional MRI and Surgical Findings

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Purpose

Acute appendicitis remains the most common acute surgical condition of the abdomen and is the most commonly misdiagnosed condition in the pediatric age group (1). It is known that one-third of patients are younger than 18 years of age and appendicitis is more frequent in developed countries (1, 2). Diagnosis sometimes may be easy only after obtaining clinical history and physical examination and sometimes may be more sophisticated even with radiological imaging techniques. Although diagnosis and treatment have improved over time, appendicitis still continues to cause significant morbidity and remains a cause of death. However, with the usage of effective antibiotics, the mortality rate for complicated appendicitis has been close to zero, but still the cause of mortality is delayed diagnosis (3).

In skilled hands, ultrasonography (US) has proved to be an effective diagnostic aid (1). It has been shown that US is more accurate than the surgeon's clinical impression (4). In the last decade, computed tomography (CT) has become more widely used in the diagnosis of appendicitis (5). Comparisons of US and CT have shown that the latter is more sensitive whereas the former is more specific (1, 6). However, ultrasonography is the first choice radiological technique because it is a noninvasive, easily available, and rapid method with lack of ionizing radiation, although it has some limitations like operator-dependency, obesity, and retrocecal appendix location. Contrast-enhanced CT is another technique for acute appendicitis diagnosis. However, ionizing radiation and the use of iodinated contrast medium are disadvantages, especially in pregnant women and children.

Magnetic resonance imaging has become more widely used with an avoidance of ionizing radiation and contrast medium. Diffusion-weighted MRI is a non-invasive technique capable of probing the micro-environment of tissue by measuring water movement (7). In DW MR imaging, the image contrast is influenced by the Brownian motion of water molecules. The apparent diffusion coefficient (ADC) value in DWI determines the motion of water protons in the environment. If water molecules are restricted in their motion because of cell membranes or, in the case of free fluid, by high viscosity, the signal intensity is high. If water molecules can diffuse freely, the signal intensity is low (8). Diffusion-weighted MRI has been increasingly used in the abdomen, and findings of DWI of different diseases (malign or inflammatory processes) have been reported (9, 10).

To our knowledge, only one report has been published in the literature for detection of acute appendicitis in adults with DW MR imaging (11). The aim of our study was to determine the value of DWI for the diagnosis of acute appendicitis in pediatric patients when added to conventional MRI. We hypothesize that DWI will increase the sensitivity/
accuracy for imaging diagnosis of acute appendicitis in children compared to conventional MRI alone.

Methods and Materials

Patients

A total of 45 consecutive patients (mean age, 7; range, 0-14 years; 18 women, 27 men) with a clinical diagnosis of acute appendicitis during a period of 4 months were enrolled in the study. The medical ethics committee of our hospital approved the study, and written consent of the parents was obtained before MRI examination. All patients had undergone MR imaging and 39 of them were operated for acute appendicitis with a mean interval between surgery and MR imaging of 8 hours. The time range between examinations and surgery resulted from pre-operative procedures and preparation. The remaining six of the patients did not undergo surgery after MR imaging. They were followed clinically over a period of 2 weeks-2 months. Clinical characteristics of patients are shown in Table 1.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Patients</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (mean) [years]</td>
<td>7 (range 0-14)</td>
</tr>
<tr>
<td>Body Mass Index (mean) [kg/m²]</td>
<td>25 (range 4-48)</td>
</tr>
<tr>
<td>Sex (m/f)</td>
<td>17/18</td>
</tr>
<tr>
<td>Leukocyte (mean) [x10³/mm³]</td>
<td>13 (range 6-20)</td>
</tr>
</tbody>
</table>

Table 1: Patient characteristics

Magnetic resonance imaging

Magnetic resonance imaging was performed with a 1.5 T body MRI (Magnetom Avanto, Siemens Healthcare) using an 18-channel phased-array body coil. Before DWI, the subjects underwent a free-breathing axial and coronal turbo spin-echo T1-weighted sequence (TR, 536 ms; TE, 11 ms; FA, 150°), axial and coronal fat-saturated turbo spin-echo T2-weighted sequence (TR, 5030 ms; TE, 101 ms; FA, 150°), and an axial diffusion-weighted single-shot spin-echo echoplanar sequence with chemical shift-selective fat-suppression technique (TR/TE, 4900/93); matrix, 192 × 192; slice numbers, 30; slice thickness, 6 mm; interslice gap, 35%; FOV, 45 cm; averages, 5; acquisition time, approximately 3 minutes; PAT factor, 2; PAT mode, parallel imaging with modified sensitivity encoding (mSENSE). Diffusion-weighted imaging was performed with b factors of 50, 400, and 800s/mm². All slices were acquired from diaphragm to the bottom of the
pelvis. Oral and intravenous contrast material was not used. Only 4 of the patients needed general anesthesia for MRI. There were no post-anesthetic problems. Each patient’s qualitative DWI findings were recorded and compared with the histopathological results.

**Image analysis**

Two radiologists with 10 and 6 years of experience with abdominal MRI reviewed the MR examinations with consensus in an independent workstation (Leonardo console, software version 2.0; Siemens) without the knowledge of the physical examination results of the patients. First, the DW images, including the images with b values of 50, 400, and 800 s/mm² were reviewed alone, followed by the conventional MR images, and finally the combined DW images and conventional MR images were reviewed together. This order of image review was kept constant to avoid any recall bias for the DW images, which were always reviewed first. The criteria for the diagnosis of acute appendicitis on MR imaging were thickening of the appendix (> 6 mm in outer diameter), intraluminal fluid, inflammation of the periappendiceal tissue, periappendiceal fluid collections, and markedly hyperintense on DWI, hypointense on ADC maps.

**Correlation of MRI and Surgical Findings**

After a blinded review of the MR examinations, a comparison of the findings of DWI, conventional MRI, and combined DWI and conventional MRI was made with the results of the histopathological evaluation.

**Statistical Analysis**

We used a McNemar’s test to analyze the diagnosis of acute appendicitis in pediatric patients for DWI, conventional MRI, and combined DWI and conventional MRI. In all cases, a two tailed p value was determined, and the null hypothesis was rejected at p < 0.05.

**Results**

Of the 45 patients with clinically suspected acute appendicitis, 39 patients (86%) were operated on. The remaining six patients had clinically suspicious findings for acute appendicitis, were not referred for surgery. They were followed clinically over a period of 2 weeks-2 months. Findings from follow-up examinations were unremarkable. In these patients, all imaging modalities showed negative findings for acute appendicitis. Histopathology revealed acute appendicitis in 36 of the operated patients (92%). Four
patients had perforated appendicitis in surgery. Three patients had normal appendix in surgery. The operative results of them were the diagnoses of ovarian cyst rupture, Crohn's disease and Meckel diverticulitis. There was apparently diffusion restriction in the periumbilical area at the right lower quadrant in the patient with Meckel's diverticulitis. In the other two patients there was no any area showing diffusion restriction. DWI revealed the diagnosis of acute appendicitis in 31 patients (86 %). In the five patients with appendicitis in surgery the inflamed appendix was overlooked by observers on DWI. Three of them were also overlooked by using combined DWI and conventional MRI. In one of these patients, the appendix could not be demonstrated on MRI but at surgery the appendix, which was located between the urinary bladder and anterior abdominal wall, was perforated. In the other two patients the greatest diameter of appendix was less than 5 mm. In the two patients with acute appendicitis which were overlooked by only DWI, there was appendicolith and wall thickening of the appendix without periappendicular fluid or inflammation.

Table 2 shows the results of imaging modalities in the diagnosis of acute appendicitis by observers' consensus. The combination of DWI and conventional MRI was the most sensitive and the most accurate method, depicting 33 cases of acute appendicitis, with corresponding sensitivity and accuracy of 0.91 and 0.92 respectively (p < 0.05) (Fig.1 and 2). Using DWI alone, observers depicted and localized 31 cases of acute appendicitis (sensitivity: 0.86; and accuracy: 0.84), whereas conventional MRI depicted and localized 26 cases of acute appendicitis (sensitivity: 0.80; and accuracy: 0.82). A case that was misidentified as acute appendicitis (false positive) in DWI was a case of Meckel's diverticulitis, which was confirmed by surgery.

Table 2. The results of imaging modalities in the diagnosis of acute appendicitis by the consensus of two observers according to the histopathological findings

<table>
<thead>
<tr>
<th>Type of imaging</th>
<th>TP</th>
<th>FN</th>
<th>TN</th>
<th>FP</th>
<th>Sensitivity</th>
<th>Specificity</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>DWI</td>
<td>31</td>
<td>5</td>
<td>2</td>
<td>1</td>
<td>0.86</td>
<td>0.66</td>
<td>0.84</td>
</tr>
<tr>
<td>Conventional MRI</td>
<td>7</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>0.80</td>
<td>1.0</td>
<td>0.82</td>
</tr>
<tr>
<td>Combined MRI</td>
<td>33</td>
<td>3</td>
<td>3</td>
<td>0</td>
<td>0.91</td>
<td>1.0</td>
<td>0.92</td>
</tr>
</tbody>
</table>


The McNemar's test of correlated proportions
There were significant differences in sensitivity and accuracy between DWI and combined imaging ($p < 0.05$) and between conventional and combined imaging ($p < 0.05$) for observers' consensus.

**Images for this section:**

**Fig. 1:** Fig. 1-4. A 11-year-old girl with acute appendicitis and fluid collection. 1. Axial TSE T2-weighted image showing the appendix. Arrow: appendix, f: fluid Arrow: appendix, f: fluid
Fig. 2: A 11-year-old girl with acute appendicitis and fluid collection. 2. Diffusion-weighted MR image of the appendix with b value of 400 s/mm² showing marked hyperintensity. Arrow: appendix, f: fluid Arrow: appendix, f: fluid
Fig. 3: Fig. 1-4. A 11-year-old girl with acute appendicitis and fluid collection. 3. Diffusion-weighted MR image of the appendix with b value of 800 s/mm² showing marked hyperintensity. Arrow: appendix, f: fluid Arrow: appendix, f: fluid
Fig. 4: Fig. 1-4. A 11-year-old girl with acute appendicitis and fluid collection. 4. ADC image showing hypointensity of the appendix (marked restricted diffusion). Region of interest (ROI) was placed on the appendix. Arrow: appendix, f: fluid
**Fig. 5:** Fig. 5-8. A 8-year-old boy with acute appendicitis. 5. Axial TSE T2-weighted image showing the appendix (arrow).
**Fig. 7:** Fig. 5-8. A 8-year-old boy with acute appendicitis. 7. Diffusion-weighted MR image of the appendix (arrow) with b value of 800 s/mm² showing marked hyperintensity.
Fig. 8: Fig. 5-8. A 8-year-old boy with acute appendicitis. 8. ADC image showing hypointensity of the appendix (marked restricted diffusion). Region of interest (ROI) was placed on the appendix (arrow).
Fig. 6: Fig. 5-8. A 8-year-old boy with acute appendicitis. 6. Diffusion-weighted MR image of the appendix (arrow) with b value of 400 s/mm² showing marked hyperintensity.
Conclusion

Acute appendicitis is the most common cause of abdominal surgical emergency in children. Although physical examination, laboratory tests, and patient's history improve the diagnosis, the negative laparotomy rate is high especially in female patients (12, 13). Further evaluation with radiological techniques like ultrasonography, computed tomography, and magnetic resonance imaging is required for minimizing negative laparotomy rates, delayed surgery, and probable complications of perforation.

Ultrasonography is an easily available and performed technique in the diagnosis of acute appendicitis with a lack of ionizing radiation. Sonographer-dependency, acute appendicitis with retrocecal location, and obesity are the disadvantages of this method. In these cases, CT is recommended with a sensitivity and specificity of more than 90% (12, 14-18). However, ionizing radiation and the use of iodinated contrast medium are disadvantages, and CT is not preferred especially in pregnant women and children (19).

Magnetic resonance imaging has become a widely used method with an avoidance of ionizing radiation especially in children and females. It has some disadvantages like long examination time, high cost, and difficulty in claustrophobic patients. Incesu et al. found sensitivity and accuracy of MR imaging in the diagnosis of acute appendicitis to be 97% and 95%, respectively (20). However, in this study fat-suppressed and gadolinium-enhanced MR imaging is recommended. Another study showed that unenhanced turbo spin echo and fat-suppressed images provide accurate diagnosis of acute appendicitis (21).

Recently, well-established diffusion-weighted MR imaging for acute cerebral infarcts has provided advances in some abdominal diseases (22). This method utilizes pulse sequences and techniques that are sensitive to very small-scale motion of water protons at the microscopic level. Recently, the use of DWI has been developed for abdominal and pelvic oncologic MRI (23). It has also been used for inflammatory diseases of the abdomen like acute-chronic pancreatitis, renal infections, hepatitis, and liver fibrosis and inflammatory bowel disease (24-29). Inci et al. evaluated the utility of DW MRI in the diagnosis of acute appendicitis in adults (11). In this study, the sensitivity and specificity of DW MR imaging for diagnosis of acute appendicitis were found to be 98.7 % and 100%, respectively.

In our study, we compared the performance of DWI and combined imaging in the evaluation of acute appendicitis in pediatric patients. For observers' consensus, the sensitivity was 80% and accuracy was 82%, by using conventional MRI alone. When DW
images were added to conventional MRI sequences, both the sensitivity and accuracy increased (sensitivity: 0.91 and accuracy: 0.92).

Combined DWI and conventional MRI missed only three patients which were surgery proven acute appendicitis. The greatest diameter of the appendix in the two patients was less than 5 mm. The diagnosis of the other one was perforated appendicitis localized between urinary bladder and anterior abdominal wall. In the two patients with acute appendicitis which were overlooked by only DWI, there was appendicolith and wall thickening of the appendix without periappendicular fluid or inflammation. Furthermore two patients were interpreted as not to have appendicitis in imaging sessions but diagnosed as ovarian cyst rupture and Crohn's disease in surgery. Only one false positive result was belonging to DWI and the diagnosis was Meckel's diverticulitis confirmed by surgery.

Our study has some limitations. One of them is the relative lowness of the number of the patients. Larger groups are needed for the evaluation of acute appendicitis with MRI. Second, there was a lack of intravenous and enteric contrast material, which plays an important role in detecting wall enhancement of inflamed appendix and intestine. Limitations of DWI include its poor anatomic localization, relatively poor spatial resolution, and increased anatomic distortion with the use of high b values (30).

Diffusion-weighted MR imaging technique is non-invasive, does not require ionizing radiation or injection of contrast material, and can be easily added to an MR examination protocol because it requires only a short time for the examination (31). This study showed that if DWI is added to the conventional MR imaging, the depiction of acute appendicitis will be easier with MRI especially in patients with clinical suspicion but without remarkable findings on the other imaging techniques.

In conclusion, when added to conventional MR sequences, diffusion-weighted MR imaging markedly improves the diagnosis of acute appendicitis especially in pediatric patients.

References


Personal Information

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