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The utility of CT scan for the diagnostic evaluation of acute abdominal pain

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ABSTRACT

AbdCT for the evaluation of AAP in the ED in the US may be excessive and is potentially (although rarely) misleading and harmful. A selective policy of 'AbdUS first' combined with an observation unit and/or surgeon evaluation prior to AbdCT is preferred to a 'routine AbdCT' policy. Repeated AbdCTs for abdominal pain are not recommended because of cumulative radiation exposure. Standardized and complete history and physical examination, such as that originally designed for computer-aided diagnosis of AAP, along with select laboratory testing and higher utilization of AbdUS lessens the necessity of AbdCT. 'Routine AbdCT' is particularly not necessary for the evaluation of suspected appendicitis. 'Routine AbdCT' lowers the negative appendectomy rate but at the expense of exposure to radiation. Right lower quadrant US and selective use of observation prior to AbdCT for suspected appendicitis, particularly in children, adolescents, and young adults, are warranted. MRI should substitute for AbdCT for the evaluation of suspected appendicitis during pregnancy.

Introduction

Acute abdominal pain (AAP) is a common complaint in the emergency department (ED).[1] Since AAP may be a harbinger of a serious problem demanding early intervention, the initial evaluating provider desires to make an accurate diagnosis expeditiously. The provider has taken a history, performed a physical exam, and obtained laboratory tests. From this initial evaluation, they have formulated differential diagnoses but have uncertainty. Fortunately, a number of adjunctive strategies and diagnostic tests have been validated. But of all the possible adjunctive tests that the initial evaluating provider may order, abdominal computed tomography (AbdCT) has by a tremendous margin in the United States (US) over the past several years become the test of choice.[1] By ordering the AbdCT, the provider hopes to increase their certainty of diagnosis and make a rational decision about a course of action. Their objective is to make a therapeutic plan in the interest of optimum patient care. If a serious problem is not present and the AbdCT scan is correspondingly normal the patient may qualify for discharge home. If a serious problem is identified the patient may need hospital admission and intervention. But prior to the advent of CT scans 30 years ago, surgeons were able to efficiently and accurately diagnose acute abdominal pain. Thus, it is appropriate to ask, is AbdCT truly necessary? In addition, CT scanning results in radiation exposure which may increase a patient's risk of future cancer.[2] Many providers, therefore, believe that AbdCTs are being overutilized in the evaluation of AAP.[3,4] We review the literature on the utility of AbdCT for the diagnosis of AAP in general and for suspected appendicitis in particular. In addition, the literature on the radiation risks of AbdCT and the literature regarding the utility of the alternative imaging modalities ultrasound (US) and magnetic resonance imaging (MRI) are reviewed.

Historical perspective

Prior to CT technology AAP was evaluated and diagnosed by history, physical examination, laboratory examination, plain radiographs and US. Much credence was given to the opinion of the surgeon as to whether the patient had a 'surgical abdomen' meaning the patient would likely benefit from surgery, e.g. an exploratory laparotomy.[5,6] In those instances where there was uncertainty, observation of the patient with serial physical and

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laboratory examinations on an inpatient ward was not unusual.[7] Jones stated a “major feature of the management of patients with the acute abdomen must be a regimen of continued observation”.[5] He also stated, “the assessment of the acute abdomen must continue to be predominately a bedside exercise”. There was, however, a risk of nontherapeutic surgery for AAP depending on the pathology. This was especially true for suspected appendicitis where 15–30% nontherapeutic surgery was the norm.[5]

Beginning in the 1970's computer aided diagnosis for patients with AAP was promoted as a possible solution to improve diagnostic accuracy.[8–11] Computer aided diagnosis required the examiner to perform a history and physical exam directed by a one-page data collection form[12] which was analyzed by software performing a “probabilistic analysis using Bayes' theorem” developed from 6000 prior patients. Use of computer aided diagnosis was shown to diminish negative laparotomy and perforated appendicitis rates.[10] Skeptics, however, asserted that the success was likely the data collection form encouraging the evaluator to consider potential diagnoses more carefully.[13,14] Bjerregaard and colleagues from Copenhagen studied 40 patients with AAP by having 4 clinicians perform separate evaluations of each patient.[13] They found that the 4 clinicians all did better than the computer aided diagnostic program in finding the ultimately correct diagnosis. They stated, “History taking and physical examination are the most important sources of information.” They noted that inputting unreliable information into the computer was a dominate reason for misdiagnosis. They also emphasized the “importance of the doctor's intuition”. Computer aided diagnosis of AAP was never widely used.

The advent of CT technology

In the mid 1990's CT scanning of patients with AAP became more prevalent. Radiologists and emergency department (ED) providers argued that the cost of CT scanning was low compared to the cost of an inpatient hospital day and that if the AbdCT could prevent unnecessary hospital admission and surgery, then it would be cost-effective. In 2000 Rosen and colleagues reported on 57 patients with a mean age of 48 years of whom 60% were female, who presented to a teaching hospital ED with nontraumatic AAP.[15] The ED provider was asked to estimate their preAbdCT certainty of diagnosis and to record their management plan if no AbdCT were available. Oral and intravenous (IV) contrast was given based on protocol for the preAbdCT diagnostic impression. In 80% of patients, the provider's certainty of diagnosis was increased and in 6% certainty was decreased. In 60% of patients, the management plan changed and 22% were able to be discharged home. Ultimately the preAbdCT diagnosis was correct in 47% of patients and different in 53%. The false positive rate was 5% and the false negative rate was 2% resulting in 97% sensitivity and 83% specificity. The authors concluded that because of the cost savings associated with sending patients home who might have otherwise been admitted and because of the high sensitivity and specificity, AbdCT for AAP is cost-effective.

In 2003 Nagurney and colleagues reported a survey of the common practices of ED providers in an urban university hospital.[16] Pointing out that about 5% of all ED visits involve non-traumatic abdominal or flank pain (NTAP), they felt that further guidance regarding the appropriate use of diagnostic imaging such as CT and ultrasound (US) was indicated. They prospectively enrolled 124 patients with NTAP (mean age 44 years, 60% female) and followed them through their ED and hospital stay. They queried the ED provider pre-testing and pre-imaging regarding their diagnostic impression and then determined following ultimate patient disposition which diagnostic test they felt was the most helpful. Of the imaging modalities, AbdCT only was felt to be the most helpful in 38% of patients, AbdUS only in 25%, and both in 10%.

In 2006 Modahl and colleagues reported on the utility of AbdCT for nontraumatic AAP in an urban teaching hospital in the years 2003–2004.[17] They retrospectively reviewed 604 patients (mean age 51, 62% female) who all had AbdCT usually with oral and IV contrast. AbdCT was 48% positive. They concluded that AbdCT allowed for discharge home in 38% and reported that in 27% an unsuspected diagnosis was found. Interestingly, 13 patients had 2 AbdCTs and 2 patients had 3 AbdCTs in separate ED visits. They reported that the higher the preAbdCT suspicion the more likely the AbdCT was to be positive. They concluded that although AbdCT may be overutilized, it has value in allowing for patient discharge and for detecting unsuspected diagnoses. Lewis and colleagues in a prospective study of AbdCT in 126 patients greater than 60 years of age found that AbdCT was ordered in 59% and that AbdCT altered the ED provider's diagnostic impression in nearly half.[18] They concluded the main utility of the AbdCT for AAP in seniors was improved diagnostic confidence of the ED provider and the provision for correct disposition of the patient, whether discharge home or admission. Similarly, Abujudeh and colleagues reporting from an urban teaching hospital in the US found that AbdCT changed the preAbdCT diagnosis of AAP in 49% and increased diagnostic certainty by 22–35% depending on ultimate diagnosis (Table 1).[19] The AbdCT was especially good at ruling out particular diagnoses, including bowel ischemia, leaking abdominal aortic aneurysm, bowel obstruction, diverticulitis, and appendicitis. They reported that AbdCT was rarely misleading.

In 2009, however, Pines reported on the trends in AbdCT use for AAP in the years 2001–2005 using the National Hospital Ambulatory Medical Care Survey.[20] Of 38.8 million estimated encounters, AbdCT was ordered in 17.8% and US in 11.7%. During the survey period the use of AbdCT from 10% to 22.5% and US from 11% to 14%, both statistically significant. In spite of this increased use, however, Pines reported that the detection rates of appendicitis, diverticulitis, and gallbladder disease did not change and there was no reduction in admission rates.

More recently, Pandharipande and colleagues reported a multicenter prospective observational trial of 460 patients referred for AbdCT for AAP.[21] Pre and post AbdCT diagnoses and admission plans were compared. AbdCT changed the provider's diagnosis in 51% of patients and the admission plan in 25%.

Perspectives on the utility of AbdCT for AAP from outside the United States

Lameris and colleagues reported on the results of multicenter prospective trial conducted at teaching hospitals in the Netherlands in the years 2005–2007.[22] Recognizing that increased use of ED AbdCT resulted in increased costs and radiation exposure, they sought to determine if AbdCT use could be rationally reduced with a strategy of US first. They enrolled 1101 patients (mean age 47, 55% female) with AAP and performed US and AbdCT (with IV contrast, no oral contrast) on all patients. Retrospectively they evaluated

Table 1
Representative most common diagnoses confirmed by CT scan.[19]

Confirmed Diagnosis	Percent
No acute condition/NSAP	30
Renal colic	17
Bowel obstruction	7
Abscess	6
Appendicitis	5
Diverticulitis	4

NSAP = nonspecific abdominal pain.

several strategies for accuracy, including location specific strategies as had been proposed by the American College of Radiology.[23–26] Of all the possible strategies, US of all patients followed by AbdCT if the US was negative or inconclusive had the highest sensitivity (99%) with a 68% specificity, a 6% false negative rate, and a 16% false positive rate. Following this strategy, they estimated they could safely reduce routine AbdCT by 50%.

Recognizing that the most common diagnosis of patient with AAP in the ED is NSAP and that AbdCT is costly and potentially harmful, Cooper and colleagues at the University of Leeds in the United Kingdom studied the use of an ED-based clinical decision unit (CDU) where appropriate patients are observed rather than referred for AbdCT, specialty referral or admission.[27] For evaluation the structured assessment form similar to computer aided diagnosis was utilized to ensure a complete standardized initial assessment. 28% of patients with AAP were discharged from the CDU without any intervention within 48 h. In 69% of patients the initial ED provider's impression was correct. The authors reported no untoward complications related to this selective initial observation strategy and conjectured that it would be found to be fiscally responsible.

Lehtimaki and colleagues of Finland reported a randomized trial of routine AbdCT versus selective AbdCT for AAP in 2013.[28] AbdCT in this study was a 64-row multi-detector row system with IV contrast. They found that the treatment costs were 57% per patient higher in the routine AbdCT group without change in discharge from emergency department rates or ultimate outcome. They concluded that selective AbdCT for AAP based on clinical grounds was more cost-effective and equally efficacious to a routine AbdCT approach.

Gans and colleagues of the Netherlands recommend discriminating between nonurgent and urgent situation with clinical and laboratory evaluation alone.[29] Nonurgent patients are managed as outpatients. For urgent patients they recommend an AbdUS policy first followed by an AbdCT only if believed necessary.

Caporale and colleagues at the University of Bologna surveyed ED evaluations for AAP in 2013 and found that 36% of patients were ultimately determined to have nonspecific abdominal pain.[30] Following a policy of selective imaging, 44% of patients received an AbdUS and only 16% an AbdCT (half of those with IV contrast). 64% of patients were discharged from the ED to the care of their general practitioner. Duration of ED stay ranged from 17 min to 24 h.

Alshamari and colleagues in Sweden performed 'low dose' noncontrast AbdCT on 58 patients with a wide variety of AAP etiologies resulting in a 75% sensitivity and 87% specificity.[31] They suggested the abandonment of plain radiographs and the substitution of 'low dose' noncontrast AbdCT as a screening evaluation for AAP.

Velissaris and colleagues of the University of Patras, Greece reported the results of a prospective study of AAP in the ED in 125 patients with a mean age of 46 years, 66% female.[32] Utilizing a standardized data collection form to guide the history and physical examination, they utilized a selective, AbdUS first strategy. 46% of patient received an AbdUS and only 17% received AbdCT. They concluded, "… all diagnostic studies can have false negative findings. The decision to admit a patient to the hospital without a clear diagnosis or explanation for the pain is a matter of debate, and several approaches are considered reasonable. The phrase 'treat the patient, not the test' is still very appropriate for patients with AAP, and ongoing patient reassessment in the ED seems to be a reasonable option."

Table 2 summarizes and compares the findings of these key reports on the utility of AbdCT for AAP. AbdCT is currently considered an acceptable option for the urgent evaluation of AAP, but it may be over-utilized, especially in the US. AbdCT may not be clinically necessary in situations where more liberal use of US and inpatient observation are applied.

Is AbdCT scan an ideal screening test for AAP?

Because AbdCT is widely used to evaluate AAP, it is reasonable to ask whether it is appropriate to use AbdCT as if it were a screening test. The characteristics of an ideal screening test have been defined.[33] The ideal screening test should be reliable (consistent), valid (accurate), cause minimal discomfort, be inexpensive, easy to administer, and safe. The disease being screened should be serious, necessitate urgent rather than delayed treatment, and the prevalence of the disease in the screened population should be relatively high.

Is the AbdCT accurate, reliable, and valid for the diagnosis of AAP? Yes, but with the caveats as reviewed earlier in this review.

Does AbdCT cause minimal discomfort? Yes, in the majority of cases.

Is the AbdCT inexpensive? No. Lehtimaki and colleagues in Finland reported in 2013 the higher costs associated with a routine contrast enhanced AbdCT scan policy for AAP versus a selective

Table 2
Representative key studies on the utility of AbdCT for the evaluation of generalized acute abdominal pain.

Authors/Year	Study Type	CT Technique	Patients	% Scan	Changed plan/helpful	Country
Rosen et al. 2000[15]	Prospective	Helical Variety IV/oral contrast	57	100%	60%	US
Nagurney et al. 2001[16]	Prospective	Not specified	124	48%	43%	US
Modahl et al. 2006[17]	Retrospective	4-slice Variety IV/oral/rectal contrast	604	100%	38%	US
Lewis et al. 2007[18]	Prospective	Not specified	126	59%	46%	US
Lameris et al. 2009[22]	Prospective	3 mm slices IV contrast No enteral contrast	1101	100%	50%	Netherlands
Abujudeh et al. 2011[19]	Prospective	Not specified	584	100%	42%	US
Lehtimaki et al. 2012[28]	Prospective Randomized	64 row multidetector IV contrast No enteral contrast	254	74%	Not reported	Finland
Pandharipande et al. 2015[21]	Prospective	Not specified	460	100%	51%	US
Caporale et al. 2016[30]	Prospective	Not specified Variable contrast	239	16%	87%	Italy
Alshamari et al. 2016[31]	Prospective	Low-dose 5 mm slices No contrast	58	100%	Not reported	Sweden
Velissaris et al. 2017[32]	Prospective	Not specified	125	17%	Not reported	Greece

imaging policy.[28] Parker and colleagues reported a comparative effectiveness study using US Center for Medicare and Medicaid Services datasets from 2007 showing a $459 savings per patient using an 'US first' policy for appendicitis as well a projected prevention of 180 excess cancer deaths from avoided AbdCT.[34] They estimated an additional savings of $339.5 million from the value of years of life lost from AbdCT related radiation exposure.

Is the AbdCT easy to administer? Yes and no. CT is readily available 24 h a day in the majority of EDs in the United States. However, because a highly trained technician, advanced technology, and a radiologist are required, one could argue an AbdCT is not 'easy to administer'.

Is the AbdCT safe? Yes, in the majority of all cases but with caveats. Mansouri and colleagues reported that in the years 2006–2012 in their large academic medical center that patient safety incidents occurred in 0.22% of CT scans.[35] In 45% of incidents there was no harm, in 22% there was temporary harm, and in <1% there was permanent harm or death. Adverse drug reaction was the most common reported incident. But, 8% of incidents involved the patient getting a CT scan in error. In addition, as reviewed above, even a single CT is likely associated with a low, but defined risk of the future development of cancer, and this is true especially in patients with repeated CTs.

Is AAP serious? Yes, but in the minority of all cases. The majority diagnosis is NSAP.

Does APP necessitate urgent treatment? Yes, but in the minority of all cases. The majority of patients are discharged from the ED with outpatient follow-up.

Is the prevalence of the disease in the screened population high? No, the percentage of AAP patients ultimately diagnosed with a serious diagnosis is only 17%.[1]

Answer: AbdCT used as a screening test for AAP is reliable, accurate, valid, usually causes minimal discomfort but is expensive and may cause harm. An AbdCT scan with IV contrast is mostly safe, but life-threatening complications rarely occur, and the patient is exposed to a measured amount of radiation. A highly trained technician, advanced technology, and a radiologist are required. An AbdCT is therefore not an ideal medical screening test.

Concerns and experience of the authors

As practicing general surgeons who regularly take emergency general surgery call, we have concerns about the overuse of AbdCT by ED providers for the evaluation of AAP (non-appendicitis). In many patients, the specificity of AbdCT is helpful in that a normal AbdCT may allow the ED provider to avoid asking us to personally evaluate the patient. In other patients, however, the AbdCT has been oversensitive for particular diagnoses, e.g. small bowel obstruction. In a noticeable small percentage of patients, it becomes clear after our evaluation that an US would have sufficed, e.g. in patients with acute cholecystitis. We recognize that ED providers are in an unenviable position of having to diagnose and either discharge or refer for admission a patient with AAP as soon as possible. Observation units run by the ED providers would likely contribute to the success of a more selective AbdCT policy. In addition, ED providers that are less experienced often rely on imaging when clinical acumen may be all that is needed. More data gathering, e.g. with an AbdCT, may in many instances be used as a substitute for clinical decision making. Early involvement of a general surgeon in the workup of AAP, before AbdCT is obtained, may often be warranted to avoid unnecessary expense and radiation exposure.

The utility of CT in suspected appendicitis

Suspected appendicitis is a common subset of AAP accounting for approximately 300,000 hospital visits every year in the US.[36] Most patients with appendicitis in the US are young (mean age 28 years) and the lifetime risk is about 8%.[36] In the late 1980's and early 1990's, with the intent to lower the rate of nontherapeutic surgery, scoring systems for the evaluation of suspected appendicitis were reported, for example the 8 item Alvarado score and the 5 item 'Simple' score modeled after Cope's 5 signs of appendicitis, which gave the surgeon the option of taking the patient to the operating room for a right lower quadrant incision with a low rate of finding a normal appendix.[37,38] Table 3 Several other scoring systems have been proposed and are followed in select countries where CT scanning is considered too costly or is not routinely available.[39–43] A recent addition to appendicitis scoring systems is the Appendicitis Inflammatory Response (AIR) score which incorporates the CRP concentration.[41] Table 3.

As CT became more available and less costly, it was inevitable that CT would be applied to suspected appendicitis.[44] In 1998 an influential report was that of Rao and colleagues who obtained a pelvic CT without intravenous contrast and with rectal contrast on 100 consecutive patients with suspected appendicitis.[45] Prior to knowing CT results, the surgeon was asked to formulate their plan. The costs of removing a normal appendix and of a day of observation in hospital were estimated. CT prevented appendectomy in 13 patients, discovered alternative diagnoses in 11 patients, and saved $45,000 USD. Three normal appendices were removed. CT sensitivity, specificity, positive predictive value, and negative predictive value were all 98%. In 2000 Peck and colleagues reported a retrospective study of 443 patients (mean age 25, 55% female) with suspected appendicitis at a nonteaching community hospital of whom 90% received 'limited' pelvic CT (i.e. without oral or IV contrast).[46] Limited pelvic CT had 92% sensitivity and 99% specificity and allowed an alternative diagnosis in 22% of patients. 55% of

Table 3
Comparison of 3 suspected appendicitis scoring systems.

Alvarado Score 1986	Points	Simple Score 1992	Points	AIR Score 2015	Points
Migratory abdominal pain	1	Abdominal pain	1	Right iliac fossa pain	1
Anorexia/acetone in urine	1	Vomiting	1	Vomiting	1
Nausea/vomiting	1	RLQ tenderness	1	RLQ guarding/rebound	1–3
RLQ tenderness	2	Low grade fever	1	Fever (>38.5)	1
Rebound pain	1	Leukocytosis	1	Leukocytosis	1–2
Fever	1			% PMNs	1–2
Leukocytosis	2			CRP	1–2
Leftward shift	1				
Maximum score	10		5		12
High likelihood	7–10		4–5		9–12

AIR = Appendicitis Inflammatory Response, RLQ = right lower quadrant, PMN = polymorphonuclear neutrophils.
CRP = C-reactive protein.

patients were able to be sent home and the nontherapeutic surgery rate was 5.4%. They concluded that although the 90% CT rate probably reflected overutilization, limited pelvic CT was useful to allow patients to be discharged home and to keep the nontherapeutic surgery rate low.

There was skepticism, however. Lee and colleagues at a university teaching hospital retrospectively reviewed 776 patients (55% male) who underwent appendectomy in years 1995–1999.[47] Overall they found a 16% nontherapeutic surgery rate. They compared history/physical exam/lab testing only with the addition of CT and US. The accuracy of history/physical exam/lab testing only was 75% and the addition of CT was equivalent at 75%, while the accuracy of US was only 43%. They concluded CT had little value in the diagnosis of suspected appendicitis. Morris and colleagues retrospectively reviewed the clinical course of 129 patients who presented to a community hospital emergency department with suspected appendicitis and who after evaluation by the emergency provider received a 'limited' AbdCT, i.e. no IV contrast.[48] The mean age was 35 years and 55% were female. Retrospectively, blinded to the results of the AbdCT and the ultimate outcome, 4 experienced surgeons reviewed the medical record and were asked to give 1 of 3 opinions: appendectomy, observation, discharge. Limited AbdCT had 88% sensitivity and 91 specificity whereas surgeons' judgement had 91% sensitivity and 77% specificity. The authors concluded that a surgeon should evaluate a patient with suspected appendicitis prior to limited AbdCT. In agreement, Flum and colleagues reported a retrospective population-based analysis of the Washington State hospital discharge database that indicated the frequency of misdiagnosis of appendicitis leading to nontherapeutic surgery had not changed between 1987 and 1997 with the introduction of advanced diagnostic testing, including US and CT.[49]

Perez and colleagues, surgeons at a community teaching hospital, had developed a practice management guideline for suspected appendicitis in 1994 that did not include AbdCT.[50] In spite of their practice management guideline, however, the use of AbdCT, mostly ordered by ED providers, was steadily increasing. In 2003 they reported a retrospective study of 118 patients (mean age of 33 years, 60% male) with suspected appendicitis and compared the results with their series several years earlier.[50] 48% of these patients received AbdCT with oral and IV contrast. They found that despite a four-fold increase in the use of AbdCT and a sensitivity of 96%, the rate of nontherapeutic surgery was relatively unchanged (12% versus 18%).

Nonetheless, research from an ED physician and radiologist perspective continued to produce data that indicated the value of the CT scan for the diagnosis of suspected appendicitis in the ED. In 2003 Rosen and colleagues reported an expanded review of their earlier review of a patient group from 1998 to 1999, this time with 556 consecutive patients and focusing on the evaluation of appendicitis.[51] Once again, they confirmed, that from the ED providers perspective, Abd CT for the evaluation of AAP had value. For patients with suspected appendicitis, they claimed that AbdCT reduced the hospital admission rate by 28% and changed surgical management in 40% of patients. AbdCT scan use for suspected appendicitis has correspondingly rose in the US in adults from 6% in 1996 to 69% in 2006, and in children from 0% to 60%.[52] In 2008 Kim and colleagues; with the goal of reducing nontherapeutic surgery, observation rates, delayed surgery, and the use of hospital resources; reported a prospective observational study of helical multidetector (16 detector row) AbdCT (with IV and no oral/rectal contrast) of 157 patients with suspected appendicitis based on Alvarado score likelihood.[53] Nineteen nontherapeutic surgeries were prevented. They found 16 detector helical AbdCT more accurate than both clinical impression and Alvarado score.

Table 4 summarizes and compares the results of these key studies and a recent meta-analysis[54] on AbdCT for the evaluation of suspected appendicitis. Currently CT is considered an acceptable option when adjunctive imaging is felt necessary in the evaluation of suspected appendicitis. CT lowers the nontherapeutic surgery rate at the expense of increased radiation exposure.

But can suspected appendicitis be managed safely without CT? Yu and Shah from Texas Children's Hospital in Houston believe that the CT role should be more limited especially in children but also in adults.[3] They point out an US first policy in children and pregnant females is prudent and that because of the risk of radiation with CT exposure, MRI may eventually replace CT. While sympathetic with the need for the initial evaluator, i.e. the ED provider, to make a correct diagnosis, they assert that in most cases the diagnosis can

Table 4
Representative key studies on the utility of AbdCT for the evaluation of suspected appendicitis.

Authors/Year	Study Type	CT Technique	Patients	% Scans	% Positive	% NT Surgery	Changed plan/helpful	Country
Rao et al., 1998	Prospective	Helical Pelvic No IV contrast With rectal contrast	100	100%	53%	3%	59%	US
Peck et al., 2000	Retrospective	Helical 5 mm slices Pelvic No IV or enteral contrast	443	90%	26%	5.4%	Not reported	US
Lee at al. 2001	Retrospective	Not specified	776	6%	Not reported	16%	Not reported	US
Morris et al., 2002	Retrospective	'Limited' No IV or enteral contrast	129	100%	46%	4%	Not reported	US
Perez et al., 2003	Retrospective	High speed 5 mm slices IV and oral contrast	118	48%	Not reported	18%	0%	US
Rosen et al., 2003	Prospective	Helical Variable contrast	91	100%	69%	Not reported	16%	US
Kim et al., 2008	Prospective	16 detector row IV contrast No enteral contrast	157	100%	58%	.6%	38%	Korea
Krajewski et al., 2011	Meta-analysis	Variety	2491	Not reported	Not reported	8.6%	Not reported	Various
Kim et al., 2015	Prospective	128 detector row Low dose radiation IV contrast No enteral contrast	102	100%	58%	1%	Not reported	Korea

NT = non-therapeutic.

be made without CT. They recommend the establishment of institutional clinical pathways emphasizing standardized clinical workup, risk stratification, and selective imaging. Benabbas and colleagues have recently reported a meta-analysis of Emergency Department Point-of-Care Ultrasound (ED-POCUS) in children with suspected appendicitis concluding that a 'positive' ED-POCUS obviates the need for CT or MRI. Ref[55] the pooled sensitivity and specificity of ED-POCUS for acute appendicitis were 86% and 91%, respectively.[55]

Radiation exposure from CT and risk of cancer

In 2004 Lee and colleagues surveyed patients, ED providers, and radiologists regarding the radiation risks of AbdCT.[56] 7% of adult patients reported remembering being told about the radiation risks of CT scanning whereas 22% of ED providers reported telling patients about the risks. Only 47% of radiologists, 9% of ED providers, and 3% of patients reported that they believed a CT scan increased the risk of cancer.

Although exact predictions for the development of cancer secondary to an AbdCT are still being studied, extrapolated data from the atomic bomb radiation exposure indicates that the lifetime risk of all cancers due to AbdCT is small.[57,58] For the average 25 year old receiving an AbdCT the lifetime risk is estimated to be 0.06%.[57] The risk is age-related, i.e. the younger the patient is when they have an AbdCT, the higher their lifetime risk, and it is cumulative for multiple CT scans. It has been estimated that 1.5–2% of all cancers diagnosed currently in the US are related to CT scan radiation.[57] Estimated risk of an AbdCT related cancer developing in 20 year old female patients is 4 cancers per 1000 patients (range 0.8–11.1).[57] Giannitto and colleagues have recently emphasized that women of child-bearing potential are particularly vulnerable to CT radiation and that multi-phase CT of the abdomen and pelvis to evaluate abdominal pain in women of child-bearing potential occur frequently and increase the radiation dose to the uterus and ovaries 3–4 fold.[4] They reported instances of multi-phase abdominal-pelvic CT scans delivering radiation doses of up to 100 mSv to young women with AAP.

In 2011 Baumann and colleagues reported a survey of ED patients who had presented with AAP performed in 2008 and 2009 at an urban teaching hospital.[59] Patients reported they had minimal confidence in their ED evaluation if only history, physical exam and laboratory testing were accomplished but dramatically higher confidence if an AbdCT was performed. They reported a poor understanding of the radiation risks associated with CT scanning. In addition of those patients who reported that they had not had a prior CT scan, 39% were documented in the medical record to have had a prior CT.

Jones and colleagues, in a review intended to educate ED providers of the radiation risks of CT, asserted that in the majority of urgent or emergent situations, the benefits of a CT scan likely outweigh the risks.[60] They identified three situations, however, where repeat CT scans are common and where the benefit may not outweigh the risks: rule out pulmonary embolism, renal colic, and recurrent abdominal pain.

Low dose radiation CT

CT technology has improved greatly over the past decades with higher resolution images possible with less radiation.[61] The typical radiation dose for AbdCT has dropped from 23 mSv in the 1980's to 6–10 mSv most recently.[62] Kim and colleagues reported a retrospective analysis of low (3 mSv) versus standard radiation dose full AbdCT with IV but without enteric contrast for the evaluation of suspected appendicitis.[63] The sensitivity and specificity of the low dose AbdCT was nearly identical to the standard dose AbdCT. Two recent meta-analyses of low dose CT for the evaluation of suspected appendicitis confirm these results.[64,65] Investigations into the accuracy of low dose AbdCT for generalized AAP are currently lacking.

Magnetic resonance imaging

MRI is indeed a promising modality for suspected appendicitis with the caveat that current protocols do not allow the radiologist to determine perforation.[66,67] In a prospective study of 230 patients (mean age 35, 60% female) with suspected appendicitis MRI had a positive predictive value of 94% and a negative predictive value of 96%, equivalent to a protocol of US with conditional CT.[66] The sensitivity of MRI to differentiate perforated appendicitis, however, was only 57%. Long and colleagues report that CT is contraindicated in the evaluation of right lower quadrant pain during pregnancy, instead recommending US and, if necessary MRI.[68] The literature regarding the utility of MRI to evaluate generalized AAP is still in its infancy but is also promising.[69]

Summary

AbdCT for the evaluation of AAP in the ED in the US may be excessive and is potentially (although rarely) misleading and harmful. Although from an ED physician perspective the AbdCT has value in allowing for an efficient management decision, it may not be clinically necessary in situations where more liberal use of US and inpatient observation are applied. Table 5 A selective policy of 'US first' combined with an observation unit and/or surgeon evaluation prior to AbdCT is an acceptable alternative to a 'routine AbdCT' policy. Repeated AbdCTs for abdominal pain are not recommended because of cumulative radiation exposure. Standardized and complete history and physical examination, such as that originally designed for computer-aided diagnosis of AAP, along with select laboratory testing and higher utilization of US lessens the necessity of AbdCT. 'Routine AbdCT' is particularly not necessary for the evaluation of suspected appendicitis. 'Routine AbdCT' lowers the nontherapeutic surgery rate at the expense of exposure to radiation. Because of the radiation risk right lower quadrant US and selective use of observation prior to CT for suspected appendicitis, particularly in children, adolescents, and young adults (especially women of child-bearing potential), are warranted. Low dose radiation CT maintains diagnostic accuracy and should be strongly considered whenever CT is used to evaluate suspected appendicitis. MRI should substitute for CT for the evaluation of suspected appendicitis during pregnancy.

Table 5
Benefits and alternatives to AbdCT.

Benefits
Efficient discharge from ED
Improved ED provider diagnostic confidence
Improved patient diagnostic confidence
Lowers nontherapeutic surgery rate
Eliminates need for observation
Alternatives
Standardized & complete history and physical exam
US first policy
Observation Unit
Low dose RLQ/pelvic CT (suspected appendicitis)
MRI (suspected appendicitis)

ED = emergency department, US = ultrasound, RLQ = right lower quadrant. MRI = magnetic resonance imaging.

Conflicts of interest

The authors report no conflicts of interest related to the subject matter of this review article.

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