Provider Density and Health System Facility Factors and Their Relationship to Rates of Pediatric Perforated Appendicitis in US Counties

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Objective: To examine whether density of providers or health care facility factors have a significant effect on the rates of perforated appendicitis in the pediatric population.

Design: A retrospective database analysis. Data were linked to the Area Resource File to determine if there was an association between perforated appendicitis and density of provider and facility factors.


Patients: All patients included had an age at admission of younger than 18 years and were selected by International Classification of Diseases, Ninth Revision code as having perforated appendicitis (540.0 or 540.1) or acute appendicitis (540.9).

Main Outcome Measure: Odds ratio of perforated appendicitis to acute appendicitis by county-level density of provider and health care facility factors.

Results: The odds ratio of perforated appendicitis to acute appendicitis when stratified by quartiles of increasing density of providers and facility-level factors was statistically significant only for the highest-density quartile of pediatricians (odds ratio=0.88; 95% confidence interval=0.78-0.99).

Conclusions: Increasing geographic density of pediatricians was associated with a decreasing trend in the odds ratio of perforated appendicitis, with a statistically significant protective effect observed in the highest-density quartile of pediatricians. The density of all other provider and health care facility factors analyzed did not demonstrate a significant association with the rates of perforated appendicitis.

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Appendicitis is one of the most common diseases requiring surgical intervention in the pediatric population. Perforated appendicitis occurs in approximately one-third of children with appendicitis, with a resultant increase in length of hospital stay, postoperative complications, and cost. However, knowledge regarding risk factors associated with an increased likelihood of perforation is limited. Previous studies have confirmed disparities in race and insurance status as contributing factors toward increasing the likelihood of perforated appendicitis. The importance of prehospital health care system–level factors has been suggested by Hale et al, who found that a significant proportion of patients with perforated appendicitis had outpatient delays prior to presentation. Other health system factors that may affect the rate of perforated appendicitis have also been investigated. The availability of advanced diagnostic testing, for example, was not shown to be associated with a reduction in the rates of perforated appendicitis in the population.

The purpose of the present study was to identify health care system–level factors that may potentially be related to the rate of perforated appendicitis specifically in the pediatric population. As a child with a case of evolving appendicitis presents to the health care system, he or she generally will require the assistance of pediatricians, emergency department physicians, radiologists, and a surgeon. Beyond providers, hospital-level factors, such as the emergency department resources, availability of computerized tomography (CT), and operating room facilities, also play a vital role. Therefore, we hypothesized that certain health care system–level factors, such as adequacy in numbers of medical providers and health care infrastructure, may affect timely diagnosis in the population. To answer this question, nationwide data from more than 93 million hospital admissions were screened to identify more than a quarter million chil-
dren with acute and perforated appendicitis. These data were then linked to the Area Resource File (ARF) to obtain information related to provider density and health care system factors.

METHODS

This study was deemed exempt from review by the institutional review board of the Johns Hopkins Medical Institutions.

DATABASES

A retrospective analysis of a nonoverlapping combination of the National Inpatient Sample (NIS) database and Kids’ Inpatient Database (KID) (1988-2005) was performed. Both databases have been developed as part of the Healthcare Cost and Utilization Project of the Agency for Healthcare Research and Quality. The NIS is an all-payer database that contains data on up to 8 million inpatient discharges from approximately 1000 hospitals across the United States each year. Hospitals are sampled to represent a 20% stratified sample of all community hospitals from 37 states.7 The KID contains a sample of pediatric patients who carried a diagnosis most consistent with either acute or perforated appendicitis. Our approach of using only diagnosis codes but not procedure codes in the inclusion criteria because they could capture additional patients who had a relevant procedure code but lacked a relevant diagnosis code, such as patients who underwent a negative appendectomy. Our approach of using only diagnosis codes but not procedure codes to capture pediatric patients with appendicitis is similar to that adopted by Kokoska et al.10

Furthermore, we did not include procedure codes in the inclusion criteria because they could capture additional patients who had a relevant procedure code but lacked a relevant diagnosis code, such as patients who underwent a negative appendectomy. Our approach of using only diagnosis codes but not procedure codes to capture pediatric patients with appendicitis is similar to that adopted by Kokoska et al.10

DATA MANAGEMENT AND ANALYSIS

Comparisons between groups were performed using Pearson χ² for categorical outcomes and the Kruskal-Wallis test for non-normally distributed continuous variables. Total hospital charges were adjusted for inflation to reflect 2006 dollars.11

Data obtained from the NIS and KID were linked to the ARF. Health care systems–level factors were stratified into quartiles based on the density of providers or hospital facility–level factors per population in the county,9 with the first quartile representing the lowest-density areas. The variables of race, age, sex, insurance status, type of hospital, and median household income were controlled for in the logistic regression analysis. The health care systems–level factors examined were the densities of pediatricians, emergency department physicians, radiologists, surgeons, hospitals, hospitals with emergency departments, hospitals with CT scanners, and volume of surgical operations.

Figure 1. Time course of appendicitis.

Figure 2. Conceptual framework depicting the sequential and temporal relationships between provider- and facility-level factors. CT indicates computed tomography; ED, emergency department; and OR, operating room.

PATIENT SELECTION

Because the intent of our article was to compare rates of appendicitis perforation vs health system factors, we focused on pediatric patients who carried a diagnosis most consistent with either acute or perforated appendicitis. We aimed to exclude any diagnosis codes that did not directly address whether a child was either in the acute or perforated group on presentation. Patients were included in the analysis as having perforated appendicitis if they had an International Classification of Diseases, Ninth Revision diagnosis code of 540.0 (acute appendicitis with generalized peritonitis) or 540.1 (acute appendicitis with peritoneal abscess) and as having acute appendicitis if they had an International Classification of Diseases, Ninth Revision diagnosis code of 540.9 (acute appendicitis without mention of peritonitis). Only patients younger than 18 years were included. We did not include diagnosis codes 541 (chronic, recurrent, or subacute appendicitis) or 541 (unqualified appendicitis) because they did not give us information as to whether the patient presented with either acute or perforated appendicitis.

Furthermore, we did not include procedure codes in the inclusion criteria because they could capture additional patients who had a relevant procedure code but lacked a relevant diagnosis code, such as patients who underwent a negative appendectomy. Our approach of using only diagnosis codes but not procedure codes to capture pediatric patients with appendicitis is similar to that adopted by Kokoska et al.10

CONCEPTUAL FRAMEWORK

The logic model describing the rationale for our analysis is shown in Figure 1 and Figure 2. With respect to physician providers and hospital facility factors, it is important to first consider the time course of appendicitis. As shown in Figure 1, the time-
line progresses from recognition of symptoms to accurate diagnosis and then branches into appendicitis with perforation or appendicitis without perforation. The branch point in this timeline depends on the interaction of multiple different providers and facility-level factors in a sequential and expeditious fashion. Figure 2 is a conceptual framework depicting the temporal (prehospital vs hospital) and sequential relationships between the different provider- and facility-level factors we chose to include in the analysis. For provider-level factors, we included physicians who would typically be involved in the care of a child with appendicitis from diagnosis to treatment: pediatricians, emergency department physicians, radiologists, and surgeons. For facility-level factors, we included those factors that might affect the quality of care that a child with appendicitis receives: density of hospitals, hospitals with emergency departments, hospitals with CT scanners, and volume of surgical operations in a given hospital.

**RESULTS**

In 1074 US counties, 164,204 children were identified as having acute appendicitis, while 77,097 children were identified as having perforated appendicitis. Sex, race, and age data are presented in Table 1. Patient hospitalization characteristics, including geographic region, type of hospital, admission source, and insurance status, are presented in Table 2. Outcomes data, including inhospital mortality, length of stay, and total hospital charges, are presented in Table 3.

Figure 3 depicts the odds ratio of perforated appendicitis to acute appendicitis stratified by quartiles of increasing density of providers, controlling for race, age, sex, insurance status, type of hospital, and median household income. Increasing average household size and density of emergency department physicians, radiologists, and surgeons did not have a statistically significant effect on the odds ratio of perforated appendicitis because all the 95% confidence intervals cross 1.0. Increasing density of pediatricians did result in a decreasing trend in the odds ratio of perforated appendicitis and a statistically significant protective effect was observed in the highest-density quartile of pediatricians (odds ratio = 0.88; 95% confidence interval = 0.82-0.95). A decreasing trend was also observed in the odds ratio of perforated appendicitis with increasing density of surgeons, but statistical significance was not achieved even in the highest-density quartile (odds ratio = 0.91; 95% confidence interval = 0.80-1.03).

Figure 4 displays the odds ratio of perforated appendicitis to acute appendicitis stratified by quartiles of increasing density of facilities or facility factors, controlling for race, age, sex, insurance status, type of hospital, and median household income. Increasing county-level density of hospitals, hospitals with emergency departments, hospitals with CT scanners, and total number of surgical operations in the county were not observed to have a statistically significant effect on the odds ratio of perforated appendicitis because all the 95% confidence intervals cross 1.0.

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**Table 1. Demographics**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Acute Appendicitis (n=164,204)</th>
<th>Perforated Appendicitis (n=77,097)</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex</td>
<td>M</td>
<td>97,261 (59.23)</td>
<td>46,112 (59.81)</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>64,488 (39.27)</td>
<td>30,009 (39.92)</td>
</tr>
<tr>
<td></td>
<td>Unknown</td>
<td>2455 (1.50)</td>
<td>976 (1.27)</td>
</tr>
<tr>
<td>Race</td>
<td>White</td>
<td>77,088 (46.35)</td>
<td>32,065 (41.72)</td>
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<tr>
<td></td>
<td>Black</td>
<td>6148 (3.74)</td>
<td>3486 (4.23)</td>
</tr>
<tr>
<td></td>
<td>Hispanic</td>
<td>22,919 (14.32)</td>
<td>10,951 (14.26)</td>
</tr>
<tr>
<td></td>
<td>Other</td>
<td>6635 (4.08)</td>
<td>3953 (5.16)</td>
</tr>
<tr>
<td>Age</td>
<td>Median (IQR)</td>
<td>12 (9-15)</td>
<td>11 (7-14)</td>
</tr>
</tbody>
</table>

Abbreviation: IQR, interquartile range.

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**Table 2. Hospitalization Characteristics**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Acute Appendicitis (n=164,204)</th>
<th>Perforated Appendicitis (n=77,097)</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geographic region</td>
<td>Northeast</td>
<td>41,254 (25.12)</td>
<td>16,694 (21.65)</td>
</tr>
<tr>
<td></td>
<td>Midwest</td>
<td>34,887 (21.25)</td>
<td>14,436 (18.72)</td>
</tr>
<tr>
<td></td>
<td>South</td>
<td>31,167 (18.98)</td>
<td>15,463 (20.06)</td>
</tr>
<tr>
<td></td>
<td>West</td>
<td>56,896 (34.65)</td>
<td>30,504 (39.57)</td>
</tr>
<tr>
<td>Type of hospital</td>
<td>Urban, teaching</td>
<td>59,199 (36.05)</td>
<td>32,840 (40.60)</td>
</tr>
<tr>
<td></td>
<td>Urban, nonteaching</td>
<td>77,459 (47.17)</td>
<td>33,050 (42.87)</td>
</tr>
<tr>
<td></td>
<td>Rural</td>
<td>27,577 (16.76)</td>
<td>11,201 (14.53)</td>
</tr>
<tr>
<td>Admission source</td>
<td>Emergency department</td>
<td>113,823 (69.32)</td>
<td>51,420 (66.70)</td>
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<td></td>
<td>Non–emergency department</td>
<td>43,377 (26.42)</td>
<td>23,126 (30.00)</td>
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<tr>
<td></td>
<td>Unknown</td>
<td>7004 (4.27)</td>
<td>2551 (3.31)</td>
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<tr>
<td>Insurance status</td>
<td>Insured</td>
<td>145,894 (84.85)</td>
<td>67,962 (88.15)</td>
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<tr>
<td></td>
<td>Unknown</td>
<td>8132 (4.95)</td>
<td>3767 (4.89)</td>
</tr>
</tbody>
</table>

Abbreviation: IQR, interquartile range.

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**Table 3. Outcomes**

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Acute Appendicitis (n=164,204)</th>
<th>Perforated Appendicitis (n=77,097)</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>In-hospital mortality</td>
<td>Death</td>
<td>16 (0.01)</td>
<td>51 (0.07)</td>
</tr>
<tr>
<td></td>
<td>Unknown</td>
<td>19 (0.01)</td>
<td>11 (0.01)</td>
</tr>
<tr>
<td>Length of stay, d</td>
<td>Median (IQR)</td>
<td>10,385 (5500-12,381)</td>
<td>20,581 (74,610)</td>
</tr>
</tbody>
</table>

Abbreviation: IQR, interquartile range.

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The odds ratio of perforated appendicitis to acute appendicitis was also analyzed by quartiles of increasing density of socioeconomic status factors including median household income, married-couple families, children aged 0 to 17 years in poverty, and people 25 years or older with at least a high school diploma. None of these socioeconomic status factors had a statistically significant effect on the odds ratio of perforated appendicitis because all the 95% confidence intervals cross 1.0 (data not shown).

The aim of our study was to examine whether the density of health care system–level factors played a role in affecting the odds ratio of perforated appendicitis as compared with acute appendicitis in children. To try to answer this question, we chose to focus on a subset of specific health care systems–level factors that relate to the quality and efficacy of care for children presenting with appendicitis. We considered quality of care as it relates specifically to the timely diagnosis of appendicitis by analyzing whether the density of providers and availability of specific resources within facilities affected perforation rates. An underlying assumption is that system factors that may increase the risk of delay in treatment of acute appendicitis may contribute to a higher rate of perforated appendicitis in the population. Based on our conceptual framework as presented in Figure 2, we included in our analysis 4 critical providers involved in making the diagnosis of appendicitis: pediatricians, emergency department physicians, radiologists, and surgeons. The specific question tested was whether increasing densities of these providers affected the rate of perforation. Similarly, we analyzed facility-level factors to determine if they might be associated with the timely diagnosis of appendicitis. The facility-level factors tested within the hypothesis were overall density of hospitals, density of hospitals with emergency departments, density of hospitals with CT scanners, and volume of surgical operations in a county (we did not examine hospital volume, as most volume-outcome research in the literature has focused on). Of all the provider- and facility-level factors analyzed, the
only factor that had a statistically significant impact on the rate of perforated appendicitis in children was an increased density of pediatricians. A decreasing trend in the odds ratio of perforated appendicitis was observed with an increasing density of pediatricians and a statistically significant protective effect was observed in the highest-density quartile. A similar decreasing trend was also observed in the odds ratio of perforated appendicitis with increasing density of surgeons but statistical significance was not achieved.

This analysis, which connects surgical outcomes to an increase in density of pediatricians, also has implications for surgical disease beyond appendicitis with respect to health care system infrastructure development and management. Indeed, this finding reaffirms the central role that pediatricians play in the physician-provider pathway. We believe that the most common scenario is that parents will call their pediatrician first when a child develops abdominal pain. The pediatrician will briefly discuss what symptoms the child might be having and appropriately direct the parents to seek or not seek additional medical attention. This premise is supported by Green et al., who reported that among children who presented with abdominal pain and received a surgical consult, approximately 50% were referred by a community physician such as a pediatrician. It may be in this manner that the increased density and availability of pediatricians is having an effect on the rates of perforated appendicitis, even though they may not be the first provider to physically evaluate the child.

Previous studies have looked at racial disparities, insurance status, and hospital volume of appendicitis cases as reasons to explain an increased likelihood of perforated appendicitis. In children, higher rates of perforated appendicitis have been shown to occur in minority groups as well as in those with public insurance or those who lack insurance. Hospital volume, used as a surrogate marker of experience, has been shown in previous studies to have differing effects on the rates of appendiceal perforation in children. One study has shown that a higher hospital volume of pediatric patients is associated with a higher odds ratio of perforated appendicitis, while other studies have demonstrated that the volume of pediatric cases of appendicitis or the volume of appendectomies performed per year has no significant effect on the rates of perforated appendicitis.

Recognition of symptoms and the interval until when care is initiated seems to be critically important. A previous study of a combined adult and pediatric population determined that inpatient and outpatient delays directly contribute to a higher rate of perforation. Another small study specifically in Irish children determined that perforated appendicitis was correlated with duration of symptoms. Reasons for a longer duration of symptoms included parental delay in seeking medical care, a delay in referral or an inappropriate referral to the hospital on the part of the primary care physician, or a delay in diagnosis after consultation by a surgeon. Delays in diagnosis in the hospital setting were most often attributed to nonspecific symptoms and therefore often deemed unpreventable. The association of perforated appendicitis with prolonged symptom duration and delay in seeking care, delay in referral, or delay in diagnosis lends credence to the importance of pediatricians as a critical point of first contact with the health care system for children with appendicitis.

The issue raised about nonspecific symptoms contributing to a delay in diagnosis once a child reaches the hospital setting is a valid one, and addressing these types of diagnostic dilemmas may be challenging. A study by Flum et al. examined whether CT scans, ultrasonography, and laparoscopy had an impact on decreasing the rates of perforated appendicitis. They concluded that these diagnostic technologies did not have any effect on altering the rates of perforated appendicitis over a 12-year period from 1987 to 1998. Thus, even with timely referral to the emergency department and the ability to obtain a CT scan, an accurate determination of a diagnosis of appendicitis and intervention prior to perforation is not guaranteed. These findings are consistent with our data, which did not demonstrate any added benefit of an increased density of CT scanners on the rates of perforated appendicitis.

Limitations of our study include that we did not address the crucial role that family medicine physicians may play in the physician-provider pathway even though they may be a major source of care for children, especially for those living in rural areas. We also did not fully explore the relationship between negative appendectomy and perforation rates per county. However, our preliminary analysis showed that neither the density of family practitioners (alone or in combination with pediatricians) nor negative appendectomy rates had a significant association with the rates of perforated appendicitis (data not shown). Additional limitations relate to the use of large nationwide databases, in which the accuracy and completeness of coding of procedures and diagnoses can be variable. Errors due to inaccurate coding, however, should be nondifferential between the perforated and acute groups and bias results toward the null. The NIS and KID also do not contain data onprehospital delays or prior emergency department visits, since they are deidentified hospitalization data sets and do not contain longitudinal patient data.

A specific limitation of linking the data from the NIS and KID to the ARF is that individual-level data were linked to county-level data to make inferences at the population level. The patient information contained in the NIS and KID identifies the location of the hospital where the patient was admitted, not where the patient actually lives. Similarly, the density data of provider- and facility-level factors from the ARF correspond to the treatment location, which may not necessarily be the same as where the patient lives. However, for acute conditions such as appendicitis, it is unlikely, although not impossible, that a patient would not seek care near where his or her family lives, especially in rural areas. Also, we were unable to examine the impact of the density of pediatric surgeons because the ARF does not code for this specialty, which is why we looked at the density of general surgeons.
The present study has potential policy implications. An increased density of pediatricians was shown to be associated with a decreasing likelihood of perforated appendicitis. Augmenting the pediatrician workforce, however, also carries potential costs to the system. These costs and benefits must be weighed carefully.

In conclusion, this analysis highlights the role that pediatricians play in the process of recognition of symptoms, accurate diagnosis of appendicitis, and prompt referral for surgical intervention. Identifying key areas that have a low density of pediatricians and a corresponding high rate of perforated appendicitis would be the first step in creating policies that may improve patient outcomes and reduce public health costs for this surgical disease.

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Author Contributions: Dr Abdullah had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis including statistical analysis. Study concept and design: Chang, Arnold, and Abdullah. Acquisition of data: Zhang, Arnold, Gabre-Kidan, and Bathurst. Analysis and interpretation of data: Camp, Chang, Zhang, Arnold, Sharpe, Gabre-Kidan, and Abdullah. Drafting of the manuscript: Camp, Chang, Zhang, Sharpe, Bathurst, and Abdullah. Critical revision of the manuscript for important intellectual content: Camp, Chang, Arnold, Gabre-Kidan, and Abdullah. Statistical analysis: Chang, Zhang, and Arnold. Obtained funding: Abdullah. Administrative, technical, and material support: Sharpe, Bathurst, and Abdullah. Study supervision: Abdullah.

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REFERENCES