Surgeon-performed ultrasound as a diagnostic tool in appendicitis

Jeffrey M. Burford [a,b], Melvin S. Dassinger [a,*], Samuel D. Smith [a]

[a]Pediatric Surgery, Arkansas Children's Hospital 1 Children's Way Little Rock, AR 72202-3591, USA
[b]Surgery, University of Arkansas for Medical Sciences, Little Rock, AR, USA

Abstract

Purpose: Diagnosing appendicitis may require adjunct studies such as computed tomography or ultrasound (US). Combining a clinical examination with surgeon-performed US (SPUS) may increase diagnostic accuracy and decrease radiation exposure and costs.

Methods: A prospective study was conducted including children with a potential diagnosis of appendicitis. A surgery resident performed a clinical examination and US to make a diagnosis. Final diagnosis of appendicitis was confirmed by operative findings and pathology. Results were compared with radiology department US (RDUS) and a large randomized trial. Analysis was performed using Fisher exact test.

Results: Fifty-four patients were evaluated and underwent SPUS. Twenty-nine patients (54%) had appendicitis. Overall accuracy was 89%, with accuracy increasing from 85% to 93% between the 2 halves of the study. Radiology department US was performed on 21 patients before surgical evaluation, yielding an accuracy of 81%. Surgeon-performed US on those 21 patients yielded an accuracy of 90%. No statistical differences were found between any groups ($P > .05$).

Conclusion: Accuracy of SPUS was similar to RDUS and that of a large prospective randomized trial performed by radiologists. Furthermore, when the same clinician performs the clinical examination and US, a high level of accuracy can be achieved. With this degree of accuracy, SPUS may be used as a primary diagnostic tool and computed tomography reserved for challenging cases, limiting costs, and radiation exposure.

© 2011 Elsevier Inc. All rights reserved.

Appendicitis is one of the most common surgical diseases treated in children. Diagnosis of the disease was traditionally made based solely on history and clinical examination, leading to a negative appendectomy rate of up to 20% [1,2]. This complication rate had been considered acceptable because of the preference of a negative laparotomy or laparoscopy over the morbidity of a perforated appendix [2-4]. However, the improved quality of computed tomography (CT) has led to the liberal use of this imaging modality to improve the accuracy of diagnosis in both adult and pediatric populations [4,5].

More recently, the routine use of CT for appendicitis has been questioned because of concerns over inefficiency, high costs, and the long-term effects of ionizing radiation exposure [2,6-9]. As a result, groups have implemented clinical

* Corresponding author. Tel.: +1 501 364 1446; fax: +1 501 364 1516.
E-mail address: dassingermelvins@uams.edu (M.S. Dassinger).

pathways using ultrasound (US) as the primary imaging modality [10]. However, US studies are operator dependent and are typically performed in the radiology department, where access may be limited after "business" hours.

The use of surgeon-performed US (SPUS) in trauma, endocrine, breast, and vascular surgery has been well documented [11]. Furthermore, we have published our institution's experience with SPUS for pyloric stenosis [12]. This increasing familiarity with US techniques coupled with the lack of access to "after hours" US led us to design a study to assess the role of SPUS in the diagnosis of appendicitis.

We hypothesized that a surgeon appropriately trained in abdominal sonography should be able to perform an abdominal US for appendicitis at the time of initial evaluation with accuracy comparable with a study performed in the radiology department US (RDUS).

1. Methods

After institutional review board approval, demographic and clinical data were prospectively collected during a 7-month period from patients evaluated in a tertiary referral children's hospital emergency department for possible appendicitis. All patients were initially evaluated by emergency department physicians who subsequently obtained a pediatric surgical consult.

A postgraduate year 3 surgical resident who had participated in a 3-day introductory abdominal ultrasonography course was designated to evaluate all patients. If he was on call, he performed the initial evaluation; if he was not immediately available, the patient was seen by a pediatric surgery resident, and the postgraduate year 3 surgical resident evaluated the patient at the earliest opportunity. In all cases, this resident was blinded to the surgical team members' opinions as well as any imaging obtained before surgical consultation.

Consent was obtained from the guardian, and assent was obtained from children older than 7 years; history taking, physical examination, and abdominal US were then performed. The SPUS was conducted using a Sonosite Micromaxx (Seattle, WA,) US with a 6- to 13-MHz high-frequency linear transducer. The US study was performed using a graded compression technique with initial emphasis on the area of maximal tenderness. If evidence of appendicitis was not found at the site of maximal tenderness, the right lower quadrant was scanned in both transverse and longitudinal axes. The right lower quadrant was evaluated for signs of appendicitis including a noncompressible blind-ending tubular structure with a diameter greater than 6 mm. Hyperemia, periappendiceal fluid, appendicoliths, and fluid collections were considered secondary signs of appendicitis [1,13,14].

The resident then documented 2 "final" diagnoses: the first based solely on US findings, simulating diagnostic decisions made in the radiology department, and the second based on the complete clinical evaluation, which included history taking, physical examination, and US. The decision to perform an appendectomy was ultimately the attending pediatric surgeon's and took into account all relevant clinical data including any and all imaging studies. The final diagnosis of appendicitis, both uncomplicated and perforated, was confirmed by operative findings and pathology.

1.1. Statistical analysis

The resident's diagnoses were then compared with either the operative findings or the condition at discharge, for those patients who were observed. Sensitivity, specificity, positive predictive value, negative predictive value, and accuracy were calculated when US alone was used to make the diagnosis as well as when it was used in conjunction with history and physical examination. A second analysis was performed focusing on the cohort of patients who underwent US studies both by the surgery resident and by the radiology department. Nominal variables were compared using Fisher exact test, with $P < .05$ considered statistically significant.

2. Results

Fifty-four of 55 consecutive patients evaluated by the surgical resident for possible appendicitis were enrolled in the study. The mean age of the patients evaluated was 8.8 years (range, 3-16 years). Twenty-eight patients (52%) were male, and the mean body mass index of all patients was 19.3 kg/m^2 (range, 13.9-28.9 kg/m^2). Forty-nine (91%) of 54 patients underwent imaging—CT, US, or both—before surgical evaluation. Twenty-nine patients (54%) were found to have appendicitis at the time of operation, with 9 (17%) patients having perforated appendicitis.

Results are summarized in Table 1. Surgeon-performed US alone yielded signs of appendicitis in 23 of 29 patients determined to have appendicitis. The single patient with a false-positive US examination had an enlarged noncompressible blind-ending tubular structure with a diameter greater than 6 mm but was ultimately determined not to have appendicitis based on clinical observation. Of the 6 false-negative examinations, 2 patients had secondary signs of appendicitis, but a definitive noncompressible structure was not identified; 1 had a retrocecal appendix; and the remaining 3 were simply not seen. Mean body mass index for patients with the appendix visualized on US was 18.1 kg/m^2 compared with 19.4 kg/m^2 for those patients in whom the appendix was not seen ($P = .6109$). The overall accuracy of SPUS alone in evaluating appendicitis was 87%.

When SPUS was combined with history and physical examination, 27 of 29 patients were correctly diagnosed with appendicitis, increasing the diagnostic accuracy to 89%; however, the rate of false-positive examinations increased slightly.

Table 1 Comparison of results

	SPUS	SPUS with clinical examination	Radiology-performed US	SPUS on patients with radiology US
No. of patients	54	54	21	21
True positive (sensitivity)	23/29 (79%)	27/29 (93%)	3/6 (50%)	5/6 (83%)
False negative	6/29 (21%)	2/29 (7%)	3/6 (50%)	1/6 (17%)
False positive	1/25 (4%)	4/25 (16%)	1/15 (7%)	1/15 (7%)
True negative (specificity)	24/25 (96%)	21/25 (84%)	14/15 (93%)	14/15 (93%)
Positive predictive value	23/24 (96%)	27/31 (87%)	3/4 (75%)	5/6 (83%)
Negative predictive value	24/30 (80%)	21/23 (91%)	14/17 (82%)	14/15 (93%)
Accuracy	47/54 (87%)	48/54 (89%)	17/21 (81%)	19/21 (90%)

Twenty-one of 54 patients enrolled also underwent RDUS. Six (29%) of those 21 patients had appendicitis. Radiology department US yielded an accuracy of 81% compared with SPUS, which produced an accuracy of 90%. Of the 6 patients who had appendicitis, RDUS was able to identify appendicitis in 3 patients compared with SPUS, which identified 5 patients with the disease.

All 54 patients in the study were then stratified into 2 groups based on the accumulated experience of the surgery resident performing the US examinations. Results are summarized in Table 2. When the first 27 patients were compared with the second 27 patients enrolled, specificity increased from 70% to 93%, and accuracy increased from 85% to 93%. Furthermore, false-positive diagnoses decreased from 3 patients in the first group to 1 patient in the second.

3. Discussion

Our study was designed to assess the feasibility of SPUS in pediatric appendicitis. Obtaining an accurate diagnosis of the disease can be challenging at times because of imprecise data or poor history examinations in children, leading to the use of adjunctive imaging [13]. Computed tomography scans are commonly obtained because they are readily available to emergency department physicians. However, these studies will likely be used less frequently in the future because data concerning radiation-induced malignancy is accumulated

and published [15-17]. Moreover, appendiceal CT scans may require patients to drink oral contrast that may be unpalatable or ineffective, creating delays in the diagnosis of a patient experiencing gastrointestinal symptoms [18].

Ultrasound examinations, although potentially safer, present their own set of challenges. First, US studies for appendicitis have lower sensitivities and specificities than CT [8,16,19]. Second, the use of US also relies on personnel from an outside department, who may not keep the same business hours as the surgeons evaluate the patient. Furthermore, US is operator dependent, and studies obtained during "off hours" are likely to be performed by unsupervised technicians, which has been associated with decreased sensitivity and specificity [20].

As the pendulum shifts toward US, surgeons have a unique opportunity. Residents are increasingly exposed to US techniques during their general surgery training; most graduating residents are facile at focused abdominal sonograms for trauma, and many have been exposed to both breast and thyroid US examinations. Furthermore, we have shown that residents and fellows can accurately perform US for pediatric-specific disease such as pyloric stenosis [12]. Thus, as surgeons continue to gain experience, it seems natural that surgeons will begin to perform US when initially evaluating a patient with possible appendicitis.

Surgeon-performed US, which takes approximately 10 minutes to complete, was performed on all enrolled patients. In this study, a single resident who had attended an

Table 2 Temporal analysis of SPUS combined with clinical examination

First 27 patients				Second 27 patients			
	Appy	Not Appy			Appy	Not Appy	
Dx+	16	3	19	Dx+	11	1	12
Dx−	1	7	8	Dx−	1	14	15
	17	10			12	15	
Sensitivity			16/17 (94%)	Sensitivity			11/12 (92%)
Specificity			7/10 (70%)	Specificity			14/15 (93%)
Positive predictive value			16/19 (84%)	Positive predictive value			11/12 (92%)
Negative predictive value			7/8 (88%)	Negative predictive value			14/15 (93%)
Accuracy			23/27 (85%)	Accuracy			25/27 (93%)

Dx + indicates preoperative diagnosis of appendicitis; Appy indicates positive pathologic diagnosis of appendicitis.

introductory abdominal US course performed every examination. However, the course did not focus on specific organ systems, and the resident had no formal training specifically in sonography for appendicitis. Despite this fact, he performed the examinations with a high degree of accuracy, which increased in the second half of the study as he gained experience and confidence. This confidence is important because a normal appendix is not always visualized, and learning to appreciate the negative predictive value of an inconclusive examination combined with the history and physical examination seems important in the learning curve for SPUS [21]. Although there is no accepted learning curve for appendiceal US, our resident's experience mirrors the learning curve seen for focused abdominal sonograms for trauma examination [22].

The current study compares the results of SPUS to that of RDUS and found no statistical differences. Of the 6 patients with appendicitis who underwent both RDUS and SPUS, SPUS was able to visualize the appendix in 5 patients compared with 3 patients with visualization by RDUS. This difference may be explained by the fact that RDUS at our institution is performed by a US technician and then interpreted by a radiologist. The interpretation of US is dependent on the technician's experience and further affected by a disconnect between the patient's clinical condition and the radiologist reading the images. If the physician interpreting the images is the person scanning the patient, the examination can be tailored to the patient's specific examination findings, and more time can be focused on concerning areas or points of maximal tenderness.

Because the number of patients who underwent RDUS was relatively small, we also compared our results to a large prospective European trial evaluating imaging in the diagnosis of appendicitis. The European trial included US examination of 600 patients and was performed by physicians experienced in US. That study had an appendicitis rate of 41% compared with 54% in our study ($P = .0830$). There was no statistically significant difference in any measured parameter when the results of the study were compared with ours.

All patients enrolled in our study underwent SPUS. We are cognizant of the fact that appendicitis is still a "clinical" diagnosis, and patients presenting with a classic history and physical examination do not require further imaging. In fact, studies have logically suggested that the greatest benefit of US for appendicitis is for cases with an equivocal clinical diagnosis [23]. However, SPUS is noninvasive and essentially augments the physical examination. Furthermore, performing SPUS on all cases of suspected appendicitis will likely lead to improved accuracy in equivocal cases because previous reports suggest that sonographers or clinicians who embrace the technique have greater accuracy and confidence [9,21].

This study has demonstrated that a surgery resident can perform US for pediatric appendicitis with a high degree of accuracy. This finding suggests that an algorithm using SPUS on initial surgical evaluation is an acceptable and possibly preferred method of evaluation. This approach may improve the efficiency of diagnosis and avoid unnecessary CT scans. In addition, residents and fellows who become facile with these examinations can train other trainees and clinicians, as we have shown in pyloric stenosis [24].

References

[1] Puylaert JB. Acute appendicitis: US evaluation using graded compression. Radiology 1986;158:355-60.

[2] Kaiser S, Frenckner B, Jorulf HK. Suspected appendicitis in children: US and CT-A prospective randomized study. Radiology 2002;223:633-8.

[3] Karakas SP, Guelfguat M, Leonidas JC, et al. Acute appendicitis in children: comparison of clinical diagnosis with ultrasound and CT imaging. Pediatr Radiol 2000;30:94-8.

[4] Rao PM, Rhea JT, Noelline RA, et al. Effect of computed tomography of the appendix on treatment of patients and use of hospital resources. N Engl J Med 1998;338:141-6.

[5] Hagendorf BA, Clarke JR, Burd RS. The optimal initial management of children with suspected appendicitis: a decision analysis. J Pediatr Surg 2004;39:880-5.

[6] Pritchett CV, Levinsky NC, Ha YP, et al. Management of acute appendicitis: the impact of CT scanning on the bottom line. J Am Coll Surg 2010;210:699-705.

[7] Brenner DJ, Hall EJ. Computed tomography—an increasing source of radiation exposure. N Engl J Med 2007;357:2277-84.

[8] Doria AS, Moineddin R, Kellenberger CJ, et al. US or CT for diagnosis of appendicitis in children and adults? A meta-analysis. Radiology 2006;241:83-94.

[9] Gracey D, McClure MJ. The impact of ultrasound in suspected acute appendicitis. Clin Radiol 2007;62:573-8.

[10] Poortmand P, Oostvogel HJ, Bosma E, et al. Improving diagnosis of acute appendicitis: results of a diagnostic pathway with standard use of ultrasonography followed by selective use of CT. J Am Coll Surg 2009;208:434-41.

[11] Rozykci GS. Surgeon-performed ultrasound, its use in clinical practice. Ann Surg 1998;228:16-28.

[12] Boneti C, Mcvay MR, Kokoska ER, et al. Ultrasound as a diagnostic tool used by surgeons in pyloric stenosis. J Pediatr Surg 2008;43:87-91.

[13] Sivit CJ, Siegel MJ, Applegate KE, et al. When appendicitis is suspected in children. Radiographics 2001;21:247-62.

[14] Brown MA. Imaging acute appendicitis. Semin Ultrasound CT MR 2008;29:293-307.

[15] Frush DP, Donnelly LF, Rosen NS. Computed tomography and radiation risks: what pediatric health care providers should know. Pediatrics 2003;112:951-7.

[16] Humes DJ, Simpson J. Acute appendicitis. BMJ 2006;333:530-4.

[17] Wan MJ, Krahn M, Ungar WJ, et al. Acute Appendicitis in young children: cost-effectiveness of US versus CT in diagnosis—a Markov Decision Analytic Model. Radiology 2009;250:378-86.

[18] Strouse PJ. Pediatric appendicitis: an argument for US. Radiology 2010;255:8-13.

[19] Randen A, Bipat S, Zwinderman AH, et al. Acute appendicitis: meta-Analysis of diagnostic performance of CT and graded compression US related to prevalence of disease. Radiology 2008;249:97-106.

[20] Pohl D, Golub R, Schwartz GE, et al. Appendiceal ultrasonography performed by nonradiologists: does it help in the diagnostic process? J Ultrasound Med 1998;17:217-21.

[21] Holscher HC, Heij HA. Imaging of acute appendicitis in children: EU versus US... or US versus CT? A European perspective. Pediatr Radiol 2009;39:497-9.

[22] Gracias VH, Frankel HL, Gupta R, et al. Defining the learning curve for the focused abdominal sonogram for trauma (FAST) examination: implications for credentialing. Am Surg 2001;67:364-8.

[23] Lessin MS, Chan M, Catallozzi M, et al. Selective use of ultrasonography for acute appendicitis in children. Am J Surg 1999;177:193-6.

[24] Mcvay MR, Copeland DR, McMahon LE, et al. Surgeon-performed ultrasound for diagnosis of pyloric stenosis is accurate, reproducible, and clinically valuable. J Pediatr Surg 2009;44:169-72.

Discussion

Walter Chwals (Boston, MA): Your study highlights the fact that ultrasound is a viable way in which to determine whether or not you have acute appendicitis. Did you compare your data with other imaging studies, i.e. CT scan studies that had been obtained in the same patients to determine how the ultrasound compared with CT scans?

J. Burford: Some patients in the study did receive CT scans. The resident was blinded to the results prior to his evaluation, but results were very similar between the CT scan findings and the findings of the surgery resident. There were some patients that had positive CT scans ultimately that led to surgery that these surgery resident did not pick up.

W. Chwals: I observed that the data you present here are similar to accuracy, sensitivity, specificity, positive and negative predictive value in CT scan related studies. Did you note that when you were over the appendix there was increased pain on the part of the patient?

J. Burford: We did find I guess as experience was gained that the ultrasound did serve also as an extension of the physical exam and in some patients where findings were somewhat in conclusive there was I guess increased pain or findings on physical exam that aided in the diagnosis.

Douglas Barnhart (Salt Lake City, UT): I have two questions: First, what is the added benefit of the ultrasound? You clearly demonstrate that a surgery resident with an ultrasound can have a high degree of accuracy. Two presentations later, we are going to see surgeons present the use of clinical exam and laboratory values to make similarly accurate diagnoses. My question is what data do you have that suggests that there actually was an added benefit to the ultrasound, for example, do you have data that show that if you go back and reinterpret these ultrasounds blinded to the patient information, that you actually are making the diagnosis based on the ultrasound and not on the total clinical composite picture.

Second, obviously the patients that go to radiology for an ultrasound are different than the 54 patients that you routinely performed an ultrasound on for the study. Some of these patients could have been diagnosed clinically without an ultrasound. Based on that I question the conclusion that your accuracy rate is as high as that of the radiology performed ultrasound because I think the latter are patients with an indeterminate exam that have been sent for that reason. It is probably not fair to compare them to the ones that might have otherwise gone to the operating room with no diagnostic study if your protocol had not been in place.

J. Burford: We didn't exactly look at the preoperative diagnosis of appendicitis versus no appendicitis with or without ultrasound. We did find that some patients obviously would benefit or would not benefit from an ultrasound to make the diagnosis. So we don't have that data to look at. As far as blinded results from the radiology images, we didn't look at that exactly but we do have our images available for possible further investigation in the future to look if an outside party could accurately identify it and the slides are based on the images that we obtained.

Dennis Vane (St Louis, MO): I assume it is you who did the ultrasounds?

J. Burford: Yes, sir.

D. Vane: How long did it take you to learn how to do it? There is a lot of data to indicate that attending radiologists do a fairly good job basically equivalent to what you found when they do the ultrasounds. However, if residents, second and third year radiology residents do the ultrasounds, the accuracy is nowhere near what you found, so how long did it take you to learn how to be better than a second or third year resident?

J. Burford: I had attended a weekend course in abdominal ultrasound and then throughout our study we noticed that as time progressed, our first half of our patients compared with the second half, we noticed a steep decline in errors and if we carried it out even further to another ten patients included in our study, results were almost 100% correct. So I think there's a fairly steep learning curve and a future study would include teaching new residents to perform the same exam.

Sherif Emil (Montreal, Canada): I think we're way behind our European counterparts in taking this on. Did you get consent from the patients, I mean when you sit with a child who has appendicitis and is undergoing ultrasound, it's not a particularly pleasant experience for the child, so if you are to repeat this ultrasound again, how did you explain this to a parent and how did you get consent to be able to do that?

J. Burford: We just explained it to the parents. We did obtain consent from the parents and we obtained consent from the patients that were greater than seven years of age in our study. All patients tolerated it very well, with the exception of one or two that were extremely tender on physical exam.

Daniel van Allmen (Cincinnati, OH): Corollary to Dennis' question: there is increasing concern in our institution about clinicians who are not formally trained to do ultrasound for clinical decision making purposes. Did you bill for the study and was it documented in the charts, saved in radiology?

J. Burford: It was documented in the chart as an extension of the surgeon's physical exam.

D van Allmen: But the ultrasound itself was not recorded?

J. Burford: The ultrasound results were documented in the chart as an extension of the surgeon's physical exam. And there was no billing done for this.

Ronald Hirschl (Ann Arbor, MI): I find this study fascinating. Ultrasound is becoming a tool not just for radiologists but a clinical tool in the ICU, in the trauma bay and so on, this is just another extension. I want to bounce off Doug Barnhart's question. The radiologist just gets a requisition that says rule out appendicitis, and the surgeon has all the clinical data available to help with the evaluation. So, I think your data confirm that in fact, this is the surgeon's advantage using the ultrasound, and I think that's fantastic.

J. Burford: Indeed, it was our premise that we could improve the efficiency and accuracy of the diagnosis based on our knowledge of the patient.