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A simple MRI protocol in patients with clinically suspected appendicitis: results in 138 patients and effect on outcome of appendectomy

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Abstract To establish the value of breathhold magnetic resonance imaging (MRI) in the diagnosis of acute appendicitis. Over a 14-month period, 138 patients clinically suspected of having appendicitis were evaluated prospectively with MRI and comprised the study group. Fast turbo spin-echo breathhold T1, T2 and T2 fat suppression sequences were used in coronal and axial planes. The imaging results were recorded separately and subsequently correlated with clinical, radiological and histopathological follow-up. The effect of imaging strategies in patients suspected of appendicitis on hospital resources was calculated. Sixty-two of the 138 patients had a histopathologically proven appendicitis. MRI determined appendicitis in 63 patients, with one examination being false positive. The resulting sensitivity and specificity were 100% and 99%, respectively. MRI showed an alternative diagnosis in 41 of the 75 remaining patients. In 22 of the remaining 34 patients, a normal appendix was depicted with MRI. In two patients, where MRI showed no appendicitis, an alternative diagnosis or normal appendix, an unnecessary appendectomy was performed. The overall effect of using MRI in patients suspected of appendicitis on the use of hospital resources could have been a net saving between € 55,746 and € 72,534. MRI has a high accuracy in detecting and excluding appendicitis, an alternative diagnosis or showing the normal appendix, and can be a valuable and cost-effective tool in the workup of patients clinically suspected of having appendicitis.

Keywords Gastrointestinal · MRI · Appendicitis · Appendix

Introduction

Acute appendicitis is the most common cause of acute right lower quadrant abdominal pain and of emergency abdominal surgery. Traditionally, surgeons have accepted a high negative appendectomy rate (15-30%) in patients with suspected appendicitis, in order to avoid a high number of perforated appendicitis cases [1–5]. Over the past 2 decades, transabdominal ultrasound (US) and abdominal computed tomography (CT) have been increasingly used in an effort to cut down both the negative appendectomy rate and ill-advised delay, possibly leading to perforation and its sequelae [6].

There have been reservations regarding the sensitivity and/or specificity of US, ascribed to variability in operator abilities or because the appendix cannot be seen due to obesity of the patient or a retrocecal position; in these circumstances CT can be an alternative [7, 8].

The major disadvantage of CT is the considerable amount of radiation that is involved. A typical dose for an abdominal CT examination is about 10 mSv, meaning that one CT examination carries about the same radiation dose as 500 chest radiographs [9]. An effective dose of 10 mSv corresponds to an excess risk of radiation-induced cancer of 1 in 2,000 [10, 11]. A recent article by Brenner and Hall in the NEJM concerning the increasing source of radiation exposure by CT in the general population [12] received a lot of media attention in the Western world and made the general public more aware of these radiation-related issues.

One can therefore make the assertion that the routine use of diagnostic CT examinations in the case of benign diseases, such as appendicitis, is to be avoided, especially in young patients and in pregnant women; it is reasonable to propose that US or possibly MRI should have preference.

During the past decade, MRI has become widely available in the Western world. Technological developments have made ultrafast sequences possible, resulting in shorter examination times and fewer motion artifacts. Detection of appendicitis with MRI has been published in a small group of pregnant and non-pregnant patients [13–19]. This is, to our knowledge, the first prospective blinded clinical study, in more than 100 patients, to evaluate MRI in patients clinically suspected of having appendicitis.

The aim of our study therefore was to:

1. establish the clinical value of MRI imaging in patients with suspected appendicitis;
2. evaluate other added values such as financial or practical consequences.

Materials and methods

Patient population

This prospective study included 138 patients who, between January 2005 and October 2006, were directly referred to the radiology department by the emergency department physician. In this period 142 consecutive patients (80 female, 62 male; age range 6–80) with clinically suspected appendicitis visited our institution (a 350-bed community hospital), and all underwent an abdominal US study (as is the policy in our hospital) for suspected appendicitis.

After the US examination, 138 patients underwent an abdominal MRI examination; this group (n=138) then made up our study group.

Of the original 142 patients, 3 refused the MRI examination because of claustrophobic anxiety (2 had a US and surgically proven appendicitis; 1 had a US-diagnosed non-palpable rectus sheath hematoma); for 1 patient with a US- and histopathologically proven appendicitis, an MR could not be performed, as the machine was out of order.

The medical ethical commission of the hospital approved the study, and written informed consent of the patient was obtained prior to the MRI examination.

Clinical evaluation

The referring physicians had to fill in a form before requesting imaging, in which they scored the chance of the patient having appendicitis: low, moderate or high.

1. Patients with a *high* chance would have been those patients taken to surgery without imaging;
2. the *moderate* group was made up of the patients in whom no immediate appendectomy would have been performed, but these patients would have been hospitalized for clinical evaluation, to rule out a developing appendicitis;
3. the group with a *low chance* of having appendicitis was made up of patients who were to be followed by a clinical follow-up within 12–24 h on an out-patient basis.

MRI technique

All MRI examinations were performed on a 1.0-T system (Siemens, Erlangen, Germany). Breathhold T1 FLASH (TR 133 ms/TE5, 5 ms/flip angle 75), T2TSE (3,300/108/160) and T2TSE fat-suppression (3,360/108/160) sequences were obtained using a body phased array coil with two elements. No sedation or anesthesia was used. A multislice imaging technique was used for all patients with 5-mm-thick slices with a distant factor of 0.5 mm with acquisition times of 13–24 s. The FOV chosen was as small as possible, ranging from 260 to 400 mm, and was dependent on the patients habitus. First, six scout images were obtained. Then, T2TSE-weighted slices were obtained in the coronal plane around the region where the ileocecal region was suggested as seen on the scout images. Following this T2 coronal sequence, the other sequences were made, and if necessary, extra sequences were obtained in the axial plane when the entire region of interest was not included in the volume. Because we used a basic MRI protocol, only consisting of T1, T2 and T2 fat suppression breathhold sequences, the average MRI examination was completed within 20 min from patient registering, positioning the patient on the table and reviewing the images with preliminary results. Prior to the examination, the technician explained the MRI procedure to the patient and trained the patient in holding their breath for about 20 s, using a hyperventilation method, implying three deep breaths, followed by a breathhold during deep inspiration. All patients could perform this adequately, and no major breathing artifacts were seen.

MRI interpretation

The MRI criteria for appendicitis were an enlarged appendix with a diameter of 7 mm or more and signs of periappendiceal inflammatory changes, such as fat stranding, phlegmon or a frank abscess (Fig. 1) [20]. The MRI criteria that excluded appendicitis were a normal appendix of 6 mm or less, or an appendix with a diameter of more than 6 mm without evidence of peri-appendiceal inflammatory changes (Fig. 2) [20].

The MRI studies were all performed within 1 h of the US studies. US and MRI were performed as a 24-h service with a policy to postpone imaging studies ordered between 12 P.M. and 7 A.M. to the subsequent morning, if the condition of the patient allowed for such an operative delay. It is the policy in our hospital not to operate on patients with appendicitis after midnight, unless the patient is very ill. During the study period no patient underwent surgery for appendicitis between midnight and 7 a. m.

In the clinical setting, the MRI studies were prospectively interpreted by a gastrointestinal radiologist (LC, JP, EC), with at least 5 years of experience, who was blinded to the results of the US studies. There were four possible MRI results: (1) acute appendicitis, (2) normal appendix visualized but no alternative condition detected, (3) alternative condition explaining the clinical symptoms, with or without the demonstration of a normal appendix, or (4) equivocal: when no appendix was identified, no inflammatory changes in the peri-appendiceal region and no alternative diagnosis that explained the clinical symptoms; this was considered as negative for appendicitis.

These initial interpretations became the MRI study results.

These results, combined with the US results, were conveyed to the referring clinician, who integrated these results into the final case management decision.

The time from the request for imaging by the referring physician until the time the imaging reports were made available was assessed and defined as imaging time.

Patient follow-up

All patients with radiological signs of appendicitis or with clinically high suspicion of having appendicitis were operated on within a few hours of the MRI studies.

The pathological criteria for acute appendicitis were the presence of polymorphic granulocytes throughout the appendiceal wall, including the muscularis [21]. When peroperatively there was a macroscopic hole in the appendix, an appendicular abscess or presence of pus in

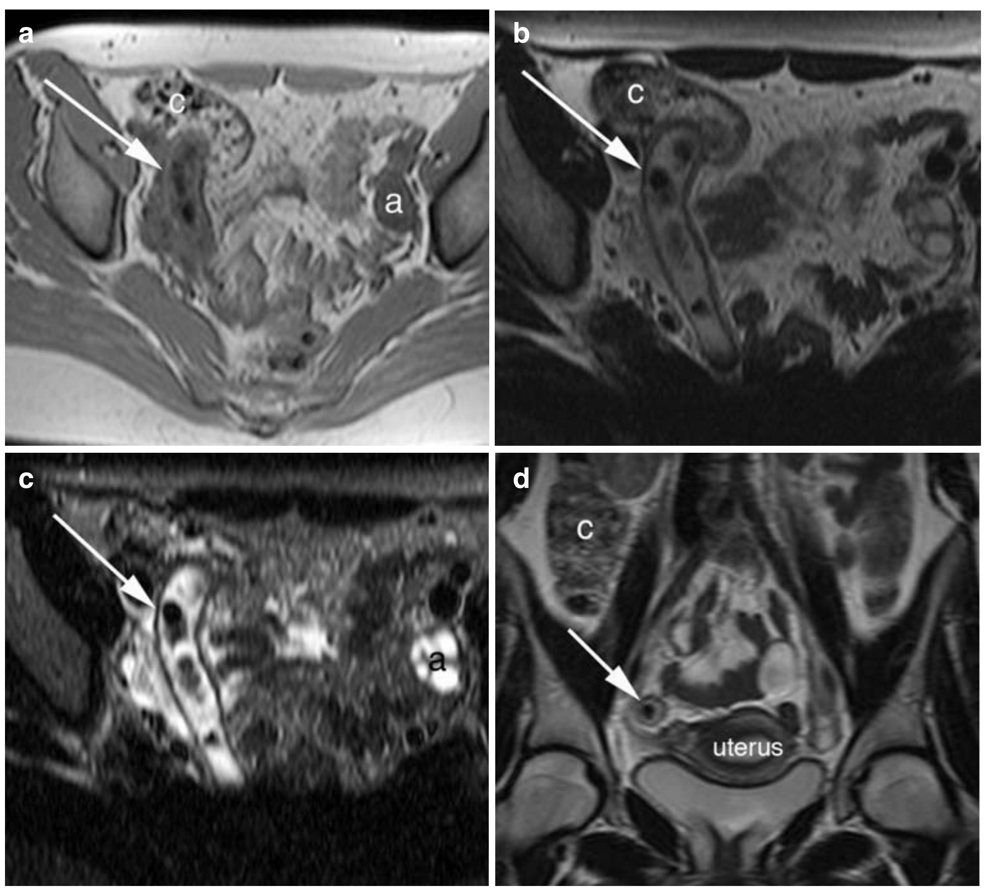

Fig. 1 A 16-year-old female clinically suspected of having appendicitis. Transverse T1- (**a**), T2- (**b**), T2-fat-suppression- (**c**) and coronal T2- (**d**) weighted images show an inflamed appendix (arrow), with a diameter of 12 mm and with signs of periappendicitis and an intraluminal fragmented appendicolith. Surgery and pathology revealed an empyematous appendicitis without perforation. C = cecum, a = left adnex

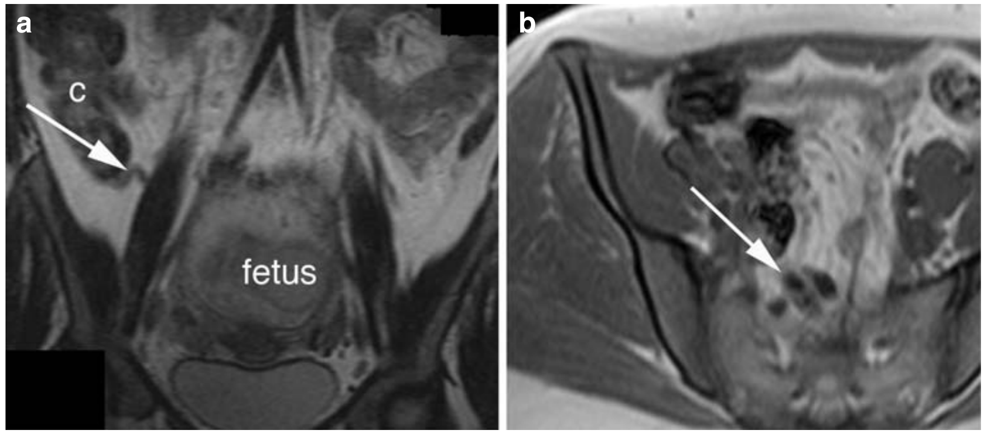

Fig. 2 A 26-year-old pregnant female (a) and an 18-year-old woman (b) both clinically suspected of having appendicitis. Coronal T2- (**a**) and transverse T1- (**b**) weighted images show a normal appendix (arrow) without secondary signs of appendicitis. C = cecum

the abdomen, this was considered as a case of perforated appendicitis [21].

Patients who had no specific radiological findings suggestive of appendicitis and thus did not undergo surgery were sent home and were clinically followed up at the outpatient clinic within 1 week. None of them developed appendicitis or complications of a possible missed appendicitis in the follow-up period of at least 2 years.

Statistical analysis

True-positive cases were those with a positive imaging diagnosis at MRI for appendicitis and histopathological confirmation. True-negative results were those with negative imaging results for appendicitis, or with imaging results of an alternative diagnosis explaining the clinical condition, and did not develop appendicitis at follow-up. The sensitivity, specificity, positive and negative predictive values for detecting acute appendicitis were calculated.

Effect of performing a MRI to diagnose appendicitis on the use of hospital resources

To calculate the effect of our imaging strategies in patients suspected of having appendicitis on hospital resources, the following data were collected from the financial department of the hospital (price index 2008): the mean cost of hospital admission for uncomplicated appendectomy, an emergency department evaluation, 1 hospital day of observation at the lowest level of severity of illness and the costs of US, CT and MRI examinations.

Results

Of the 138 patients, the final diagnosis was acute appendicitis in 62, an alternative diagnosis in 42 and non-specific abdominal pain (NSAP) in 34. Eight patients had a perforated appendicitis at surgery. Of the 76 patients who did not have appendicitis, 2 patients underwent appendectomy: histology confirmed a non-inflamed appendix. In the remaining 74 patients, symptoms resolved, and no patient in this group had appendicitis during the follow-up period (2–4 years).

Clinical results

In 61 of 138 patients suspected of having appendicitis, the clinical findings alone warranted an immediate appendectomy. Because only 39 of these 61 patients had a histopathologically proven appendicitis, a negative appendectomy rate of 35% would have been the result, showing 22 normal appendices being removed.

There were 64 patients in the group with moderate clinical suspicion of having appendicitis in whom clinical evaluation would have been warranted. In this group 18 patients had a histopathologically proven appendicitis.

The group with low suspicion of appendicitis consisted of 13 patients, in whom a clinical follow-up in 12–24 h was suggested on an out-patient basis. In this group, five patients had a surgically proven appendicitis.

US results

US was performed in all 142 patients. The US findings were interpreted as positive for appendicitis in 58 patients. In 57 the diagnosis was confirmed by subsequent surgery and pathology. One patient, in whom US showed an enlarged appendix, turned out to have acute pancreatitis and was not operated.

US findings showed a normal appendix in 10 patients, an alternative diagnosis in 29 and a combination of a normal appendix with an alternative diagnosis in 9 patients. If an equivocal US was deemed negative, sensitivity and specificity for detecting acute appendicitis were 88% and

99%, respectively; positive and negative predictive values were 98% and 90%, respectively. In 36 patients US showed no abnormalities at all, and also did not visualize the appendix; therefore, the result was deemed equivocal. In these 36 patients MRI showed acute appendicitis in 8, a normal appendix in 22 and an alternative diagnosis in 4.

MRI results

There were 62 true-positive results of MRI, and all correlated with surgical and pathological findings. There was one false-positive MRI, determined by means of resolution of symptoms at follow-up and not at surgery and pathologic examination. The false-positive MRI in this patient in whom an enlarged appendix of 8 mm with signs of periappendicitis and some fluid around the appendix was seen turned out to be early pancreatitis and was not operated (Table 1).

The true-positive MRI examinations each demonstrated two or more signs of appendicitis. All positive MRI scans depicted part or all of an enlarged appendix (>6 mm), and all showed periappendiceal inflammatory changes, usually fat stranding. The median diameter of the inflamed appendix was 10 mm (7–20 mm).

In 59 patients a normal appendix could be seen with a median diameter of 4.5 mm (3–8 mm).

There were 75 true-negative MRI results for appendicitis, which correlated with the pathologic findings at appendectomy in two patients and with the results of clinical follow-up with symptom resolution in 73 patients.

In 41 of 75 patients (55%) in whom the results of MRI were negative for appendicitis, an alternative diagnosis was identified at MRI examination (Table 2). Clinical and radiological follow-up suggests that these alternative diagnoses were correct in all.

In the end in 34 patients no diagnosis in relation with the appendicitis-like symptoms could be made with MRI, but in 22 of these patients a normal appendix could be seen with MR, thus excluding appendicitis (Table 1). In 12 patients the MRI was equivocal, but the combined imaging reports revealed that US showed a normal appendix in 10 of these patients.

The median imaging time ranged from 0.5 to 8 h with a median of 1.5 h. There was no difference in average imaging time for the perforated versus the non-perforated appendices.

Sensitivity and specificity for detecting acute appendicitis were 100% and 98%, respectively; positive and negative predictive values were 98% and 100%, respectively.

In our group of patients there were 38 patients younger than 20 years (6–20 years) and 5 pregnant patients. In the 38 young patients MRI showed an inflamed appendix in 18, which was confirmed at appendectomy, a normal appendix in 12 and/or an alternative diagnosis in 10. In six young patients the MRI was equivocal, meaning no appendicitis, a normal appendix or an alternative diagnosis was detected. But in five of these patients US had depicted the normal appendix. In one young patient in whom neither MRI nor US could depict the appendix or an alternative diagnosis, an appendectomy was performed, and a normal appendix was removed. Of the five pregnant patients, in three a normal appendix could be seen with MRI and an alternative diagnosis as well. In two pregnant patients MRI was positive for appendicitis; in one of these two, US did not visualize the appendix. The MRI study prevented an unnecessary operation in three pregnant patients by demonstrating the normal appendix.

In ten young patients in whom the US study was equivocal, MRI examination showed a normal appendix in

Table 1 MRI results in relation to the final diagnosis in 138 patients clinically suspected of having appendicitis

MRI results	Final diagnosis			
	Appendicitis	Alternative diagnosis	NSAP	Total
Appendicitis	62	1		63
Normal appendix, no alt. diagnosis			22	22
Alternative diagnosis		41		41
Equivocal			12	12
Total	62	42	34	138

NSAP = non specific abdominal pain

Table 2 Alternative diagnoses in 41 patients, as demonstrated by MRI

Diagnosis	MRI
Gynecological	
Tubo-ovarian abscess	1
Ovarian torsion	3
Urologic	
Kidney hydronephrosis	3
Ureteral stones	4
Pyelonefritis	1
Gastroenterologic	
Mesenteric adenitis	9
Ileocecal intussusception	1
Terminal ileitis (bacterial or Crohn's)	10
Cecal carcinoma	1
Cecal diverticulitis	2
Sigmoid diverticulitis	1
Segmental omental infarction	1
Appendagitis epiploica	1
Non-palpable rectus sheath hematoma	2
Cholecystitis	1
Total	41

five, an alternative diagnosis in two and an inflamed appendix in two. In one both US and MRI were equivocal.

Effect of MRI on the use of hospital resources

The mean cost of hospital admission for unnecessary appendectomy in a patient without another condition requiring surgery is € 3,453. The mean cost of an emergency department evaluation is € 137, and thus the savings resulting from preventing an unnecessary appendectomy after the cost of the initial emergency department evaluation has been subtracted is € 3,316. The overall cost savings from the prevention of 22 appendectomies among the 138 patients was therefore € 72,952.

The mean cost of 1 hospital day of observation at the lowest level of severity of illness is € 314. At least 64 hospital days of observation were avoided because of the imaging results: 46 days for patients discharged from the emergency department and 18 days for patients who had necessary appendectomies without being first hospitalized for observation. Thus, the total cost savings from the 64 avoided days of hospital observation was € 20,096. Total savings were € 93,048.

In our institution, sonography of the abdomen costs € 84, an abdominal CT € 230 and an abdominal MRI € 263. Because it is a policy in our hospital to perform an abdominal US in all patients suspected of having appendicitis, the total cost of the 138 appendiceal US examinations was € 11,592. The evaluation of the combined imaging reports revealed that in 36 of 138 patients, the US results showed no appendix and no alternative diagnosis explaining the clinical condition of the patients; a further evaluation with CT or MRI would have been the next step in our institution: MRI in patients younger than 20 years and in pregnant patients and CT in the others. In this group of 36 patients, in 22 patients a CT examination and in 14 patients (in this study 10 patients <20 years and 4 pregnant patients) an MRI would be the next step resulting in extra imaging costs of € 8,922. The total imaging costs in this group of patients based on the criteria above would have been € 20,514.

The overall effect of these imaging examinations on the use of hospital resources was a net saving of € 72,534 (Table 3).

If MRI had been performed as a first imaging study in all 138 patients, this would have cost € 36,294 and an added € 1,004 for 12 extra US studies in those MRIs that were equivocal, meaning total imaging costs of € 37,302. The overall effect on the use of hospital resources would then be a net saving of € 55,746.

Table 3 Effect of US, and optional CT or MRI on the treatment and use of resources for 138 patients with suspected appendicitis

Treatment change	No. of patients	Savings or costs per patients (euros)	Total savings or costs (euros)
Avoided unnecessary appendectomy	22	3,316	72,952
Avoided observation for 1 day before appendectomy	18	314	5,652
Avoided observation for 1 day before discharge	46	314	14,444
Savings			93,048
US	138	84	11,592
CT	22	230	5,060
MRI	14	263	3,862
Costs			20,514
Overall cost savings			72,534

Table 4 Outcome of appendectomy in 64 patients resulting in a negative appendectomy rate of 3% and a perforation rate of 13%

Condition	Outcome of appendectomy
Normal appendix	2
Acute appendicitis	54
Perforated appendicitis	8
Total	64

Discussion

In a recent study US has been advocated as the preferred imaging technique in adult patients with suspected appendicitis, with CT only recommended for patients with an equivocal US study [22]. In patients with suspected appendicitis, US examination with the option of additional CT significantly lowers the negative appendectomy rate as compared to the clinical acumen alone, without adverse effects on the perforation rate or in-hospital delay [23]. A major disadvantage of CT remains the considerable radiation dose, which is especially important in children, young patients and pregnant patients.

MRI has been reported to obtain good results for excluding or detecting appendicitis [13–17, 19]. Our prospective study in a large group of patients confirms that MRI yields excellent diagnostic results and markedly decreases the negative appendectomy rate, without an increase in perforation rate. There were 8 patients with perforated appendicitis in the group of 62 patients with appendicitis, resulting in a perforation rate of 13%, which is low compared to rates reported in surgical surveys (10–28%) [24–27] (Table 4).

All in all, there was only one false-positive diagnosis of appendicitis and two patients for whom MRI was equivocal and eventually an unnecessary appendectomy was performed.

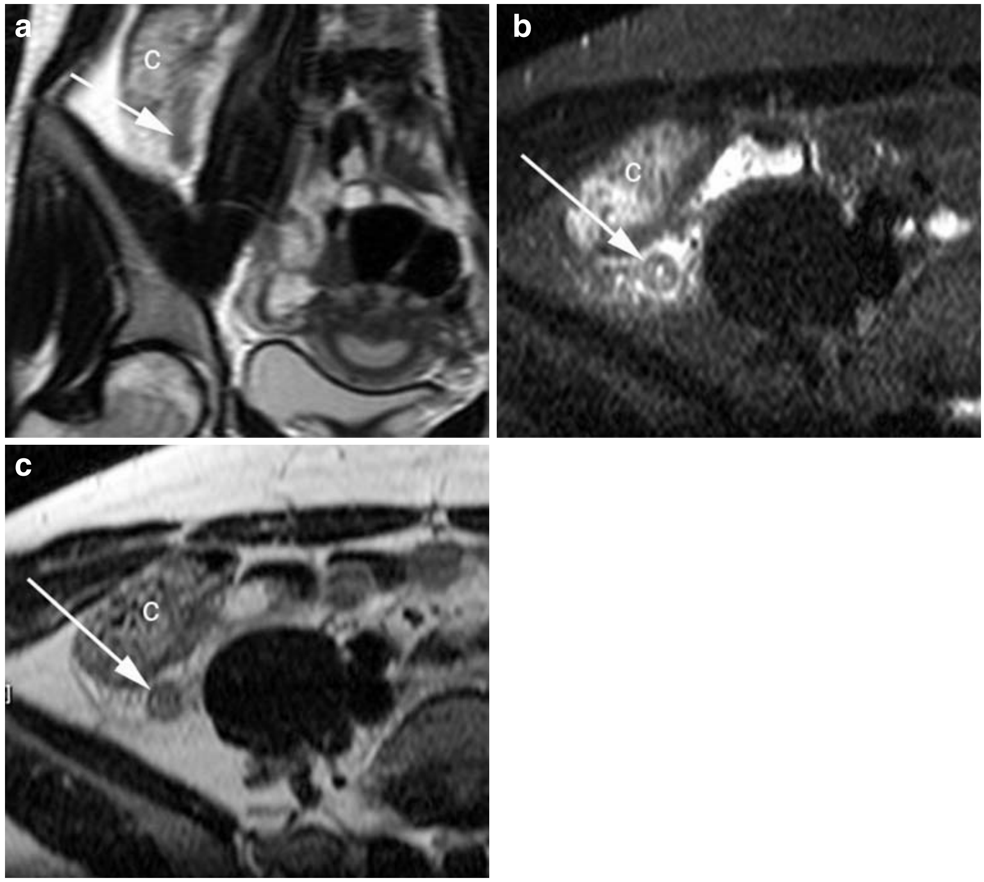

Fig. 3 A 13-year-old girl with suspected appendicitis in whom US was equivocal due to a retrocecal position of the appendix and a cecum filled with fecal material. Coronal T2 (**a**), transverse T2 fat suppression (**b**) and transverse T1-weighted (**c**) images show an enlarged appendix (arrow) with a diameter of 11 mm and with signs of periappendicitis. Appendicitis without perforation was confirmed at surgery and pathology. C = cecum

In one patient with early pancreatitis, an enlarged appendix with a diameter of 8 mm with signs of periappendical inflammation and some fluid around the appendix was found. The false-positive diagnosis was probably due to local irritation of the appendix, caused by local pancreatic fluid, with secondary thickening of the appendix. The diagnosis of pancreatitis was made on clinical and biochemical grounds, shortly after the MRI examination, and an unnecessary appendectomy was avoided.

In two patients the combined US and MRI were equivocal, i.e., both US and MRI were not suspect for appendicitis, but appendicitis could not be ruled out, because neither a normal appendix nor an alternative diagnosis was demonstrated. In both patients an appendectomy was performed on clinical grounds, and in both cases a normal appendix was removed, resulting in a negative appendectomy rate of 3% (Table 4).

In 12 patients the MRI was equivocal, but the combined imaging reports revealed that US showed a normal appendix in 10 of these patients. MRI did not depict the normal appendix in these ten patients, probably because of the lack of intraabdominal fat in these thin patients. As in CT examinations, intraperitoneal fat is the intrinsic contrast medium of a noncontrast MRI examination [14–17, 28, 29]. This study indicates that when MRI is equivocal, an appendicitis is unlikely to be present, and a follow-up examination is not required.

In our institution US is the preferred imaging technique to evaluate all patients with clinically suspected appendicitis. In patients in whom the US is equivocal, and thus not ruling out appendicitis, an additional CT or MRI is performed. The decision to perform an additional CT or MRI is made on age criteria and possible pregnancy; a MRI will be done in pregnant patients or patients younger than 20 years of age and a CT in the others. Some MRIs are performed if a patient specifically requests this. In this study the combined imaging reports of US and MRI

Table 5 Results of combined US-MRI in 138 patients suspected of having appendicitis

	No. of patients	Appendicitis, alternative diagnosis or normal appendix	Equivocal
US	138	102	36
MRI in 36 equivocal US	36	34	2
US + MRI combined	138	136	2

US was performed in all patients; 36 were equivocal in these 36 patients. MRI was equivocal in only two patients revealed that there were 36 patients in whom the US was equivocal. In this group of patients there were ten patients younger than 20 years and four pregnant patients. In this study an optional CT would have been made in 22 patients and an optional MRI in 14 patients. In these 36 patients MRI showed acute appendicitis in 8 (Fig. 3), a normal appendix in 22 and an alternative diagnosis in 4. Combined US and MRI were inconclusive in two patients. In these two patients neither US nor MRI was able to identify the appendix; however, no secondary signs of appendicitis were seen. In both patients, subsequent appendectomy revealed a non-inflamed appendix (Table 5).

Our data confirm the high (35%) negative appendectomy rate when an appendectomy is performed on clinical grounds alone [1–5]. In the group with low clinical suspicion of appendicitis, in whom a clinical follow-up in 12–24 h was suggested on an out-patient basis, there were 13 patients, 5 of whom (38%) had a surgically proven appendicitis. In these five patients MRI was positive for appendicitis in all, and US was positive in two patients. In three equivocal US cases MRI was positive for appendicitis, so one can state that even in the low suspicion group an equivocal US study does not rule out an appendicitis, and a follow-up examination should be performed.

We did not find a delay in the management of appendicitis caused by imaging. On the contrary, our median imaging time delay of 1.5 h compares favorably to the 6.5–9.0-h hospital delays reported in surgical studies [27, 30]. We can even suggest that imaging speeds up the diagnostic process.

In a landmark study by Rao et al., it was shown that routine appendiceal CT performed in patients who present with suspected appendicitis improves patient care and reduces the use of hospital resources [31]. One could even argue that the use of US as a primary imaging investigation would be even more cost-effective [32].

Additionally, in a recent article by Bijnen et al. the removal of a normal appendix was shown to be associated with considerable complications and costs. In an attempt to prevent these costs, extra diagnostic tools should be considered. Expensive diagnostic tools such as diagnostic laparoscopy should be used selectively in order not to further increase costs [33]. In our study to calculate the effect of imaging strategies, calculations were based on US in all patients suspected of having appendicitis and in a selected group of patients an additional CT or MRI examination. We compared this with the costs of uncomplicated appendectomies and a short 1-day admission for observation at the lowest level of severity of illness. We assume that in daily practice these costs will be actually higher because some appendectomies will be complicated and hospital observations may take longer in some patients, so actual savings could have been higher than calculated in this study.

A frequently encountered problem of MR is the availability out of hours. For many institutions, the staffing issues around providing such a service means it is not always available, leaving ultrasound and CT as the only practical options available. This is the reason why in this study a simple imaging protocol of T1, T2 and T2 fat-suppression breathhold sequences was used. These sequences are easy to use and learn and are quick, and as this study indicates are sufficient to detect or rule out appendicitis. Perhaps making MRI more user-friendly will indeed lead to its more frequent use out of hours.

In conclusion, one could state that based on this study, an abdominal MRI in the evaluation of patients suspected of having appendicitis is a safe, reliable and potentially cost-effective technique in patients suspected of having appendicitis, especially when used in a selected group of patients in whom US was equivocal and CT is contraindicated.

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