Low Field-Of-View CT in the Evaluation of Acute Appendicitis in the Pediatric Population

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ABSTRACT

Computed tomography (CT) is a widely-used imaging modality used in the evaluation of appendicitis but it carries risks of radiation. A recent retrospective review localizes all appendices (both normal and abnormal) below the level of the L1 vertebral body, obviating the need to scan superior to that level. This study is a retrospective review of prospectively-collected data from 171 consecutive pediatric patients presenting with clinical suspicion of acute appendicitis and undergoing “low field-of-view (FOV) CT.” The low FOV CT uses the L1 vertebral body as the superior aspect of the exam instead of the dome of the diaphragm as in the standard CT of the abdomen and pelvis. Results showed the FOV was reduced by an average of 26% without any reduction of sensitivity or specificity when compared to the current standard FOV. All visualized appendices (both normal and abnormal) were at or below the level of L2, allowing us to lower the superior aspect of the field of view and thus decrease the ionizing radiation dose without affecting the appendix visualization rate. The eight non-visualized appendices in this study were likely obscured by surrounding bowel. The cecum (and likely the non-visualized normal appendix as well) was located at the level of sacrum; therefore, the appendices were most likely not missed due to the low FOV.

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INTRODUCTION/ SIGNIFICANCE

Acute Appendicitis in Pediatrics: Background, Clinical Presentation, and Diagnosis

Acute appendicitis is a common pathology among the general population, with a lifetime risk of roughly 8% and 6% for males and females, respectively. The highest incidence of acute appendicitis occurs in patients aged 10-19 years old. In addition to being a common pediatric pathology, it is also the most common indication for emergent abdominal surgery in the pediatric population.[1] Acute appendicitis most commonly occurs due to obstruction of the lumen by a fecalith, undigested materials, or enlarged lymphoid follicle.

The common presenting symptoms of acute appendicitis are well known and can be further divided into different age groups. Though rarely seen under the age of 5 years, acute appendicitis in infants and young children manifests with nonspecific symptoms of abdominal pain, fever, and vomiting.[2] In children aged 3-12 years, the most common presentations include inability to walk, right lower quadrant pain, and nausea.[3] Symptoms in adolescents closely resemble those in adults, including fever, anorexia, vomiting, and initial periumbilical abdominal pain.[4]

Physical exam findings may also aid in the diagnosis. In a meta-analysis of over 4000 patients, it was found that right lower quadrant pain, rigidity, and migration of initial periumbilical pain to the right lower quadrant have the highest likelihood ratios, thus the most useful in identifying patients with acute appendicitis.[5]

Laboratory assessment could contribute to the evaluation of acute appendicitis. Leukocytosis of greater than 10,000 per mm^3 and neutrophilia are common findings, though they both exhibit low specificities. Due to the nonspecific signs, symptoms, and laboratory findings, several assessment tools have been developed in order to stratify appendicitis risks. Most notable of these tools include the Alvarado Score, which may be used on persons of all ages, and the Pediatric Appendicitis Score (PAS), which is designed for patients 3-18 years old (Table 1).

Table 1: The Alvarado Score and the Pediatric Appendicitis Score (PAS)

The Alvarado score and the Pediatric Appendicitis Score

Clinical Variable	Alvarado Score	PAS
Migration of pain	1	1
Anorexia	1	1
Nausea or vomiting	1	1
Right lower quadrant tenderness	2	2
Rebound pain	1	–
Elevated temperature*	1	1
Leukocytosis (≥10,000/μL)	2	1
Shift of WBC count to the left (≥75% polymorphonucleocytes)	1	1
Cough/percussion/hopping cause pain in the RLQ	–	2
Total	10	10

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PAS, Pediatric Appendicitis Score; WBC, white blood count; RLQ, right lower quadrant. *Fever generally defined as greater than or equal to 37.3 ºC (91.2 ºF) for the Alvarado score and greater than or equal to 37.3 ºC (99.2 ºF) or 38.0 ºC (100.4º F) for PAS.

Table 2: Risk of Appendicitis Stratified by the Alvarado and Pediatric Appendicitis Scores

Risk of Appendicitis	**Alvarado Score**	**PAS**
Low	≤4	≤3
Intermediate	5-6	4-6
High	≥9	≥7

Both the Alvarado and PAS assessments take into account signs, symptoms, and laboratory findings. [6] The risks of appendicitis are then stratified into low, intermediate, and high (Table 2). Low risk indicates that appendicitis is unlikely and patient may be discharged home, while high risk indicates emergent surgical evaluation. Patients in the intermediate category may benefit from continued observation or admission with diagnostic studies that are centered on radiologic imaging.

Radiologic Evaluation of Acute Appendicitis

The primary imaging modalities utilized in the evaluation of acute appendicitis include ultrasound and computed tomography (CT). Magnetic resonance imaging (MRI) can also be used, but its availability is limited in most institutions.[7,8] Ultrasound is commonly used as an initial diagnostic imaging due to its wide availability, portability, low cost, and absence of radiation exposure. However, ultrasound findings are limited by operator skills, patient's body habitus, and appendix location. Ultrasound findings may be equivocal in increased abdominal wall thickness in the setting of obese children, and a retrocecal position of the appendix is more difficult to visualize on ultrasound.[9] Due to its poor accuracy, the sensitivity of ultrasound on diagnosing acute appendicitis ranges from 44% to 100%, while the specificity ranges from 49% to 99%.[10] Comparatively, the sensitivity and specificity of CT are >90% and >95%, respectively.[11] If not used as first-line, CT is utilized in the setting of equivocal ultrasound findings. The CT findings may also reveal alternative diagnoses such as inflammatory bowel disease and mesenteric adenitis. However, this method also involves the use of intravenous contrast, higher cost, and radiation exposure.

Radiation Risk

The estimated effective radiation dose of standard CT abdomen and pelvis is 10 mSv, which is estimated to be equivalent to 3 years of natural radiation background dose.[12] However, other studies have shown that up to 25% of CT abdomen/pelvis require an effective dose of over 20 mSV.[13] It has been shown that radiation risk becomes more prominent at doses above 10 mSv, as in cases with repeated imaging, and in the pediatric population where rapidly growing organs are most radio-sensitive. Children are also more likely to develop radiation-induced malignancy due longer latency periods.[14] For instance, a 10-year-old patient is more likely to develop a neoplastic process within a 30-year period compared to a 50-year-old, based on life expectancy. It has been hypothesized that a radiation-induced malignancy may occur once out of every 300-400 CT abdomen/pelvis performed in the pediatric population.[10,15] For this reason, ALARA (As Low As Reasonably Achievable) has been developed to minimize radiation exposure and risk.[16] By reducing the imaging field of view, the amount of radiation exposure is also decreased.

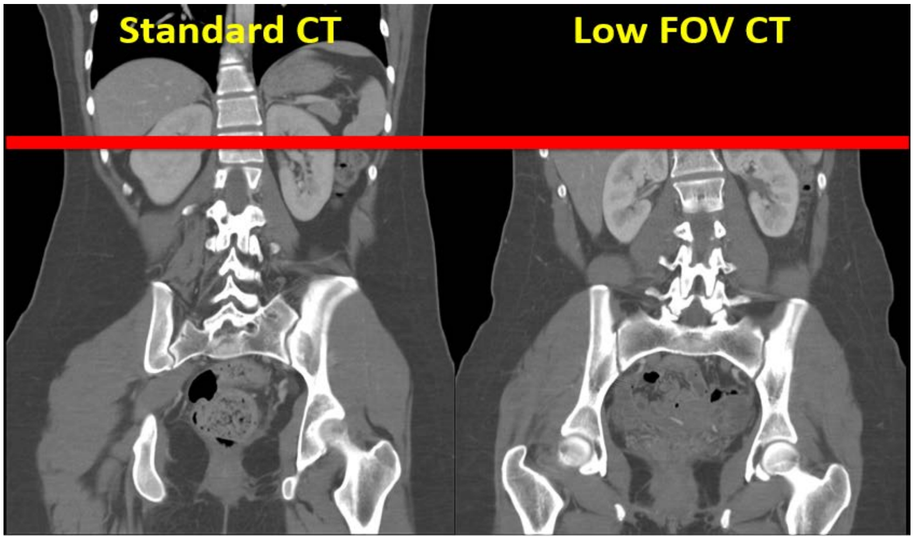
Preliminary Information

In a retrospective review recently published in 2017, Davis et al. located all of the visualized appendices below the level of the L1 vertebral body.[17] It was concluded that the CT field of view (FOV) could be reduced by using L1 as the superior aspect of the image without compromising sensitivity or specificity. By reducing the FOV, the risk of radiation exposure is also decreased. Based on this study, a "low FOV" protocol was then developed. The protocol will use the L1 vertebral body as the superior aspect of the CT, instead of dome of the diaphragm as used by standard CT abdomen/pelvis protocols (Figure 1).

Research Question and Hypothesis

Our research question is to evaluate the sensitivity, specificity, and average FOV reduction in the low FOV CT protocol in the diagnosis of acute appendicitis in the pediatric population. In addition to decreasing the FOV, we hypothesize that the sensitivity and specificity of the low FOV CT protocol will be comparable to those of standard CT abdomen/pelvis.

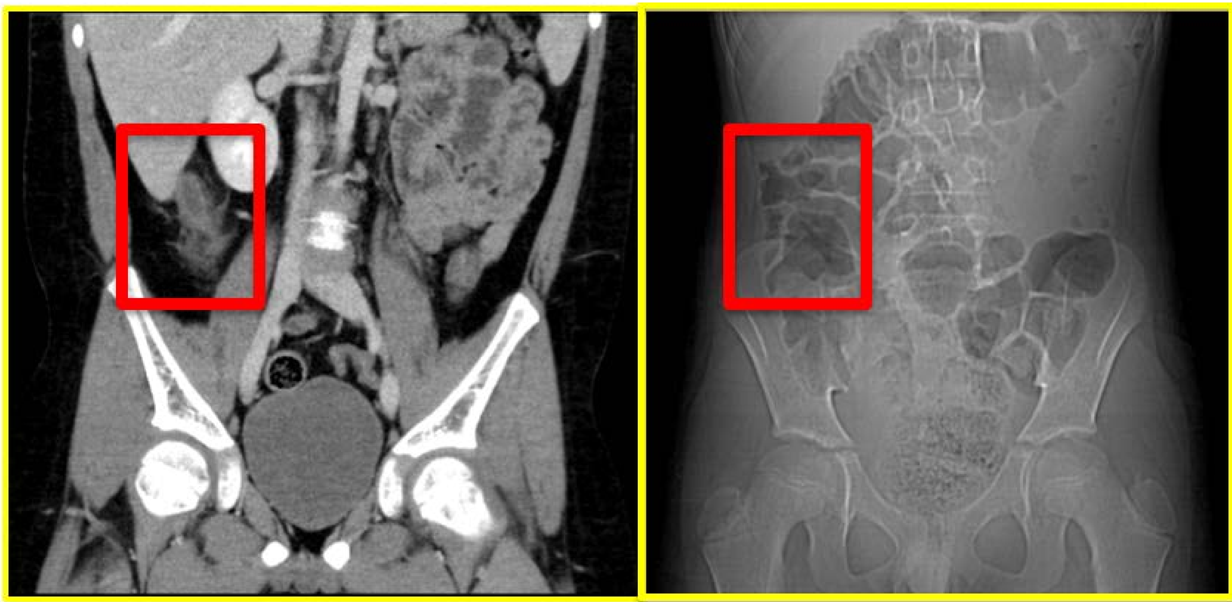
Figure 1: Coronal CT of the abdomen/pelvis with the red line depicting the area of FOV that is reduced with the low FOV protocol.



RESEARCH MATERIALS AND METHODS

Our retrospective review included all patients under the age of 18 years old who presented to the Maricopa Medical Center Pediatric Emergency Department requiring evaluation of acute appendicitis undergoing a low FOV CT from November 2016 to November 2017. A total of 171 patients met inclusion criteria and were included in the final data analysis. Patient information collected included age and gender. Data collected included: craniocaudal (CC) dimensions of low FOV and standard FOV, initial ultrasound diagnosis and appendix visualization, CT diagnosis and appendix visualization with corresponding vertebral level, clinical diagnosis, and other alternative diagnosis. Figure 2 depicts an example of how the appendix (in this case a patient with appendicitis) is visualized and subsequently corresponded to the appropriate vertebral level on the coronal view.

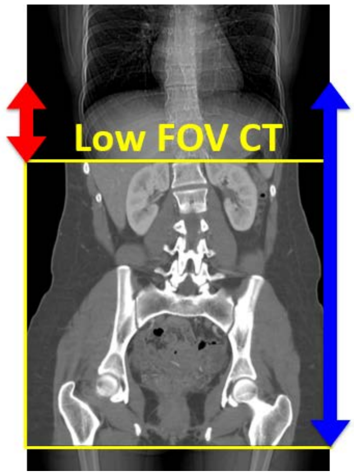
Figure 2: CT with red box indicating acute appendicitis. The right image illustrates correlation of the appendix location with the relative vertebral level.



The criteria of CT diagnosis for acute appendicitis included abnormally thickened (≥7mm), enhancing appendix with surrounding inflammation, abscess, or phlegmon formation.[18] The CT diagnosis was obtained from prospective radiology reports, which were not retrospectively reassessed in this study. All low FOV CT exams were performed on one of two scanners: a Philips 256-slice iCT system (Philips Healthcare, The Netherlands) or a Light Speed 16-slice CT system (GE Healthcare, Waukesha, WI). Isovue 350 (Bracco, Monroe Township, NJ) intravenous contrast was utilized in all cases, with a dosage of 1 mL per pound of patient weight up to a maximum dose of 150 mL. No oral or rectal contrast was administered. The percentage of FOV reduction is calculated by dividing the difference of the CC dimensions of low and standard FOV by the CC dimension of the standard FOV (Figure 3). If the patient underwent appendectomy, the clinical diagnosis was based on operative or pathology reports. If not, chart review for 30 days was used to make sure that the patient did not have a re-admission for a missed clinical diagnosis. Primary outcomes were sensitivity, specificity, and FOV reduction. Secondary outcomes were appendix visualization rate, appendicitis rate, and alternative diagnosis rate.

Figure 3: Formula used to determine FOV reduction with accompanying CT abdomen/pelvis illustration.

FOV reduction = **Reduced FOV** / **Standard FOV**



RESULTS

The average age of our patient population was 10.7 years old with gender distribution 46.8% female and 53.2% male. Out of a total of 171 patients involved in the study, 106 patients (61.9%) received a prior ultrasound, and 10 of these patients were diagnosed with appendicitis on ultrasound.

On CT imaging, the overall appendix visualization rate was 95.3% (total of 8 cases where the appendix was not visualized). The appendix was visualized at the vertebral level L5 on average, with a range of L2 to the sacrum (Table 3). No appendices were visualized above the level of L2.

The mean CT CC dimension of low FOV was 267.5 mm (SD=64.0) compared to 354.89 mm (SD=64.9) in standard FOV with mean FOV reduction of 26% (95.0 mm). The mean radiation dose to patients using low FOV CT was CT dose index mean of 9.3 mGy, ranging from 1.9 in a 3-year-old female to 26.6 in a 13-year-old female, and dose length product mean of 255 mGy-cm, ranging from 44 in a 3-year-old female to 1334 in a 13-year-old female.

A total of 51 patients were diagnosed with appendicitis on CT imaging, 47 of which were confirmed on clinical diagnosis (true positives). The remaining 4 patients had equivocal or “early” appendicitis (false positives). These patients were diagnosed with acute appendicitis on CT but, upon review, the clinical diagnosis confirmed no evidence of acute appendicitis. Six patients had alternative diagnoses, including ovarian torsion, cystitis, hydronephrosis, and pyelonephritis. The cases of ovarian torsion and cystitis were located at the level of the sacrum, while cases of hydronephrosis and pyelonephritis were located at the level of L1 or L2. 114 patients were correctly diagnosed with no appendicitis on low FOV CT (true negatives). No case of appendicitis or alternative diagnosis was missed (no false negatives). The sensitivity and specificity of low FOV CT in diagnosing acute appendicitis was determined to be 100% and 97%, respectively (Tables 4 and 5).

Table 3: Appendix visualization at corresponding vertebral levels.

Vertebral Body Level	Number of Subjects
L1	0 (0.0%)
L2	2 (1.2%)
L3	6 (3.7%)
L4	32 (19.6%)
L5	68 (41.7%)
Below L5	55 (33.7%)
Total	163

Table 4: Number of Patients with Positive or Negative CT Results and Corresponding Clinical Diagnosis

		Appendicitis	
		Positive	Negative
Low FOV CT	Positive	47	4
	Negative	0	114

Table 5: Sensitivity, specificity, and appendix visualization rate of low FOV and standard CT.

	Low FOV CT	Standard CT[4]
Sensitivity	100%	99%
Specificity	97%	97%
Appendix visualization rate	95.3%	90%

DISCUSSION

Current standard of field-of-view of the CT abdomen/pelvis uses the dome of the diaphragm as the superior border of the image. The low field-of-view (FOV) method used in this study utilized the L1 vertebral level as the superior border instead, decreasing the field of view and therefore ionizing radiation to the patient. Our study found that by lowering the superior border to L1, the FOV was reduced by an average of 26% without compromising sensitivity (97%) or sensitivity (100%). The results are comparable to those from existing literature. In the 8 cases where the appendix was not visualized, the appendix was most likely obscured by surrounding bowel, as the cecum in these cases were visualized in the sacrum (Figure 5). Therefore, it was not likely that visualization was impaired due to the smaller FOV.

Figure 5: Coronal CT with red box indicating the location of the cecum in the sacrum, with no appendix visualized.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Our study did not quantify the exact reduction in exposure to ionizing radiation, only the reduction in FOV. The precise correlation between radiation dose and FOV was beyond the scope of this study. Future studies should quantify the exact radiation dose reduction of our low FOV protocol. Our study may also be limited by possible missed alternative diagnosis above the level of L1. Examples of this include pneumonia, pyelonephritis, pancreatitis, and small bowel obstruction.[17] It is unlikely that this occurred in our study as no patients returned for an alternative diagnosis within 30 days of initial presentation according to our chart review, although it is possible that some patients may have presented to different hospitals within this timeframe.

Our research is the first prospective study in this topic. Our promising results suggest that low FOV CT of the abdomen and pelvis is as reliable and accurate as the standard CT in diagnosing acute appendicitis, and should be considered for routine use in pediatric patients, who are already most susceptible to the risks of ionizing radiation.

FUTURE DIRECTIONS

As this study was limited to pediatrics, future research should explore the application of low FOV CT in the adult population. The calculations of exposed ionizing radiation doses were beyond the scope of this study and present an avenue of research in follow-up studies. Multi-center studies in larger patient populations will further solidify the role of low FOV CT in diagnosing acute appendicitis.

CONCLUSIONS

Our study discovered that the low FOV CT reduced the FOV by 26%, thus decreasing ionizing radiation exposure without any reduction in sensitivity or specificity. This study suggests that low FOV CT is as reliable as the current standard FOV CT in diagnosing acute appendicitis in pediatric population. We recommend that larger follow-up studies be conducted to validate our findings.

REFERENCES

[1] Addiss DG, Shaffer N, Fowler BS, Tauxe RV. The epidemiology of appendicitis and appendectomy in the United States. Am J Epidemiol. 1990;132(5):910-925.

[2] Nance ML, Adamson WT, Hedrick HL. Appendicitis in the young child: a continuing diagnostic challenge. Pediatr Emerg Care. 2000;16(3):160.

[3] Colvin JM, Bachur R, Kharbanda A. The presentation of appendicitis in preadolescent children. Pediatr Emerg Care. 2007 Dec;23(12):849-55.

[4] Hardin DM, Texas A&M University Health Science Center. Acute appendicitis: review and update. Am Fam Physician. 1999; 60(7):2027-2034.

[5] Wagner JM, McKinney WP, Carpenter JL. Does this patient have appendicitis?. JAMA. 1996;276:1589-1594.

[6] Ebell MH, Shinholser J. What are the most clinically useful cutoffs for the Alvrado and Pediatric Appendicitis Scores? A systematic review. Ann Emerg Med. 2014;64(4):365-372.

[7] Duke E, Kalb B, Arif-Tiwari H, et al. A systematic review and meta-analysis of diagnostic performance of MRI for evaluation of acute appendicitis. AJR 2016; 206(3); 508-517.

[8] Koning JL, Naheed JH, Kruk PG. Diagnostic performance of contrast-enhanced MR for acute appendicitis and alternative causes of abdominal pain in children. Pediatr Radiol 2014; 44: 948-955.

[9] Butler M. Servaes S. Srinivasan A et all (2011) US depiction of the appendix: role of abdominal wall thickness and appendiceal location. Emerg Radiol. 18:525-531

[10] Pinto F, Pinto A, Russo A, Coppolino F, Bracale R, et al. Accuracy of ultrasonography in the diagnosis of acute appendicitis in adult patients: review of literature. Crit Ultrasound K. 2013;5:S2.

[11] Rao PM, Rhea JT, Novelline RA, McCabe CJ, Lawrason JN, Berger DL, et al. Helical CT technique for the diagnosis of appendicitis: prospective evaluation of a focused appendix CT examination. Radiology. 1997;202:139–44.

[12] Lin EC. Radiation risk from medical imaging. Mayo Clin Proc. 2010; 85(12):1142-1146.

[13] Miglioretti DL, Johnson E, Williams A, Greenlee RT, Weinmann S, Solberg LI, et al. Pediatric Computed Tomography and Associated Radiation Exposure and Estimated Cancer Risk. JAMA Pediatr. 2013;167(8):700-707.

[14] Brody AS, Frush DP, Huda W, Brent RL. Radiation Risk to Children From Computed Tomography. Am Acad Pediatr. 2007;120(3).

[15] Brenner DJ, Hall EJ. Computed Tomography - An Increasing Source of Radiation Exposure. N Engl J Med 2007; 357: 2277-2284.

[16] Hendee WR, Edwards FM. ALARA and an integrated approach to radiation protection. Semin Nucl Med. 1986;16(2):142-150.

[17] Davis J, Roh AT, Petterson MB, et al. Computed tomography localization of the appendix in the pediatric population relative to the lumbar spine. Pediatr Radiol 2017; 47: 301-305.

[18] Curtin KR, Fitzgerald SW, Nemcek AA, Hoff FL, Vogelzang RL. CT diagnosis of acute appendicitis: imaging findings. AJR. 1995;164:905-909.