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Implementation of an Electronic Clinical Decision Support Tool for Pediatric Appendicitis within a Hospital Network

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Abstract

Objectives—Computed tomography (CT) has been widely used in the evaluation of children with suspected appendicitis, but concerns about ionizing radiation have increased interest in ultrasound for these patients. We sought to assess the effectiveness of an appendicitis electronic clinical decision support (E-CDS) system in increasing ultrasound and decreasing CT use in children evaluated in EDs for suspected appendicitis.

Methods—This was a pre- and post-intervention analysis of an E-CDS implemented into an electronic health record system shared by an academic, tertiary care children's hospital and a community hospital. The tool consisted of a structured order set with embedded clinical advice and a link to a website. ED patients aged 3–18 years with suspected appendicitis were reviewed retrospectively. Imaging use was assessed 3 months pre- and 6 months post-implementation of the intervention.

Results—327 patients were identified, 211 post-intervention; 80% were seen in the community ED. Among community ED patients with imaging, ultrasound use increased (36% to 51%, $p=0.049$) and CT scan use decreased (81% to 66%, $p=0.044$) in the post-intervention period, with no change in complications or safety outcomes. No difference was found in US rate (100% to 97%, $p=1.000$) or CT scan rate (13% to 10%, $p=1.000$) among children's ED patients with imaging.

Conclusion—An E-CDS can effectively decrease CT scanning and increase use of ultrasound in children with suspected appendicitis in a community hospital ED. Electronic clinical decision

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support may be an effective method of disseminating pediatric best practices from a children's hospital to affiliated community EDs.

Keywords

Appendicitis; clinical decision support; ultrasound; community hospital

INTRODUCTION

Appendicitis is a common cause of urgent surgery in children, with approximately 65,000 pediatric appendectomies performed annually in the United States.[1] Computed tomography (CT) scanning is commonly used in the diagnosis. However, due to concerns about the effects of ionizing radiation from CT scans in children, there has been a movement in pediatric practice toward increasing the use of ultrasonography in the evaluation of children with possible appendicitis.[2–4] There is some evidence that practice in this regard varies for children cared for in Pediatric EDs versus in general EDs. In a recent study that examined the care of pediatric patients with abdominal pain in a national sample of emergency departments, the CT scan rate was 39% compared to an ultrasound (US) rate of 11%; the CT scan rate increased every year during the eight-year study period. The substantial majority of the analyzed centers in that study were general EDs.[5] Conversely, a study of practice in children's hospitals showed a decrease in the overall usage of CT scans during a similar time period (2003–2007).[6]

A number of recent studies have assessed the effectiveness of paper-based clinical practice guidelines (CPGs) implemented in pediatric emergency departments (EDs) to optimize the diagnosis of pediatric appendicitis, including emphasizing ultrasound use when appropriate. [7–9] These have generally been based on adaptations of previously validated scoring systems, such as the low-risk appendicitis rule,[10, 11] the modified Alvarado score,[12] and the Pediatric Appendicitis Score.[13]

Despite the known effectiveness of clinical practice guidelines, real world implementation studies are lacking. Furthermore, a number of prior studies have highlighted clinician knowledge of clinical guidelines as the key barrier to successful, long-term acceptance.[14–16] This has led to recommendations to encourage the use of technological adjuncts such as electronic alerts or messages as a means to increase clinician awareness of evidence-based guidelines.[15, 16] Clinician acceptance of guidelines is of particular consideration for hospital systems in which providers of varying training backgrounds care for children in emergency departments. A number of studies have shown variability in practice between providers with training in general emergency medicine and those with specific pediatric training, with pediatric trained providers tending to show greater adherence to pediatric guidelines[17–19] and decreased resource use, particularly in diagnostic testing.[20–23] Yet, only 20% of emergency departments in the United States have around-the-clock access to board-certified pediatric emergency physicians, and 71% of ED visits by children take place in hospitals that do not have dedicated pediatric facilities.[24] Thus, optimization of pediatric care given by general emergency medicine trained providers in non-pediatric settings is an important target in the improvement of pediatric emergency care. To address

these issues, we sought to assess the utility of an electronic health record (EHR) based clinical decision support system (E-CDS) to optimize the care of children with acute abdominal pain in a general emergency department in a community hospital.

MATERIALS AND METHODS

Study design

This study was a pre- and post-intervention analysis of the use of an EHR-based clinical decision support order set to improve the care of pediatric ED patients with suspected appendicitis. The study was approved by the relevant institutional review board prior to initiation of data collection.

Development of the E-CDS intervention

A clinical practice guideline for the evaluation of children with suspected appendicitis was developed by a multi-disciplinary group of pediatric emergency medicine physicians, radiologists and surgeons from the children's hospital. Clinical content was based on the low-risk appendicitis rule[10] and the pediatric appendicitis score.[13] The availability of US and surgical consultation did not change during the study period.

In order to provide real time, point of care access to management recommendations, the guideline content was built into a decision support order set, the E-CDS. It was designed to facilitate the ordering of laboratory studies, medications, and radiographic studies commonly used for children with suspected appendicitis. The intent was that it would be accessed by clinicians at the time of their initial order placement for these patients. It consisted of three steps. Step 1 included common orders for the initial evaluation; Step 2 guided secondary consideration of imaging after laboratory information, particularly absolute neutrophil count (ANC), was available; Step 3 contained additional orders based on the results of the workup. The E-CDS also contained a link to a website providing calculators and references for the two appendicitis scores. The layout and content of the E-CDS are shown in Figure 1.

The E-CDS was launched in the EHR throughout the hospital system on March 1, 2012. Providers were introduced to the order set in formal (grand rounds) and informal training sessions conducted by study investigators.

Patient selection and setting

Pre- and post-intervention cases were identified retrospectively by searching the electronic medical record for the keywords "abdominal pain" and "appendicitis" (including "rule out" or "possible" appendicitis), and by the ICD-9 code for appendicitis (540.0). We selected a three month period prior to implementation of the E-CDS to determine our baseline rate of imaging and a 6 month period post-intervention to measure the effect of the E-CDS. Patients were included if they were between 3 and 18 years old and had a chief complaint of abdominal pain for less than 96 hours. To avoid complicating the analysis by including patients who may have had other indications for imaging, we excluded patients who had

relevant chronic medical conditions such as metabolic disease, active cancer, current pregnancy, previous abdominal surgery, or history of abdominal trauma in the past 7 days.

The impact of the E-CDS was assessed at two different hospitals within our larger care system. The first site was an urban, tertiary care children's hospital with 11,000 pediatric ED visits per year; the second was a suburban community hospital with approximately 53,000 ED visits per year, including 12,000 children.

Outcomes

The primary outcomes for the study were the rate of US and CT in included patients at each site. Secondary outcomes selected to assess safety and capture missed diagnoses included appendectomy rate, rate of perforated appendicitis, rate of negative appendectomy, and rate of re-hospitalization (in the same hospital system) in the four weeks following discharge. Usage of the E-CDS and adherence to its clinical guidance were not separately tracked.

Data collection

Research assistants trained by study investigators gathered data through review of standard EHR documentation. Data elements collected included presenting symptoms, physical examination findings, laboratory results, imaging results, operative and pathology findings for patients who had operations, final diagnosis, disposition, and return to care in the four weeks following discharge. Operative reports and pathology reports were reviewed to determine the presence of appendicitis and perforation; a listing of key words and phrases to standardize interpretation of these reports was provided. In cases where the operative and pathology reports gave inconsistent results, physician investigators reviewed the records to make a final determination. "Negative appendectomy" was defined as a pathology result showing no signs of appendicitis in a patient who had an appendectomy.

Data analysis

The demographic characteristics of patients pre-intervention and post-intervention were compared at both hospitals. In particular, a two-sample t-test with unequal variance investigated differences in continuous variables, while Fisher's exact test was used for categorical variables. As the patient gender mix was noted to be significantly different pre-versus post-intervention and gender is a potential confounder of US and CT scan usage, a logistic regression model was used to adjust for gender. All analyses were done in SAS version 9.3.

RESULTS

A total of 511 patient records were screened for inclusion in the study over the 9 month study period, yielding 327 eligible cases for analysis. Reasons for exclusion and overall case flow are outlined in Figure 2. Included patients had a mean age of 12.3 (standard deviation (SD) 3.7) pre-intervention, 12.5 (SD 3.9) post-intervention; 55% pre-intervention and 36% post-intervention were male ($p=0.002$). Further information on clinical characteristics is presented in Table 1. Twenty percent were cared for in the children's hospital, 80% in the community hospital. Presenting characteristics were generally similar among groups,

although there were some significant differences in presenting symptoms and laboratory results between the community hospital pre- and post-intervention groups. These differences favored less severe symptomatology in the post-intervention group.

Primary Outcomes

Findings describing the use of US and CT scanning in included patients pre- and post-intervention are presented in Table 2. In the subset of patients with any imaging performed in the community ED, we report a significant increase in the use of US (36% to 51%, $p=0.049$) and decrease in the use of CT (81% to 66%, $p=0.044$), and a near-significant increase in the use of US (26% to 38%, $p=0.055$) among all patients. A small number of patients in both time periods had both US and CT performed, with no change post-intervention. At the children's hospital, US use was already high relative to CT in the pre-intervention period; no change in usage was detected with introduction of the E-CDS.

Due to the unexpected gender imbalance between the pre- and post-intervention groups and the anticipated relationship between US or CT usage and gender, a secondary analysis was conducted that adjusted for the potential confounding effects of gender (see Table 3). This adjustment slightly attenuated the effect of the E-CDS, leading to marginally non-significant differences ($p = 0.097$ for US and $p = 0.062$ for CT). It is important to note that the study was not powered to assess an adjusted effect of E-CDS as gender was not expected to vary between the pre- and post-intervention groups.

Safety Measures

Our measures for safety showed no statistical difference in the perforation rate, missed appendicitis rate, negative appendectomy rate, or four week re-hospitalization rate over the study period; these outcomes and overall rates of appendectomy and appendicitis are presented in Table 4. Missed appendicitis rate was low in all cases, and negative appendectomy rate was very low, with only one negative appendectomy performed. This was during the post-intervention period at the community hospital, in a patient who had a CT scan. The CT scan was read as "cannot rule out early appendicitis"; operative and pathologic findings revealed a normal appendix and an ovarian cyst.

DISCUSSION

This study demonstrates that the implementation of an EHR-based clinical decision support order set was associated with an increase in the use of US and decrease in the use of CT in the evaluation of suspected appendicitis in children. These changes were seen without a negative impact on clinical care; we found no increase in the rate of missed appendicitis or negative appendectomy. Moreover, our findings demonstrate that clinical decision support can be used to influence pediatric practice within a general, community emergency department.

There was significant pre-intervention variation in practice between the children's and community hospital EDs, with much greater use of US rather than CT at the children's hospital. Although there was no formal guideline in place at the pediatric hospital prior to implementation of the E-CDS, it is possible that the very high rate of US rather than CT

reflects early adoption of the ideas underlying the intervention through informal interactions between providers. Differences between the two settings diminished but were not erased as we implemented the E-CDS intervention. Given that a high proportion (89% in one study) [25] of pediatric ED visits take place outside of dedicated pediatric EDs, optimizing the care given in general emergency departments is critical to limiting unnecessary radiation exposure in children. Many hospitals participate in networks that include children's hospitals; leveraging the capabilities of shared EHR systems may be an effective means of disseminating pediatric best practices throughout the system.

Several recent studies have evaluated the use of CPGs to optimize care in children with suspected appendicitis. Fleischman, et al, evaluated the test characteristics of a pathway using a combination of high-risk and low-risk indicators from two prior scoring systems.[7] They found a decrease in CT use (from 12.7% to 6.9%, $p=0.02$) but no significant change in US use. The pathway was implemented in a pediatric ED in a prospective manner, with research assistants approaching providers in real time to prompt them to follow the pathway. Saucier, et al, found good sensitivity and specificity of a clinical pathway based on the pediatric appendicitis score with the specific intention of using US as the primary imaging modality.[9] This approach yielded 94% overall diagnostic accuracy, with CT scan obtained in 6.6% of patients. That study, too, was conducted in a children's hospital ED. However, it was implemented through a combination of print (posted in the providers' workspace) and electronic (score calculation built into the EHR) means. A third recent study, by Santillanes, et al, again showed good clinical accuracy from a novel clinical pathway based on previously published risk-stratification systems, with a focus on US as the initial imaging study. It was implemented prospectively, via posters and email reminders, in a pediatric ED. [8] In all three of these investigations, providers were aware at the time of patient evaluation that the patient was being enrolled in a study of a new appendicitis pathway.

Unlike these prior studies, we implemented our E-CDS entirely through the electronic health record system, without the use of research assistants or ongoing education, and we did not separately track usage of the E-CDS. We believe that the nature of our investigation more accurately captures provider behavior in circumstances where clinicians are not immediately aware that their management decisions are being observed to assess protocol adherence. Furthermore, in our opinion this approach provides a more real-world view of use of the guideline outside the intense focus of active prospective data collection. Finally, this study includes the novel feature of implementation in a community hospital ED of content developed by a team at an affiliated children's hospital. The content for our E-CDS was developed by the pediatric emergency physicians, radiologists, and surgeons based at the children's hospital, and it was our hope that the agreed upon best-practices would see acceptance by our general ED colleagues. Intense efforts to optimize pediatric emergency care are common in pediatric EDs, but in general and community EDs, pediatric care must compete for attention with a wide variety of concerns more common in adult patients. The intervention we report was relatively simple, with an announced rollout of a new customized order-set with embedded decision support, but without significant ongoing reminders or surveillance of use. The finding of significant behavior change in a community hospital ED after provision of this relatively modest guidance from the pediatric ED in the same hospital

system may indicate significant opportunities for pediatric EDs to work with their general ED colleagues to optimize pediatric care in other clinical settings as well.

Limitations

This study has several potential limitations. Its retrospective design required reliance on standard EHR documentation to identify patients and determine the care given. This may have led to missed eligible patients or to incomplete information about clinical circumstances. Furthermore, review of records from only a single hospital system may have led to understatement of the missed appendicitis rate if patients were later diagnosed with appendicitis at a different hospital.

In addition, the unexpected finding of significant differences in gender mix and in reported presenting symptoms and signs between the pre- and post-intervention groups complicates the results, despite identical methods of patient selection in the two time periods. In particular, there were significant decreases in the proportion of patients reported to have maximal pain in the right lower quadrant (RLQ) and a history of migration of pain. Given that the E-CDS prompted consideration of maximal RLQ pain and migration, if this change were due to the E-CDS it would have seemed more likely that such documentation would have increased in the post-implementation period. It is unclear why such documentation would have been significantly different post-intervention. The severity differences were only significant at the community hospital, with decreased severity in the post-intervention period. There is no reason to suspect that this difference would have led to increased use of US and decrease in CT.

The increased proportion of female patients in the post-intervention group is more problematic, as improved imaging of pelvic structures may lead to a preference for US in female patients. We attempted to assess the impact of this difference by conduction of an additional logistic regression analysis controlling for gender; this adjustment would be expected to account for confounding by gender. However, as this study was not powered account for variance inflation due to covariate adjustment, the significant findings became slightly attenuated and marginally nonsignificant upon adjustment for gender. Given the preservation of the direction of the effect and the near-significant p-values ($p=0.062$ for the decrease in CT use at the community hospital), we believe that future studies that anticipate and account for the inflated variance caused by covariate adjustments[26] would help confirm the results of this investigation.

The implementation of the intervention in a single health system may limit its generalizability to other centers. However, we believe that our findings would be applicable to many healthcare systems. Last, as we did not separately track E-CDS usage, it is possible that the differences found are due to the education that accompanied its launch or to a pre-existing trend in imaging use. This may mean that changes in imaging rates are only partially due to the intervention. The pre-intervention period did not contain enough data points to allow for statistical comparison of the pre-intervention and post-intervention trends.

Conclusion

Use of an EHR-based clinical decision support order set developed and implemented from a children's hospital is associated with a decrease in CT scanning and increase in use of US in pediatric patients with suspected appendicitis seen in an associated community hospital, although this study was not large enough to rule out the presence of a gender effect on imaging. The use of such order sets and clinical algorithms may be an effective means to disseminate pediatric best practices from a children's hospital to a community ED in the same system.

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Pediatric Emergency Medicine Guidelines

▶ STEP 1 - EVALUATION OF PATIENTS WITH ACUTE RLQ PAIN

▼ STEP 2 - DISPOSITION AND DIAGNOSIS

▼ Please Categorize patient's risk for appendicitis based on criteria below

Low Risk

- ANC < 6.75 and the absence of nausea OR an ANC < 6.75 with presence of nausea but no maximal pain in the RLQ
- Pediatric Appendicitis Score < 3

Suggested Management: Discharge to home with close follow-up or observation**Medium Risk**

Patients with non-reassuring exam and/or laboratory findings:

- Elevated WBC or ANC along with pain in the RLQ
- Post-Pubertal females with RLQ pain
- Persistent pain in RLQ

Suggested Management: Begin with Abdominal Ultrasound. If Ultrasound equivocal or unavailable, proceed to CT with IV contrast alone**High Risk**

Patients with classic presentations of appendicitis:

- Pain < 36 hours duration, history of focal RLQ pain and migration of pain **AND**
- Focal tenderness in RLQ/McBurney's point and/or pain with walking

Suggested Management: Surgical consult. No imaging needed unless recommended by surgical staff☐ Low Risk☒ Medium Risk☐ US Abdomen Limited*

STAT

☐ High Risk

▼ STEP 3 - MANAGEMENT

▼ If US NEGATIVE for Appy or US unavailable consider CT or Surgical consultation

☐ CT Abdomen w Contrast

STAT, IV contrast only

☐ Pediatric Surgery IP Consult☐ Surgery General IP Consult

▶ If US POSITIVE or with secondary signs

▼ Antibiotics

☐ Non-perforated Appendicitis☐ Perforated Appendicitis☐ Penicillin Allergy

▼ ADDITIONAL ORDERS

▶ Procedures

▶ X-Ray

▶ CT

▶ Ultrasound - (UU, UR, RH, SH, PH, WY)

▶ Consults

Figure 1.
E-CDS content and layout

Figure 2.
Study patient flow

Table 1

Patient Characteristics (n=327)

	All		Children's ED		Community ED	
	Pre	Post	Pre	Post	Pre	Post
Number of patients	116	211	22	45	94	166
Age in years ¹	12.3 (3.7)	12.5 (3.9)	10.5 (4.1)	11.7 (4.3)	12.7 (3.5)	12.7 (3.8)
Male gender	64 (55%)	77* (36%)	15 (68%)	16* (36%)	49 (52%)	61* (37%)
History: ²						
Anorexia	37 (61%)	76 (60%)	12 (86%)	21 (68%)	25 (53%)	55 (58%)
Nausea	70 (66%)	124 (64%)	12 (71%)	26 (72%)	58 (65%)	98 (62%)
Vomiting	49 (42%)	77 (37%)	10 (45%)	19 (45%)	39 (41%)	58 (35%)
Migration of pain to RLQ	36 (58%)	35* (18%)	4 (40%)	12 (30%)	32 (62%)	23* (15%)
Physical: ²						
Tenderness	21 (18%)	41 (19%)	2 (9%)	10 (22%)	19 (21%)	31 (19%)
Max in RLQ	26 (60%)	39* (40%)	6 (55%)	10 (42%)	20 (63%)	29* (40%)
Maximum temperature ¹	98.6 (1.0)	98.8 (1.3)	98.7 (1.3)	99.2 (1.1)	98.6 (1.0)	98.7 (1.3)
Laboratory results:						
WBC ¹	12.2 (9.5)	10.2* (3.9)	10.0 (5.3)	11.0 (4.1)	12.7 (10.1)	9.9* (3.9)
ANC ¹	8.3 (5.4)	7.2 (4.0)	7.4 (5.6)	7.7 (4.2)	8.5 (5.3)	7.1* (4.0)

¹ Mean (standard deviation)² Denominator for history and physical finding percentages is the number of patients for whom any comment was made in the chart regarding that finding

* p<0.05; all other comparisons not significant

Table 2

Imaging type

All patients	Children's ED (n=67)			Community ED (n=260)		
	Pre	Post	P	Pre	Post	P
Ultrasound	15 (68%)	30 (67%)	1.000	24 (26%)	63 (38%)	0.055
CT	2 (9%)	3 (7%)	1.000	54 (57%)	82 (49%)	0.245
Both US and CT	2 (9%)	2 (4%)	0.593	11 (12%)	24 (15%)	0.576
Patients with any imaging	Children's ED (n=46)			Community ED (n=191)		
	Pre	Post	P	Pre	Post	P
Ultrasound	15 (100%)	30 (97%)	1.000	24 (36%)	63 (51%)	0.049
CT	2 (13%)	3 (10%)	1.000	54 (81%)	82 (66%)	0.044
Both US and CT	2 (13%)	2 (7%)	0.587	11 (16%)	24 (19%)	0.698

Table 3

Odds ratios for increase in use of imaging type, adjusted for gender. OR > 1 indicates increase in the odds of that modality in the post-intervention period.

		Children's ED (n=67)		Community ED (n=260)	
		OR (95%CI)	P	OR (95% CI)	P
All patients	US	0.70 (0.22, 2.25)	0.545	1.59 (0.9, 2.82)	0.113
	CT	0.85 (0.12, 6.05)	0.872	0.74 (0.44, 1.24)	0.258
Patients with imaging	US	-- ¹	--	1.70 (0.91, 3.18)	0.097
	CT		0.958	0.50 (0.25, 1.03)	0.062

¹ Unable to calculate OR for change as ultrasound rate was 100% in this group pre-intervention.

Table 4

Outcomes (n=327)

	All		Children's ED		Community ED	
	Pre	Post	Pre	Post	Pre	Post
Appendectomy performed	28 (24%)	44 (21%)	4 (18%)	12 (27%)	24 (26%)	32 (29%)
Final diagnosis appendicitis	28 (24%)	43 (20%)	4 (18%)	12 (27%)	24 (26%)	31 (19%)
Perforated appendicitis	3 (11%)	5 (11%)	0 (0%)	1 (8%)	3 (13%)	4 (13%)
Re-hospitalization within 4 weeks	6 (7%)	7 (4%)	1 (6%)	2 (6%)	5 (7%)	5 (4%)
Missed appendicitis cases	2 (2%)	1 (0.6%)	1 (5%)	1 (2%)	1 (1%)	0 (0%)
Negative appendectomy	0 (0%)	1 (2%)	0 (0%)	0 (0%)	0 (0%)	1 (3%)

^aP<0.05 for all comparisons.