Diagnosis of Pediatric Appendicitis: Is MR Imaging More Appropriate than CT?

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Prospective and retrospective studies have shown sensitivity and specificity of MRI to be comparable to CT.

In lieu of potential radiation risks associated with CT, MRI has increased in children with suspected appendicitis.

Several studies have demonstrated MRI efficacy at stand-alone pediatric hospitals.

The purpose of our study is to determine if implementation of an MRI pediatric appendicitis protocol is feasible in the non-subspecialty pediatric setting where non-pediatric radiologists and residents routinely perform interpretation.

10 year old female with perforated appendicitis
T2 Axial Fat Saturated image (left) and a coronal HASTE image (right) demonstrate a dilated fluid filled appendix with an appendicolith (arrow) and T2 hyperintense pelvic free fluid.
Suspected Appendicitis?

- In 2012, a pediatric appendicitis work-up algorithm was established for children aged 0-17 with suspected appendicitis in collaboration with SAMMC Radiology, Emergency Room, Pediatric Surgery, General Surgery and Pediatrics staff.

- Modifications were made to the algorithm to improve efficiency including:
  - Immediate ultrasound (US) review by radiologist
  - Orders for US and MRI were placed at the same time by the ER. If US was positive or clearly negative, the MRI order was cancelled
  - If equivocal US findings or non-visualization of the appendix, the patient was transported directly from US to MRI (instead of returning to the ER)
  - MRI scan time was reduced from 21 minutes to 11 minutes from 2012 to 2015 after determining the optimal sequences to arrive at diagnosis

- The latest algorithm (Figure 1) was implemented in 2015

*This time was reduced from 21 minutes (in 2012) to 16 minutes in 2015 after reducing the total number of MRI sequences. Exams that did not include restricted diffusion took 11 minutes*
**Rapid MRI Protocol**

- A non-sedation MRI protocol was established using either 1.5T or 3T scanners and exams were worked in-between inpatient and scheduled outpatient exams.
- Multichannel torso coil was used
- Patient urinates prior to exam
- Technique for children $\geq 12$ years
  - Breath hold
  - 4 mm slice thickness with 10% gap
- Technique for children $< 12$ years old
  - Free breathing
  - 3 mm slice thickness with 10% gap
- Trial sequences were found to have limited utility or did not add to or improve interpretation and were removed from our protocol:
  - In and out of Phase T1-weighted imaging
  - Sagittal and Coronal fat-saturation HASTE
  - VIBE
  - Diffusion-weighted MRI (DW-MRI)
  - TruFisp
  - SPARE

**Current SAMMC Rapid Appendicitis Protocol**

(protocol finalized in 2015)

<table>
<thead>
<tr>
<th>Sequence</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Axial T2-weighted fat saturated images</td>
<td></td>
</tr>
<tr>
<td>Axial half-Fourier acquisition single shot turbo spin echo (HASTE)</td>
<td></td>
</tr>
<tr>
<td>Coronal half-Fourier acquisition turbo spin echo (HASTE)</td>
<td></td>
</tr>
<tr>
<td>Coronal HASTE FOV: Entire abdomen and pelvis</td>
<td>Axial HASTE and T2 FS FOV: Inferior endplate of L3 through the pubic floor</td>
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<tr>
<td></td>
<td>256 x 256 matrix</td>
</tr>
</tbody>
</table>

*Figure 2. Current SAMMC rapid MRI appendix protocol*
Between 2012 and 2015, 506 patients under the age of 18 (mean age 9.8 years) with clinically suspected appendicitis, and equivocal findings or non-visualization of the appendix on ultrasound, underwent MRI of the abdomen using our rapid MRI appendix protocol.

The majority of exams were performed during overnight and weekend hours when a pediatric radiologist was unavailable.

Approximately 40 residents (PGY2-PGY5) and 40 non-pediatric subspecialty attending radiologists interpreted >90% of the examinations.

The primary focus was to identify key findings of appendicitis and alternative explanations for the patient’s symptoms on MRI.

A key component of instituting the protocol was training non-expert radiologists and residents.

Many methods (figure 3) were also employed in 2012-2013 to educate surgeons, pediatricians and emergency physicians who were well experienced in CT and not as comfortable with MRI.

As a result, in the initial phases of our protocol, many patient’s underwent CT after MRI for confirmation.

### Methods to Educate Clinicians

<table>
<thead>
<tr>
<th>Methods to Educate Clinicians</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grand Rounds</td>
<td>Departments of Radiology, Emergency Medicine, General and Pediatric Surgery and Pediatrics</td>
</tr>
<tr>
<td>Literature</td>
<td>Sharing literature documenting similar accuracy of MRI compared to CT</td>
</tr>
<tr>
<td>ALARA Campaign</td>
<td>Robust Image Gently Campaign, fliers, posters, patient education pamphlets</td>
</tr>
<tr>
<td>Workstation teaching</td>
<td>Included radiology residents and staff, general surgery residents and pediatricians</td>
</tr>
<tr>
<td>Correlation</td>
<td>Interdepartmental radiologic-surgical-pathologic correlation</td>
</tr>
</tbody>
</table>

Figure 3. Methods used at SAMMC to educate other physicians.
In addition to didactic teaching, direct feedback was also highly effective. We maintained a database of over 500 cases at SAMMC for radiologist review with direct feedback provided to the interpreting radiologist when possible:

- MRI technique (motion, spatial resolution, etc)
- Pathology and surgical reports
- 1 month clinical follow up
- Alternative explanations for patient symptoms
- Good examples of positive and negative cases
- False positives, false negatives

**Introduction**

**Materials and Methods**

**Results**

**Conclusions**

**Important concepts used in our exam interpretation**

<table>
<thead>
<tr>
<th>Concept</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visualization of the appendix</td>
<td>A normal appendix does not need to be identified to exclude appendicitis. I.e. appendix is not seen and there is no free fluid or inflammation = no appendicitis.</td>
</tr>
<tr>
<td>Peri-appendiceal inflammation</td>
<td>Present in nearly all cases of acute appendicitis</td>
</tr>
<tr>
<td>Appendiceal wall thickening</td>
<td>Circumferential wall thickening &gt;2 mm was nearly always present in acute appendicitis</td>
</tr>
<tr>
<td>Small amount of free-fluid and appendix is not visualized</td>
<td>Appendicitis unlikely. May be physiologic or secondary to alternative pathology (ovarian, gastroenteritis, etc)</td>
</tr>
<tr>
<td>Appendiceal tip</td>
<td>If RLQ fluid of inflammation, should visualize full appendiceal length to exclude tip appendicitis</td>
</tr>
<tr>
<td>Size</td>
<td>Appendix was considered dilated when &gt;6mm; however, size is not a standalone criteria as the appendix may be enlarged without inflammatory changes</td>
</tr>
<tr>
<td>Alternative pathology</td>
<td>Assessing for alternative pathology is critical</td>
</tr>
</tbody>
</table>

**Figure 4. MR Findings that support or disfavor the diagnosis of appendicitis**

17 year old male with a normal appendix
Coronal HASTE demonstrates a tubular hypodense structure originating from the cecum, measuring 5 mm in diameter. No peri-appendiceal fluid or inflammation.

8 year old male with appendicitis
Axial T2 FS demonstrates a dilated appendix measuring 8 mm with thickened appendiceal wall, intraluminal fluid and peri-appendiceal fluid.

**Physician Education**

- MRI technique (motion, spatial resolution, etc)
- Pathology and surgical reports
- 1 month clinical follow up
- Alternative explanations for patient symptoms
- Good examples of positive and negative cases
- False positives, false negatives
Protocol Efficiency

- We compared the time parameters of the first 50 and last 50 rapid MRI exams performed at SAMMC for suspected appendicitis.

- Interval changes between first and last exam:
  - Abdominal radiograph removed from initial protocol.
  - Radiologist reviews US images and determines immediately if MRI is warranted. If so, the patient is sent directly to the MRI Suite.
  - Female patient no longer required to fill their bladder (for ovarian evaluation) resulting in decreased ER wait time.
  - Decreased number of MR sequences from 7 to 3.

### Table: Time Parameter Comparison Between the First 50 and Last 50 Rapid Appendicitis MRI Exams

<table>
<thead>
<tr>
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<th>First 50 Exams</th>
<th>Last 50 Exams</th>
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</thead>
<tbody>
<tr>
<td>Average number of sequences</td>
<td>7</td>
<td>3</td>
</tr>
<tr>
<td>Average repeated sequences</td>
<td>1.2</td>
<td>&lt;1</td>
</tr>
<tr>
<td>US Duration</td>
<td>22 Minutes</td>
<td>12 minutes</td>
</tr>
<tr>
<td>MRI scanning duration</td>
<td>21 minutes</td>
<td>11 minutes</td>
</tr>
<tr>
<td>US Start to MRI Finish</td>
<td>420 minutes</td>
<td>65 minutes</td>
</tr>
</tbody>
</table>

Figure 5. MRI Time Considerations

8 year old male with appendicitis

Left: Coronal HASTE image demonstrating a dilated fluid filled appendix.

Right: Axial T2 FS image demonstrating a thickened T2 hyper intense edematous appendiceal wall (arrows) with intraluminal T2 hyper intense fluid.
**Statistical Analysis**

506 patients* clinically suspected of having appendicitis aged 17 years or younger with equivocal ultrasound (or non-visualization of the appendix) underwent rapid MRI appendicitis imaging at SAMMC between April 2012 and Dec 2015.

* 6 cases were equivocal on MRI and were not included in the statistical analysis. These patients were admitted for observation and all were discharged without acute appendicitis

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**RESULTS**

506 patients clinically suspected of having appendicitis aged 17 years or younger with equivocal ultrasound (or non-visualization of the appendix) underwent rapid MRI appendicitis imaging at SAMMC between April 2012 and Dec 2015.

* 6 cases were equivocal on MRI and were not included in the statistical analysis. These patients were admitted for observation and all were discharged without acute appendicitis.

16 year old female with tip appendicitis.

**Left:** Axial T2 FS images demonstrate a dilated appendiceal tip with appendicolith and inflammation (arrow).

**Right:** Coronal HASTE demonstrating a dilated appendiceal tip (arrow).

**MRI was classified as either positive or negative**

**Positive**
- MRI findings consistent with appendicitis
- MRI secondary signs of appendicitis (e.g., free fluid with right lower quadrant, inflammation and no appendix visualized)

**Negative**
- Normal MRI appearance of the appendix
- Appendix not visualized but no secondary signs of appendicitis (inflammation or free fluid)

**11 % of all patient's suspected of having appendicitis were true positives (confirmed by surgery or pathology).**

<table>
<thead>
<tr>
<th></th>
<th>95% CONFIDENCE INTERVAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensitivity by MRI</td>
<td>96%</td>
</tr>
<tr>
<td>Specificity by MRI</td>
<td>98%</td>
</tr>
<tr>
<td>Positive Predictive Value</td>
<td>85%</td>
</tr>
<tr>
<td>Negative Predictive Value</td>
<td>100%</td>
</tr>
</tbody>
</table>

*Figure 6. Statistical Analysis*
**Alternative Diagnoses**

- Our exams proved useful in assessing alternative causes for the patients’ clinical presentation. And many abnormalities would be more difficult to interpret on ultrasound or CT

- Several non-appendiceal abnormalities were found to likely explain the patients’ symptoms

- All patients’ records were reviewed for 1 month following discharge to determine if any any patients returned with appendicitis

### Non-appendiceal abnormalities

<table>
<thead>
<tr>
<th>Abnormality</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ovarian Pathology</td>
<td>3%</td>
</tr>
<tr>
<td>Pyelonephritis</td>
<td>2%</td>
</tr>
<tr>
<td>Rectus Abdominus Edema/Tear</td>
<td>1%</td>
</tr>
<tr>
<td>Terminal Ileitis</td>
<td>3%</td>
</tr>
<tr>
<td>Pneumonia</td>
<td>1%</td>
</tr>
<tr>
<td>Other findings (mesenteric adenitis, choledolithiasis, large stool burden, UTI, Right hip osteonecrosis, right inguinal hernia)</td>
<td>11%</td>
</tr>
</tbody>
</table>

*Figure 7. Alternative diagnoses.*
Conclusions

1. MRI is an effective imaging modality for the evaluation of pediatric appendicitis and can be accurately interpreted by non-pediatric radiologists.

2. Because of the lack of ionizing radiation and IV contrast, non-sedated, rapid MRI may be considered more appropriate than CT in the pediatric population, which is at higher risk for radiation-induced malignancies and also has less tolerance for IV placement.

3. Clear communication with training of radiology residents, non-pediatric radiologists, clinicians and pediatric radiologists is paramount in guaranteeing the success of MRI in a predominantly adult medical center.

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References