ORIGINAL CONTRIBUTION

Magnetic Resonance Imaging Versus Ultrasound as the Initial Imaging Modality for Pediatric and Young Adult Patients With Suspected Appendicitis

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ABSTRACT

Background: While ultrasound (US), given its lack of ionizing radiation, is currently the recommended initial imaging study of choice for the diagnosis of appendicitis in pediatric and young adult patients, it does have significant shortcomings. US is time-intensive and operator dependent and results in frequent inconclusive studies, thus necessitating further imaging and admission for observation or repeat clinical visits. A rapid focused magnetic resonance imaging (MRI) for appendicitis has been shown to have definitive sensitivity and specificity, similar to computed tomography but without radiation and offers a potential alternative to US.

Objective: In this single-center prospective cohort study, we sought to determine the difference in total length of stay and charges between rapid MRI and US as the initial imaging modality in pediatric and young adult patients presenting to the emergency department (ED) with suspected appendicitis. We hypothesized that rapid MRI would be more efficient and cost-effective than US as the initial imaging modality in the ED diagnosis of appendicitis.

Methods: A prospective randomized cohort study of consecutive patients was conducted in patients 2 to 30 years of age in an academic ED with access to both rapid MRI and US imaging modalities 24/7. Prior to the start of the study, the days of the week were randomized to either rapid MRI or US as the initial imaging modality. Physicians evaluated patients with suspected appendicitis per their usual manner. If the physician decided to obtain radiologic imaging, the predetermined imaging modality for the day of the week was used. All decisions regarding other diagnostic testing and/or further imaging were left to the physician's discretion. Time intervals (minutes) between triage, order placement, start of imaging, end of imaging, image result, and disposition (discharge vs. admission), as well as total charges (diagnostic testing, imaging, and repeat ED visits) were recorded.

Results: Over a 100-day period, 82 patients were imaged to evaluate for appendicitis; 45 of 82 (55%) of patients were in the US-first group, and 37 of 82 (45%) patients were in the rapid MRI–first group. There were no differences in patient demographics or clinical characteristics between the groups and no cases of missed appendicitis in either group. Eleven of 45 (24%) of US-first patients had inconclusive studies, resulting in follow-up rapid MRI and five return ED visits contrasted with no inconclusive studies or return visits ($p < 0.05$) in the rapid MRI group. The rapid MRI compared to US group was associated with longer ED length of stay (mean difference = 100 minutes; 95% confidence interval [CI] = 35–169 minutes) and increased ED charges (mean difference = $4,887; 95% CI = $1,821–$8,513).

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Conclusions: In the diagnosis of appendicitis, US-first imaging is more time-efficient and less costly than rapid MRI despite inconclusive studies after US imaging. Unless the process of obtaining a rapid MRI becomes more efficient and less expensive, US should be the first-line imaging modality for appendicitis in patients 2 to 30 years of age.

Appendicitis is the most common surgical emergency in pediatrics[1,2] with more than 70,000 children being diagnosed with appendicitis in the United States each year.[3,4] Appendicitis is a treatable disease that when diagnosed early has a minimal risk of complications. Delayed or missed diagnosis may result in appendicular gangrene, perforation, sepsis, and death. However, the clinical diagnosis of appendicitis is often difficult in children despite laboratory testing and clinical decision rules.[5–7] Therefore, radiologic imaging plays a vitally important role in early accurate diagnosis and improving the negative appendectomy rate at surgery.[5,6] Evaluations of ultrasound (US), computed tomography (CT), and magnetic resonance imaging (MRI) have all shown similar diagnostic accuracies of clinically suspected acute appendicitis;[7] however, it still remains unclear which initial modality optimizes time- and cost-effectiveness.[8]

Ultrasound has become the recommended imaging modality of choice in pediatric patients and young adults because it does not involve ionizing radiation.[9] In addition, it may also be able to decrease ED length of stay through the use of point-of-care use by ED providers.[10] However, it lacks the necessary sensitivity and specificity to be a definitive study in many patients. In particular it is highly operator dependent, requires a dedicated technician, and has decreased effectiveness in large and obese individuals.[11] This results in significant variability in the percentage of diagnostic studies where the appendix is adequately visualized (44%–100%).[7,12,13] Patients with inconclusive studies for appendicitis may require further testing, inpatient observation, or return visits for reassessment. CT technology is widely available and definitive, having a high sensitivity and specificity for the diagnosis of appendicitis. Additionally CT may determine an alternative diagnosis for abdominal pain. CT remains the most common imaging study performed (especially outside of tertiary centers) prior to appendectomy in children in the United States.[14–16] However, CT utilizes ionizing radiation, which may be associated with a cumulated risk of radiation-related cancer in children and young adults.[17–21] MRI may also be used to image the abdomen for appendicitis with high sensitivities and specificities equivalent to CT.[22–29] However, MRI is not as commonly available as CT and may not tolerated in young children (especially under age 5).[11] Recently, short-duration, limited MRI protocols (rapid MRI) specific for appendicitis have been developed which allow for the scan to be completed in 10 to 15 minutes, rather than the 1+ hours for a typical MRI abdomen/pelvis, making it a more viable diagnostic option in the ED and for children.[19,30] Although the prevalence of ED MRI is limited[31] there is an increasing trend toward availability.[32,33] Several institutions in the United States have adopted clinical pathways using US in conjunction with rapid MRI to diagnose appendicitis, with clinical efficiency and costs similar to CT.[10,34]

Goals of This Investigation

We hypothesized that using rapid MRI as the initial imaging modality would be more time-efficient and cost-effective than an US-first approach in the emergency department (ED) diagnosis of appendicitis.

METHODS

This randomized study adheres to the CONsolidated Standards of Reporting Trials (CONSORT) reporting guidelines as described in the 2010 consensus statement.[35]

Study Setting and Population

We conducted a prospective randomized study of consecutive patients between 2 and 30 years of age who presented to a suburban academic ED from July 1, 2014, until October 31, 2014. The ED has dedicated pediatric and adult areas and has access to 24/7 US and rapid MRI capabilities. US images were obtained by highly trained and experienced sonographers, which were reviewed by a radiology fellow in real time followed by a final review by an attending radiologist. The rapid (10–15 minutes) MRI appendix protocol consisted of three planes of single-shot T2-weighted imaging, each with and without fat saturation, axial diffusion, and axial postcontrast imaging. Images with and without contrast were obtained. The MRIs were read by radiology fellows, with a final review completed by the attending radiologist. The young adult population up to age 30 was included as, although less than the pediatric population, they continue to have an increased cancer risk from ionizing radiation.[36,37]

Study Protocol

Prior to the study, each day within the study period was randomized (randomizer.org) by a research assistant to either rapid MRI or US as the initial diagnostic imaging modality. A calendar specifying the imaging modality for each day was posted in the ED. All physicians practicing in the ED were informed of the study. If the physician was ruling out appendicitis as their primary differential diagnosis and would proceed to a second-stage imaging if US were indeterminate; they were asked to use the imaging modality assigned for that day to rule out appendicitis. Physicians were given the opportunity to opt out of using the daily imaging strategy if the primary reason for the study was not appendicitis and/or they wanted to explore other diagnoses with an alternate imaging strategy.

Patients were identified through a real-time electronic tracking system that linked all imaging orders for suspected appendicitis to cell phone texts and e-mail alerts. Eligible patients were consecutively entered into the study database. If the alternate study for the particular day was ordered by the physician, the research coordinator contacted the physician and asked him or her to follow the specified imaging modality for that day. Physicians were not otherwise instructed in their practice patterns and performed laboratory testing, therapeutics, and clinical decision making, including surgical consultation and disposition, in their usual manner.

Patients met criteria for the study if the treating physician's primary differential diagnosis included appendicitis. Patients were excluded from the study if they had a surgical consultation prior to starting either strategy, appendicitis was not the primary differential diagnosis, contraindications existed for US or rapid MRI (e.g., metal implantations), the patient experienced incapacitating intolerance/claustrophobia despite anxiolysis for imaging or the provider did not follow the randomized imaging protocol. For instance, if a patient received an US first on a day that was scheduled to be rapid MRI first they were then excluded. A study physician reviewed all patients to confirm eligibility.

Appropriateness for rapid MRI was left to the treating physician's discretion with the understanding that children under 5 years of age were unlikely to tolerate even the shortened rapid MRI procedure. Anxiolysis but not sedation was available for patients undergoing rapid MRI, but only given in the ED, with no accessibility once in the MRI scanner. On most days from noon until midnight a child life professional was present in the ED and assisted in preparing all children for US or MRI.

Measurement of Key Outcomes

Time measurements were determined directly from the ED electronic medical record. Total length of stay in the ED was defined as the time from arrival in the ED to the time of ED disposition (admission or discharge decision recorded in the electronic medical record). Time to order was determined from the patient's triage time to the time the order for imaging was placed. Time to imaging was determined from the time an order for imaging was placed to the time the patient left the ED for imaging. Imaging time was determined from the time a patient left the ED for imaging until they returned to the ED. Result time was determined as the time the imaging study was completed until a preliminary read was available from the radiology fellow to the treating physician (Figure 1).

Total ED charges for each patient were available from our hospital billing department. Charges from repeat visits to our ED within 7 days for symptoms consistent with the initial patient complaints were included for analysis.

Patients were followed through the electronic medical record to determine the number of patients diagnosed with appendicitis, secondary/incidental diagnoses, missed diagnoses, return visits, hospitalizations, and complications. Patients who did not return were contacted by phone by a research coordinator starting at 7 days after ED visit to ensure all outcomes were taken into account.

Sample Size and Data Analysis

We calculated that we would need 35 patients in each group to determine a 10% difference (20 minutes) in estimated mean ED length of stay using an alpha of 0.05 and 80% power. Categorical and continuous data were compared with chi-square and parametric analysis where appropriate using SPSS version 22. Sensitivity and specificity of US and rapid MRI were calculated using surgical pathology or 7-day phone follow-up as the reference standard as it was thought that the

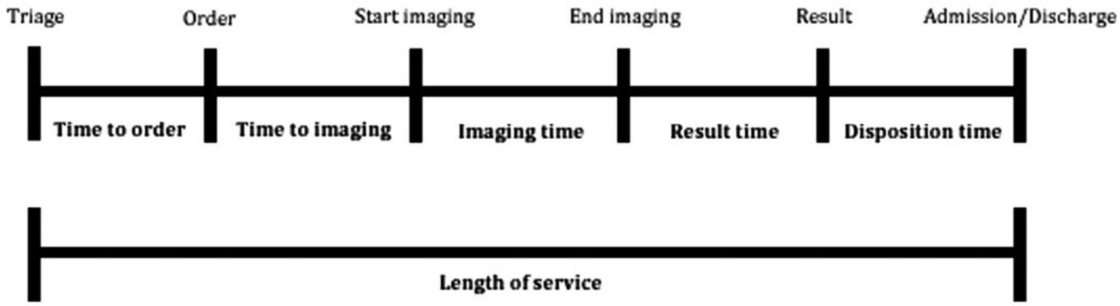

Figure 1. Timeline of ED encounter.

chances of a missed appendicitis with these parameters were low and it was consistent with the recent meta-analysis examining the sensitivity and specificity of US versus CT versus MRI.[12]

Institutional Review Board Determination

The institutional review board determined that the study could be performed under a waiver of consent since the days of the week, not patients, were being randomized and all investigations and treatment were within the standard of care.

RESULTS

Over the 100-day study period, 82 patients met criteria for the study; 45 of 82 (55%) of patients were in the US-first group, and 37 of 82 (45%) patients were in the rapid MRI–first group. No differences in patient demographics or clinical characteristics were noted (Table 1). Sensitivity and specificity of MRI and US were calculated (Table 2). There were no significant discrepancies between the fellow and final attending interpretation of any imaging. All patients requiring 7-day phone follow-up were able to be contacted. Ninety-three patients were excluded from the study: 40 (43%) for appendicitis not being the primary differential diagnosis, 35 (38%) for the study protocol not being followed, 13 (14%) because the provider determined the patient was too young to tolerate rapid MRI imaging, three (3%) as the imaging modality was not available (broken or lack of technical support staff), and two (2%) as imaging had previously been performed. No patient that attempted rapid MRI or US was unable to complete the procedure.

The US group had 11 (24%) patients with inconclusive studies resulting in follow-up rapid MRIs and five return ED visits, each for continued abdominal pain. None of the patients with inconclusive US ended up being diagnosed with appendicitis (Figure 2). The rapid MRI group had no inconclusive studies or return visits ($p < 0.05$). The rapid MRI group was associated with longer ED length of stay (mean difference = 100 minutes; 95% confidence interval [CI] = 35–169 minutes).

Table 1
Characteristics of Enrolled Patients by Imaging Modality (n = 82)

Variable	US (n = 45)	Rapid MRI (n = 37)
Male	20 (44.4)	11 (29.7)
Age (y)	12.3	13.5
Race		
White/non-Hispanic	12 (27)	13 (35)
Hispanic	22 (49)	14 (38)
Black	0 (0)	1 (3)
Asian	5 (11)	6 (16)
Other/unknown	6 (13)	3 (8)
Historical symptoms		
Fever, ED	10 (22)	9 (24)
Fever, home	8 (18)	6 (16)
Nausea	23 (51)	24 (65)
Vomiting	18 (40)	18 (49)
Diarrhea	9 (20)	7 (19)
Anorexia	23 (51)	23 (62)
Physical findings		
RLQ tenderness	36 (80)	34 (92)
Laboratory findings		
White blood cell count	6,360 mm^3	10,784 mm^3

Data are reported as number (%) or mean.
RLQ = right lower quadrant.

All cases of appendicitis were identified during initial diagnostic imaging (Figure 2). Of the 20 patients diagnosed with appendicitis, 11 diagnoses were made with US and nine with rapid MRI. There was one false-positive case with each imaging modality. One US was positive for appendicitis, but the pathology report was negative for appendicitis. One MRI reported early signs for appendicitis, but no visualization of the appendix; the pathology report was negative for appendicitis, but positive for Meckel's diverticulum. More secondary or alternative diagnoses

Table 2
Sensitivity and Specificity of Each Imaging Modality

	US (n = 45)	Rapid MRI (n = 37)
Sensitivity	10/10, 100% (95% CI = 69.2%–100%)	8/8, 100% (95% CI = 63.1%–100%)
Specificity	34/35, 97.1% (85.1% CI = 85%–99.9%)	28/29, 96.6% (82.2% CI = 85%–99.9%)

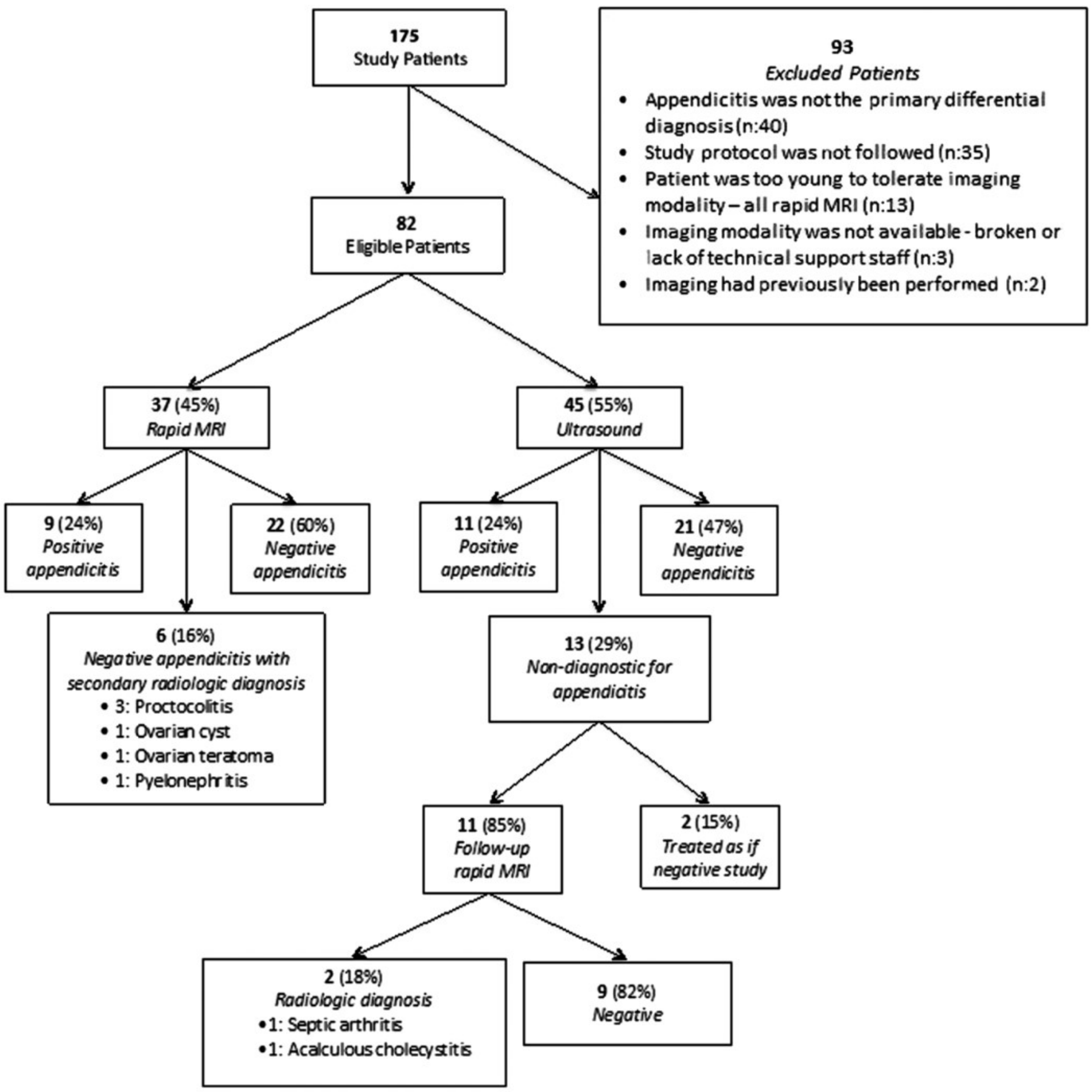

Figure 2. Diagnostic outcomes for each imaging modality.

were identified in the rapid MRI group than in the US group.

A breakdown of the ED length of stay (Table 3) demonstrated that the majority of the difference was from the order for imaging being placed to the start of imaging (mean difference = 64 minutes). Total imaging time (mean difference = 34 minutes) and time to order (mean difference = 18 minutes) also significantly

Table 3
Mean Length of Time (Minutes) to Various Endpoints in Each Imaging Modality

	US	Rapid MRI	Mean Difference
Time from triage to imaging order	56	74	18
Time from imaging order to the start of imaging	61	126	65
Imaging time (includes transport to and from)	28	62	34
Time from the end of imaging to radiology result	–2*	–8*	6
Total time from triage to radiology result	143	254	111
Total ED length of stay	299	399	100

*The negative numbers represent the fact that the radiologist was able to phone the ED physician with the result of the study before the patient physically returned to the ED from the imaging suite.

Table 4
Mean Triage to Imaging Result (Minutes) for Specific Age Subgroups and Time of Day

	US	MRI	Difference
Age-based triage–imaging result (min)			
0–5 y	114 (n = 5)	388 (n = 2)	274
6–10 y	138 (n = 14)	270 (n = 12)	132
11–30 y	163 (n = 26)	238 (n = 23)	75
Time of day triage–imaging result (min)			
Daytime (7:00 AM-6:00 PM)	136 (n = 16)	238 (n = 13)	102
Nighttime (6:00 PM-7:00 AM)	158 (n = 29)	266 (n = 24)	108

contributed to the overall difference in time. Although the number of subjects was too small for full analysis, we evaluated subgroups of patients based on demographic characteristics and time of day (Table 4). Imaging during daytime radiology staffing hours (7:00 AM-6:00 PM) was associated with shorter time from triage to imaging result for both US (mean difference = 21 minutes) and MRI (mean difference = 28 minutes). In addition, a trend in mean difference in time from triage to imaging result appears to decrease as age of the patient increases: 0 to 5 years (274 minutes, n = 7), 6 to 10 years (132 minutes, n = 26), and 11 to 30 years (75 minutes, n = 49).

In terms of costs, the rapid MRI group was associated with increased total charges (mean difference = $4,887, 95% CI = $1,821–$8,513). The US group had five patients return to care, which contributed $604 to the mean difference of total charges. Additionally the US group had 10 patients versus two from the MRI group visit primary care within 7 days for continuation of the same complaints. This contributed $141 to the difference in total charges. Overall, $745 (15%) of the mean difference can be attributed to subsequent clinical care in our study.

DISCUSSION

In this study of patients being imaged for the primary concern of appendicitis, an US-first compared to rapid MRI–first strategy was more time- and cost-efficient for the diagnosis of appendicitis. Neither imaging modality missed any cases of appendicitis although 11 patients in the US-first group had inconclusive results that resulted in subsequent rapid MRI. When used, rapid MRI uncovered several alternative diagnoses (Figure 2).

The commonly recommended strategy for diagnostic imaging in pediatric appendicitis is a stepwise approach with either US followed by CT, US followed by rapid MRI, or in some places US followed by observation and repeat US.[10] Given the increasing awareness of potential cancer risk of ionizing radiation associated with pediatric CT scans and the inconclusive potential of US, our hypothesis was that rapid MRI might be more efficient as the initial and only diagnostic modality in the diagnosis of appendicitis. This idea has gained prominence given the increase in access to rapid MRI in recent years and a sensitivity and specificity approaching 100%.[22–29] Given that after an indeterminate US, repeat imaging, and longer stays are inevitable, it was not clear which strategy would be more efficient.

Our data show that as an initial test, rapid MRI is less cost-effective and less time-efficient (even with a "rapid" abdomen protocol) than US as the first-line diagnostic modality of choice. Our findings of increased time to rapid MRI imaging, compared to US, may be the results of multiple institutional parameters for which we were unable to control, e.g., imaging location (rapid MRI in dedicated suite, 10 minutes of travel vs. US in ED radiology, 5 minutes of travel), MRI safety protocols, lack of anesthesia/sedation support in MRI, and MRI/US availability based on patient volume, which creates extended wait times for the limited imaging capacity. These factors could account for the increased time from the placement of the imaging order to start of imaging. A previous study by Moore et al.[24] showed a mean time from rapid MRI order to completion of 78.7 minutes, significantly less than our 126 minutes. This may be a result of their previous experience with the logistics of completing a dedicated rapid MRI compared to our recent implementation (6 months). Other studies have not directly quoted their time efficiency metrics (nor the breakdown of times at different parts of the imaging process) making generalizations difficult from this data. We tried to address some of these differences by reporting on the specific time points from triage to imaging result. The largest difference we found was the time between the physician placing the imaging order and imaging process starting (65 minutes). This may represent decreased availability of rapid MRI compared to US at our institution based on patient load or a lack of experience in expediting rapid MRI as it represents a new modality. In addition, patients undergoing rapid MRI must complete an MRI screening form prior to imaging and must travel to the MRI scanner, which also requires extra positioning and movement of the patient. In discussion with our ED staff the consensus was that transport, patient education, and delivery of anxiolysis were not significantly different between MRI and US and that waiting for MRI availability was the main driver of the difference in times although we were unable to measure quantitatively these differences. If so, iterative quality improvement projects or investment in additional MRI capacity may be able to drastically reduce the overall time difference between these modalities. Daytime versus nighttime imaging did not appear to significantly affect the time from triage to imaging result between US and MRI, although it was associated with longer length of stay in both groups.

In addition to the increased length of stay, rapid MRI was also associated with increased charges. While the actual operating cost may be a fraction of these charges, the MRI-first strategy was still more expensive than US first. At our institution MRI charges are similar to charges for a CT of the abdomen/pelvis. It may be possible that as our institution increases its volume of MRI studies, the charges for rapid MRI might be decreased. In addition, rapid MRI is currently charged the same rates as a full MRI abdomen/pelvis, rather than as a limited study. We were not able to determine the cost-effectiveness in terms of the alternative diagnoses found on MRI and the impact on care if those diagnoses were delayed or missed. Elucidation of these diagnostic findings may increase the value of MRI first versus US imaging. Although the US group was associated with an increased number of return and primary care visits, the charges associated with these visits represented only a small fraction (15%) of the overall mean difference in charges. We also did not have access to an itemized list of charges, which would have allowed for a more detailed understanding of the origin of the difference in total charges. Additionally, there may be costs that we were unable to account for such as productivity lost from repeat visits, delayed diagnosis, or institutional delivery/time saving costs. Further study into the exact nature of these costs may be useful to determine how the initial imaging decision may impact different hospital systems.

The 2015 AEM Consensus Conference "Imaging in the Emergency Department" set forth the goal of encouraging value-based care and limiting overutilization of ionizing radiation in the imaging decision making of emergency medicine providers.[38,39] To this end, our findings support the continued use of US as the initial diagnostic imaging study to maximize value in pediatric and young adults undergoing imaging for suspected appendicitis. In addition, this strategy is consistent with the "Choosing Wisely" recommendation by the American College of Radiology to limit CT use until after US has been considered as an option.[40]

Given these results, our institution has moved to a staged pathway in our pediatric and young adult population with US as the primary modality and rapid MRI as the secondary option if the appendix is not adequately visualized and continued clinical concern for appendicitis is present. Furthermore, we have focused on determining which patients will be more likely to have an indeterminate US and to apply an MRI-first strategy to these patients. For example, in patients who are greater than the 85th percentile for body mass index, we recommend that physicians consider using rapid MRI as the initial diagnostic test given the probability of an indeterminate US.[41] CT is used only for patients unable to tolerate the rapid MRI or who have other specific reasons indicating the need for CT. This pathway may not be generalizable to other institutions with different characteristics (24/7 US and rapid MRI imaging resources, radiologist familiarity, location factors). Although our study may have limited applicability to nonacademic EDs delivering pediatric emergency care, our results continue to support, at minimum, the continued pursuit of US whenever possible prior to the use of CT or MRI.

LIMITATIONS

The results of our study may not be generalized due to the time, charge, and resource factors outlined in the discussion. Our study was also limited by even/odd day randomization schedule that was chosen as the completion of unrestricted randomization was deemed too unreliable given the highly variable coverage schedule of the ED. Also, there were a disproportionate number of females in the study (US 66%, rapid MRI 70%), which may be due to an intrinsic bias in ED providers assessing abdominal pain. Additionally, if patient has returned for care outside of our hospital's network we were unable to quantify their additional costs. Finally, we did not include point-of-care US as part of the study protocol. This modality, although requiring technical expertise, has been shown to decrease length of stay and may have further exaggerated the findings in our study.[10]

Despite these limitations the magnitudes of our findings make us fairly confident that the results are accurate and likely reproducible by other similar centers. As such we recommend a strategy for utilizing an US-first strategy in the majority of patients requiring imaging to rule out appendicitis even when rapid MRI resources are available. Further analysis may be needed if billing charges are changed to reflect the limited nature of the rapid MRI of the appendix. Finally we did not conduct a cost-effectiveness analysis to consider the financial impact of delaying or missing a diagnosis. For example, a rare osteomyelitis on MRI could have been missed if the appendix was visualized as normal in an US-first strategy and the physician did no further investigation.

CONCLUSION

Despite inconclusive studies and return visits, ultrasound-first imaging is more time-efficient and less costly than rapid magnetic resonance imaging, making it the preferred diagnostic approach when appendicitis is the primary and most important diagnosis in the differential of pediatric and young adult patients.

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