Original Article

Diagnostic Performance and Reliability of the Standardized Computed Tomography Reporting System for Acute Appendicitis: Experience in a Tertiary Care Academic Center

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Background: Computed tomography (CT) is generally accepted as a modality of choice for imaging workup in patients with suspected appendicitis. A standardized CT reporting system, CT certainty score, has been proposed to improve diagnostic accuracy and to reduce ambiguous CT reports.

Objective: To assess the diagnostic performance and the reliability of the standardized CT reporting system for acute appendicitis in Thai adults.

Materials and Methods: The present study was a retrospective data review of 421 adult patients who had CT scans of the appendix between January 2016 and December 2017. The clinical and imaging data were extracted and analyzed. The pathological result was used as a standard of reference. The diagnostic performance and interobserver agreement of the standardized CT reporting system were estimated.

Results: One hundred sixty-three patients, with a mean age of 41.7 years, had clinical diagnoses of acute appendicitis. Using standardized CT report, radiologists were highly accurate at diagnosing appendicitis [area under curve (AUC) 0.988 (95% CI 0.98 to 1.00); $p<0.001$]. The estimated sensitivity, specificity, positive predictive value, negative predictive value, and accuracy were 95.1% (95% CI 90.6 to 97.9), 95.7% (95% CI 92.5 to 97.9), 93.4% (95% CI 88.7 to 96.2), 96.9% (95% CI 93.0 to 97.2), 95.5% (95% CI 93.0 to 97.3), respectively. The interobserver agreement was greater than 80% for all binary objective findings and more than 90% agreement on the presence or absence of greater-than-3-mm wall thickness, appendicolith, periappendiceal air, and right lower quadrant fluid collection. The use of CT certainty score had interobserver agreement of 78% ($\kappa=0.69$; 95% CI 0.62 to 0.77).

Conclusion: Using a standardized CT reporting system yielded a high diagnostic accuracy and high reproducibility of supportive CT findings for appendicitis in at-risk patients. The standardized CT reporting system can improve diagnostic certainty, accuracy, and guide patient management.

Keywords: Appendicitis; Certainty score; Computed tomography; Standardized reporting system

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Acute appendicitis is a common clinical problem in the emergency department (ED) with an estimated incidence of up to 9.4 patients per 10,000 populations per year(1). Urgent surgical intervention is preferred to avoid delayed diagnosis and risk of perforation or abscess formation(2). Cross-sectional imaging, especially computed tomography (CT), plays a pivotal role in the diagnosis of appendicitis. CT not only confirms the diagnosis of appendicitis but also provides alternative diagnoses and related complications.

ACR Appropriateness criteria® currently recommends a CT scan as a modality of choice in patients with suspected appendicitis(3). Despite excellent CT performance in diagnosing appendicitis, no single CT finding is sufficient to provide an accurate diagnosis. The diagnosis of appendicitis on CT is usually made by the subjective assessment of multiple CT findings that are either supportive or against the diagnosis(4,5). Radiologists commonly encounter cases in which CT findings are inconclusive or equivocal. These inconclusive or equivocal CT exams have been reported in 9% to 13% of CT studies, of which 30% to 52% are later diagnosed as acute appendicitis(6,7). Few different scoring CT systems in the diagnosis of acute appendicitis have been proposed(8-10). Godwin et al had proposed a standardized CT reporting system for acute

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appendicitis to reduce ambiguous CT reports[11]. This standardized CT reporting system, also known as CT certainty score, comprises of 5-point scales ranging from 1 to 5. This CT certainty score is used to express the likelihood of acute appendicitis from definitely negative (score 1) to definitely positive (score 5). The standardized reporting system ensures the consistent use of terminology and can improve report quality and clarity. Simianu et al had demonstrated high accuracy and high reproducibility of radiologists' certainty in diagnosing appendicitis across the readers in their validation study[12]. An excellent inter-observer agreement of this standardized CT reporting system has also been reported[13].

The authors' institution has endorsed using this standardized CT reporting system shortly after it was proposed. Although there has been large evidence of excellent CT performance in the diagnosis of appendicitis, most of the data are based on studies in American or European populations, which may differ from the Thai population. Moreover, performance data and the reliability of this reporting system at the authors' institution is still questionable among surgeons and emergency physicians. Therefore, the authors conducted the present study to assess the diagnostic performance and reliability of the standardized CT reporting format in the diagnosis of acute appendicitis in the authors' institution.

Materials and Methods

The present study was a retrospective cross-sectional study approved by the Institutional Ethics Committee Board (protocol number: ID 03-61-51). The need for informed consent was waived.

The present study was carried out in a tertiary academic center. The authors included adult patients with an age range of 15 to 99 years, who visited the ED between January 2016 and December 2017 with clinically suspected appendicitis and had an appendiceal CT scan. Four hundred thirty-eight patients met the inclusion criteria. Seventeen patients were excluded due to incomplete medical records. The final cohort consisted of 421 patients with 421 appendiceal CT exams.

Clinical data

An ultrasound-first strategy for suspected acute appendicitis had been implemented in the authors' institution. All patients transferred for imaging workup for clinical suspicion of acute appendicitis would have protocolized ultrasound (US) performed. The US protocol included a systematic search for the urinary bladder, kidney, gallbladder, pelvic, and appendix pathology. The decision to operate was based on the integration of clinical findings, laboratory results, and imaging findings. Surgery consultation was made upon the positive US result and the patient was directed to the operative room. A second-line CT scan was performed only if the US result was inconclusive, the appendix was not visualized on the US, or clinical and radiological findings were discordant.

Patient medical records were reviewed to obtain demographic data, laboratory results, intraoperative findings, operative notes, and pathological reports. Patients were defined as having appendicitis if they had appendectomy with pathologically confirmed appendicitis (n=155) or periappendiceal phlegmon or abscess (n=8). If the patients did not have appendectomy or initial treatment for appendicitis, follow-up records or telephone follow-up were reviewed for alternative diagnoses other than acute appendicitis (n=258). The follow-up records were reviewed up to one month after the initial ED visit to ensure that the patients did not revisit ED for untreated appendicitis.

CT technique

All appendiceal CT exams were done using a 128-slice multi-detector CT scanner (Aquillion CX, Toshiba Medical Systems Corporation, Tokyo, Japan). The CT parameters were adjusted as 120 kVp, automated tube current modulation ranging from 40 to 440 mA, 0.5-mm beam collimation, 0.6-second rotation time, and 0.906:1 helical pitch. Single-phase helical scan was obtained at 120 seconds after initiation of contrast administration with coverage from the superior endplate of L3 vertebra to the pubic symphysis. Intravenous non-ionic iodinated contrast medium, followed by a saline chaser, was injected at a rate of 2 to 3.3 mL/second by a power injector, with a dosage ranging from 50 to 160 mL according to the patients' body weight. A rectal contrast was also given using a mixture of 25 mL of iodinated contrast medium and 1000 mL of normal saline. Coronal and sagittal reformations were performed in all cases.

Image analysis

Two of the authors independently reviewed all 421 official CT reports for the pertinent CT findings and CT certainty score. These reports were finalized as part of daily routine practice by a group of boardcertified staff radiologists with expertise in body imaging or emergency imaging and with two to ten years of experience. The likelihood of appendicitis was expressed by a 5-point ranking scale ranging from certainty score 1 to certainty score 5 as previously described[11]. Later, a proportional stratified random sampling of 200 CT examinations were selected for a second independent review by one of the authors, with 3-year experience in emergency imaging, to assess the interobserver reliability. The second reader was blind to the official CT results and the final diagnosis. All CT images were reviewed via the Picture Archiving and Communications System (PACS) using a DICOM Conformance (Synapse version 3.2.0, FUJIFILM Medical Systems USA's Synapse® PACS System, USA). The reader had access to all 3-mm axial sections as well as 3-mm-thick coronal and sagittal reconstructions for review.

Statistical analysis

The authors described the characteristics of the cohort and the presence of specific CT findings stratified by the patient status, with and without appendicitis. Categorical variables were expressed as count and percentage. Continuous variables were summarized as mean and standard deviation (SD) or median and interquartile range (IQR). Comparison of gender and CT findings between the two groups was performed using the chi-square test. The age and Alvarado score were compared using independent sample t-test. Mann-Whitney U test was used to compare white blood cell (WBC) count and absolute neutrophil count. The performance of CT certainty score in diagnosing appendicitis was estimated by a receiver operating characteristic (ROC) curve analysis and the area under the ROC curve (AUC) with 95% confidence interval (CI). The sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and accuracy of CT certainty score for predicting appendicitis were estimated with the decision threshold of score 4 and 5 being considered as positive for appendicitis. The interobserver reliability of the CT interpretation was quantified using Cohen's Kappa statistic (κ) and percentage agreement. A κ value of less than 0.20 indicated poor agreement, 0.21 to 0.40 as fair agreement, 0.41 to 0.60 as moderate agreement, 0.61 to 0.80 as substantial agreement, and 0.81 or greater as excellent agreement. A p-value of 0.05 was considered statistically significant. The statistical analyses were performed using IBM SPSS Statistics for Windows, version 22.0 (IBM Corp., Armonk, NY, USA).

Table 1. Demographic and clinical data of 421 patients

Parameters	n (%)
Demographic data	
Gender	
• Male	107 (25.4)
• Female	314 (74.6)
Age (years); mean±SD	39.5±17.7
Body mass index (kg/m^2); median (IQR)	22.5 (19.5 to 25.5)
Alvarado score; mean±SD	6±1.7
Laboratory results; median (IQR)	
WBC count	11,305 (9,000 to 14,775)
Absolute neutrophil count	8707 (5,940 to 12,150)

SD=standard deviation; IQR=interquartile range; WBC=white blood cell

Results

The final analysis group consisted of 421 patients, with 74.6% female and a mean age of 39.5±17.7 years. The demographic and clinical data are shown in Table 1. One hundred sixty-three patients (38.7%) had a final diagnosis of appendicitis. Appendectomy was performed in 166 patients. Among these, pathology was able to confirm appendicitis in 155 patients (93.4%), giving a negative appendectomy rate of 6.6% (11/166). Eight patients had phlegmons or periappendiceal abscesses.

Patients with appendicitis were more frequently older, male, had higher WBC count, higher absolute neutrophil count, and higher Alvarado score than those without appendicitis (p=0.035). A comparison of CT findings between the two groups is shown in Table 2. The supportive CT features of acute appendicitis, including an outer-to-outer diameter of more than 6 mm, a wall thickness of more than 3 mm, presence of mucosal hyperenhancement, presence of appendicolith as well as inflammatory changes in the right lower quadrant such as fat stranding and cecal wall thickening, were more frequently found in patients with appendicitis (p<0.001).

The CT certainty score assigned to each patient is shown in Table 3. Overall, the AUC of CT certainty score in diagnosing appendicitis was 0.988 (95% CI 0.98 to 1.00; p<0.001). The estimated sensitivity, specificity, PPV, NPV, and accuracy were 95.1% (95% CI 90.6 to 97.9), 95.7% (95% CI 92.5 to 97.9), 93.4% (95% CI 88.7 to 96.2), 96.9% (95% CI 93.0 to 97.2), and 95.5% (93.0 to 97.3), respectively.

In the subset of 200 CT scans reviewed by a second radiologist, the agreement was greater than 80% in all binary objective findings, with more

Table 2. Comparison of CT findings between patients with and without appendicitis

Parameters	Appendicitis; n (%)	Non-appendicitis; n (%)	p-value
Appendix visualized	163 (100)	257 (99.6)	1.000
Outer-outer wall diameter			<0.001
>10 mm	75 (46.6)	1 (0.4)	
6 to 10 mm	84 (52.2)	135 (52.5)	
≤6 mm	2 (1.2)	121 (47.1)	
Tip diameter			<0.001
>10 mm	39 (24.5)	1 (0.4)	
6 to 10 mm	108 (67.9)	81 (31.5)	
≤6 mm	12 (7.5)	175 (68.1)	
Single wall thickness >3 mm	32 (20.0)	1 (0.4)	<0.001
Mucosal hyperenhancement	154 (95.1)	35 (13.8)	<0.001
Fat stranding	153 (93.9)	42 (16.3)	<0.001
Appendicolith	32 (19.8)	6 (2.3)	<0.001
Focal cecal thickening	106 (65.0)	13 (5.1)	<0.001
Periappendiceal air	9 (5.5)	1 (0.4)	0.001
RLQ fluid/phlegmon or abscess	28 (17.3)	4 (1.6)	<0.001
Absence of gas in appendix lumen	122 (75.3)	82 (31.8)	<0.001
Absence of right ovarian abnormality	2 (1.9)	11 (5.0)	0.234

CT=computed tomography; RLQ=right lower quadrant

Table 3. Diagnostic performance of CT certainty score in predicting appendicitis

Certainty score	Appendicitis (n=163); n (%)	Non-appendicitis (n=258); n (%)	AUC (95% CI)	p-value
Certainty score 1 (appendicitis definitely absent)	0 (0.0)	158 (61.2)	0.988 (0.98 to 1.00)	<0.001
Certainty score 2 (appendicitis unlikely)	1 (0.6)	73 (28.3)		
Certainty score 3 (indeterminate)	7 (4.3)	16 (6.2)		
Certainty score 4 (appendicitis likely)	39 (23.9)	10 (3.9)		
Certainty score 5 (appendicitis definitely present)	116 (71.2)	1 (0.4)		

CT=computed tomography; CI=confidence interval

than 90% agreement on the presence or absence of greater-than-3-mm wall thickness, appendicolith, periappendiceal air, and right lower quadrant fluid collection (Table 4). The measurement of outer-outer wall diameter and tip diameter had a slightly lower agreement of 72% for both parameters. The use of CT certainty score had agreement of 78% (κ=0.69; 95% CI 0.62 to 0.77).

Discussion

The standardized CT reporting system for acute appendicitis was originally proposed to increase diagnostic accuracy and to improve communication between radiologists and patient care teams[11]. High accuracy and high reproducibility are important in the acute care setting.

The present study reported excellent performance and reliability of the standardized CT reporting system in predicting appendicitis. The sensitivity and specificity of the present study were greater than 95% with an AUC of 0.988. There was moderate to substantial agreement for most objective CT findings and substantial agreement for CT certainty score in diagnosing appendicitis. Readers were able to correctly assign CT certainty score of 4 or 5 to 95% of patients who had clinically confirmed appendicitis, and correctly assigned CT certainty score of 1 or 2 to 90% of patients without appendicitis. The CT performance in the present study is comparable with the previous literature of the Western population, which reported a sensitivity of 80% to 100%, a specificity of 84% to 100%, and an accuracy of 81%

Table 4. Interobserver agreement of CT interpretation based on a second review (n=200)

Parameters	No.*	Official CT reports; n (%)	Second review; n (%)	κ value (95% CI)	% agreement
CT certainty score	200			0.69 (0.62 to 0.77)	78
1: Appendicitis definitely absent		76 (38.0)	84 (42.0)		
2: Appendicitis unlikely		35 (17.5)	28 (14.0)		
3: Indeterminate		10 (5.0)	12 (6.0)		
4: Appendicitis likely		23 (11.5)	15 (7.5)		
5: Appendicitis definitely present		56 (28.0)	61 (30.5)		
Individual imaging finding					
Appendix visualized	200	199 (99.5)	199 (99.5)	1.00	100
Outer-outer wall diameter	198			0.55 (0.45 to 0.65)	72.2
• >10 mm		42 (21.2)	31 (15.7)		
• 6 to 10 mm		100 (50.5)	95 (48.0)		
• ≤6mm		56 (28.3)	72 (36.4)		
Tip diameter	196			0.52 (0.42 to 0.63)	72.4
• >10 mm		25 (12.8)	12 (6.1)		
• 6 to 10 mm		83 (42.3)	66 (33.7)		
• ≤6 mm		88 (44.9)	118 (60.2)		
Single wall thickness >3 mm	197	16 (8.1)	18 (9.1)	0.49 (0.27 to 0.70)	91.9
Mucosal hyperenhancement	197	88 (44.75)	84 (42.6)	0.69 (0.59 to 0.79)	84.8
Periappendiceal fat stranding	199	90 (45.2)	84 (42.2)	0.71 (0.62 to 0.81)	85.9
Appendicolith	198	13 (6.6)	18 (9.1)	0.69 (0.49 to 0.88)	95.4
Focal cecal thickening	198	56 (28.3)	60 (30.3)	0.73 (0.63 to 0.84)	88.9
Periappendiceal air	198	4 (2.0)	5 (2.5)	0.66 (0.30 to 1.00)	98.5
RLQ fluid/phlegmon or abscess	199	18 (9.0)	15 (7.5)	0.44 (0.22 to 0.66)	91.5
Absence of gas in appendix lumen	198	104 (52.5)	105 (53)	0.77 (0.68 to 0.86)	88.4
Absence of right ovarian abnormality	141	97 (68.8)	100 (70.9)	0.68 (0.55 to 0.81)	86.5

CT=computed tomography; RLQ=Right lower quadrant; CI=confidence interval

* Number of examinations may differ from the total case (n=200) to represent actual cases where the findings were assessed in both official reports and second review

to 99% for second-line CT evaluation(14-19).

Despite the high diagnostic accuracy of CT, false negative and false positive diagnoses still occur. Poortman et al reported approximately 24% false positive and 16% false negative in 199 patients that received pre-operative CT imaging(20). The authors found only one false-negative case (0.6%) in the present study. This patient was initially assigned to a CT certainty score of 2 (appendicitis unlikely). With a retrospective review, the appendix was visualized only at the base, the other part was obscured by dilated small bowel loops. There was minimal amount of intra-abdominal fat, making the assessment of periappendiceal fat inflammation very challenging (Figure 1). The paucity of intra-abdominal fat, lack of inflammatory change on CT scan, and the presence of small bowel dilatation were found to be the underlying factors for false-negative diagnosis in a previous study(21). In this subgroup of patients, careful identification of the whole appendix along with the periappendiceal inflammatory change is crucial(20). Alternatively, graded compression US of the appendix would be of value in the patient with a body mass index equal to or less than 22 kg/m^2(22).

Based on the present study, the standardized CT reporting system for acute appendicitis showed good diagnostic accuracy for acute appendicitis and a very low false-negative rate. This standardized CT reporting system should improve communication between radiologists and surgeons or emergency physicians on how to proceed with the management. Nevertheless, the management decision should not be based solely on imaging findings, but rather on a combination of clinical, laboratory, and imaging

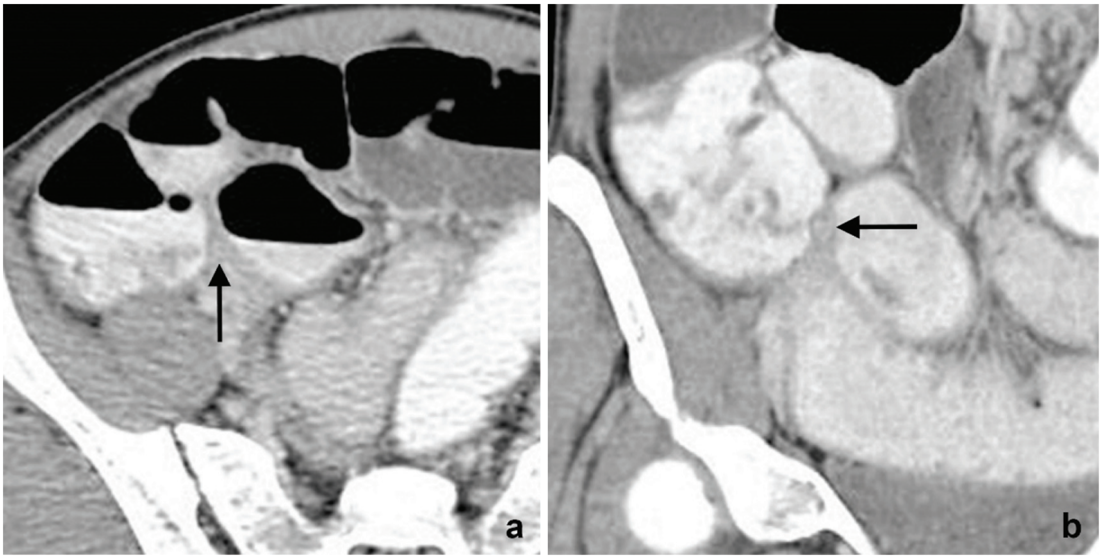

Figure 1. Axial (a) and coronal (b) contrast-enhanced CT images show a normal appendiceal base (arrow). It is very difficult to identify the appendix and periappendiceal inflammation due to the paucity of the intra-abdominal fat. Acute appendicitis was confirmed upon surgery.

parameters. A future validated study can be performed by weighing the score of each pertinent CT finding and calculating it into CT likelihood score.

Several limitations should be noted. The present investigation was a retrospective study, in which incomplete or missing data were inevitable. The data obtained from the present study were based on the use of the second-line CT approach for appendicitis. The performance could be influenced by the different pre-test likelihood of the patients. The time spent in the assessment of each CT findings varied across the radiologists and this factor was not taken into consideration. However, the authors believe that this analysis would reflect true diagnostic performance in the "real world" practice in ED, where the communication with attending physicians, additional imaging such as targeted US, or other relevant factors may influence time spent evaluating the appendix. The present study did not compare the diagnostic performance between the standardized CT reporting system and the traditional descriptive CT reporting system. The authors suggest further prospective studies to directly compare the standardized CT reporting system to the traditional free-text report.

Conclusion

In summary, the present study demonstrated high accuracy and high reproducibility of the standardized CT reporting system for acute appendicitis in Thai population. This standardized CT reporting system can improve diagnostic certainty, accuracy, and can guide the next step of patient management. The present database also reflects an excellent performance in real-world practice and can serve as a benchmark for future relevant research.

What is already known on this topic?

There is significant supportive evidence regarding excellent CT performance in diagnosing appendicitis. However, most of the published data are based on studies in the Western population, which may differ from the Thai population.

What this study adds?

The present study provides excellent performance and reliability of the standardized CT reporting system for the diagnosis of acute appendicitis in the Thai population. It can serve as a benchmark for future research.

Conflicts of interest

The authors declare no conflict of interest.

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