Patients Who Undergo Colectomy for Pediatric Ulcerative Colitis at Low-Volume Hospitals Have More Complications

Matthew D. Egberg,[*,‡] Joseph A. Galanko,[*] and Michael D. Kappelman[*,‡]

*Center for Gastrointestinal Biology and Disease, Chapel Hill, North Carolina; ‡Department of Pediatrics, Division of Gastroenterology and Hepatology, University of North Carolina at Chapel Hill, Chapel Hill, North Carolina

BACKGROUND & AIMS: **Adults with ulcerative colitis (UC) who undergo colectomy at high-volume centers have better outcomes and fewer complications than those at low-volume centers. We aimed to evaluate the hospital volume of total abdominal colectomy (TAC) for pediatric patients with UC and explore time trends in the proportion of colectomies performed at high-volume centers. We then evaluated the association between hospital colectomy volume and complications.**

METHODS: **We performed a cross-sectional analysis of pediatric patients (age, ≤18 y) hospitalized for UC using the Kids' Inpatient Database, a nationally representative database of pediatric hospitalizations. We identified UC hospitalizations with a procedural code (International Classification of Diseases, 9th or 10th revision) for TAC from 1997 through 2016. We defined complications using diagnosis codes adapted from published algorithms. We defined high-volume as hospitals that performed 10 or more TACs annually. We used multivariate statistics to evaluate the association between hospital volume and in-hospital complications.**

RESULTS: **A total of 1453 hospitalizations of children with UC included a TAC (2306 colectomies nationwide). A total of 766 hospitals performed 1 or more annual colectomies and only 36 (4.7%) were high-volume hospitals, accounting for 21% of colectomies. The proportion of colectomies at high-volume hospitals decreased over time. The absolute risk of complication was 16% at high-volume centers compared with 22% at low-volume centers (adjusted odds ratio, 0.7; 95% CI, 0.5–0.9). The effect of annual TAC volume on complication risk was not statistically significant for nonemergent admissions.**

CONCLUSIONS: **Pediatric patients with UC who undergo colectomy at high-volume centers have fewer complications. However, only a small proportion of pediatric colectomies (<5%) are performed at high-volume centers.**

Keywords: IBD; Guidelines; Epidemiology; Risk Factor.

The volume-outcome relationship for adult surgical procedures has been well established in the US health care system for nearly 40 years,[1–5] and many national efforts to improve surgical outcomes by directing patients to high-volume centers have been launched.[6] Nevertheless, low-volume centers continue to perform the majority of adult colorectal surgeries despite better outcomes at high-volume centers for inflammatory bowel diseases (IBD) surgery,[3] as well as colorectal cancer.[7]

Although the volume–outcome relationship is well recognized in adult IBD colorectal surgery, little is known about procedural volume and its association with pediatric ulcerative colitis (UC) surgical outcomes. However, findings from a recent study suggested that pediatric patients of low-volume surgeons (<10 pouch surgeries annually) are more likely to develop chronic pouchitis.[8] Based on this and the adult UC literature, recently published guidelines from the European Society for Pediatric Gastroenterology, Hepatology, and Nutrition recommend that pediatric UC surgical procedures involving pouch formation be completed at high-volume centers performing 10 or more pediatric pouch surgeries annually.[9]

To evaluate the extent to which the care delivered to pediatric UC patients in the United States adheres to these guidelines and the impact on patient outcomes,

Abbreviations used in this paper: **HCUP, Healthcare Cost and Utilization Project; IBD, inflammatory bowel disease; ICD-9, International Classification of Diseases, 9th revision; ICD-10, International Classification of Diseases, 10th revision; IQR, interquartile range; KID, Kids' Inpatient Database; OR, odds ratio; TAC, total abdominal colectomy; UC, ulcerative colitis.**

we used a large national pediatric inpatient database for the following: (1) to evaluate the hospital volume of total abdominal colectomy (TAC) for pediatric UC, (2) to explore time trends in hospital colectomy volume, (3) to identify factors associated with having a colectomy in a high-volume center, and (4) to evaluate the association of hospital colectomy volume and in-hospital complications.

What You Need to Know

Background

We studied hospital volumes of total abdominal colectomy for pediatric patients with ulcerative colitis and the proportion of colectomies performed at high-volume centers. We then evaluated the association between hospital colectomy volume and complications.

Findings

Pediatric patients with ulcerative colitis who undergo colectomy at high-volume centers have fewer complications. However, only a small proportion of pediatric colectomies (<5%) are performed at high-volume centers.

Implications for patient care

Medical centers that perform low numbers of colectomies in pediatric patients should take steps to reduce complications. It is best for a pediatric patient to undergo colectomy at a hospital that performs a large number of these procedures on children.

Methods

Study Design and Data Source

We performed a cross-sectional analysis using 1997 to 2016 data from the Kids' Inpatient Database (KID), a nationally representative sample of pediatric hospitalizations from the Healthcare Cost and Utilization Project (HCUP) sponsored by the Agency for Healthcare Research and Quality. KID is a large publicly available, all-payer, pediatric inpatient database from the United States and includes data from up to an estimated 7 million annual pediatric discharges when using weighting techniques.[10] By using data from up to 44 states and 4200 hospitals, KID is designed to be nationally representative of pediatric hospital care. The database contains more than 75 clinical and nonclinical variables, 25 International Classification of Diseases, 9th revision (ICD-9), clinical modification diagnostic and procedure codes, as well as up to 30 ICD 10th revision (ICD-10) codes per discharge, hospital characteristics, and outcomes.[10] KID has been used in published studies of pediatric IBD, as well as IBD-related surgical procedures.[11–13]

Study Sample and Procedural Definitions

We examined discharge data from hospitalizations of patients age 18 years and younger between the years of 1997 to 2016 using a triennial interval. Hospitalizations with either an ICD-9 (556.xx) or ICD-10 (K51.xx) diagnostic code indicating UC as well as ICD-9 (45.8x) or ICD-10 (0DTE.xx/0DBE.xx) procedural code indicating a TAC were included. ICD procedural definitions have been used in prior studies, including HCUP database studies.[3,14,15] Consistent with prior HCUP study publications,[16,17] we excluded hospitalizations with ICD-9 or ICD-10 coding listing both UC and Crohn's disease diagnoses to minimize misclassification. We also excluded hospitalizations with a concurrent ICD-9/ICD-10 diagnosis of Hirschsprung's disease or familial adenomatous polyposis.

Variables

We analyzed the following patient-related variables: age (categorized as ≤6, 7–12, 13–18 y), sex, race (Caucasian, African American, Hispanic, other [other was defined as Asian Pacific, Native American, or unknown]), payer type (Medicaid, health maintenance organization/private, other [other was defined as self-pay, Medicare, or unknown]), and admission type (elective vs nonelective). Hospital-related variables included US regional location (Northeast, Midwest, South, and West) as well as location and teaching status (rural, urban/nonteaching, and urban/teaching).

Procedural Volume Definition

For each year, we summated each hospital's frequency of UC discharges involving a colectomy. By using the 2018 European Society for Pediatric Gastroenterology, Hepatology, and Nutrition guidelines for the management of pediatric UC,[9] we defined high-volume centers as those performing 10 or more annual TACs for pediatric UC. Those that performed fewer than 10 were categorized as low-volume centers.

Outcome Definition

We analyzed surgical complications using a modified definition of complication as used by Kaplan et al,[3] Soon et al,[15] and Berry et al.[18] We based our definitions on ICD-9 and ICD-10 procedural and diagnosis codes that were broadly classified as pertaining to procedural, cardiovascular, respiratory, gastrointestinal, urinary, and/or infectious (Supplementary Tables 1 and 2). Secondary outcomes included mortality and length of stay.

Statistical Analysis

All analyses were performed using SAS version 9.4 (Cary, NC). We applied the appropriate weighting measures, included with and unique to each year of KID data, provided by the Agency for Healthcare Research and Quality/HCUP[10] to calculate the national estimates from the raw data provided in the data sets. Descriptive statistics of the weighted estimates included frequency count and 95% CIs. We used the chi-square test for bivariate analyses of association between categoric variables. We summarized continuous variables using median and interquartile range (IQR). We used linear models to fit the temporal trends of colectomy volume as well as the proportion of colectomies performed at high-volume centers between 1997 and 2016. We used the Spearman correlation coefficient to evaluate the trend of total colectomy volume over time, and the Cochrane–Armitage linear trend test was used to evaluate the proportion of colectomies performed at high-volume centers over time. We used multivariable logistic regression to evaluate predictors for colectomy at a high-volume center. Predictors included age, sex, race, payer type, admission type, US region, as well as hospital location and teaching status.

After calculating the absolute risk of in-hospital complications for high- and low-volume centers, we used multivariable logistic regression to evaluate the association of annual hospital colectomy volume and the risk of in-hospital complications, controlling for age, sex, race, payer type, admission type, US region, as well as hospital location and teaching status. We reported the odds ratios (ORs) and 95% CIs for the primary predictor and covariates.

In addition, we identified the top 5 complications for the surgical hospitalizations involving at least 1 in-hospital complication. We compared the frequency of these complications between hospital volume groups using the chi-square test.

We performed several subanalyses. First, we evaluated the association of hospital procedure volume and complication frequency in hospitalizations of older (age, 10–18 y) UC patients as well as younger patients (age, $<$10 y). Our second subanalysis included the use of alternative thresholds to define high-volume centers and we evaluated the association of higher thresholds and complication frequency. Third, we identified hospitalizations containing data specifying the technique of the TAC: open vs laparoscopic. For that subset of hospitalizations, we evaluated the association of hospital volume and complications adjusting for surgical technique. Finally, for those hospitalizations with data pertaining to the time from admission to TAC (measured as days; KID data element), we evaluated the association of hospital volume and complication frequency after stratifying by emergent procedure (TAC on day of admission or day immediately after) vs nonemergent (TAC $\geq$2 days after admission).

A 2-tailed *P* value of .05 was chosen as the threshold for statistical significance in bivariate analyses as well as multivariable regressions. We selected covariates a priori based on clinical relevance and previously published literature.[3,12,14,15]

Ethical Considerations

Because of the de-identified nature of the data, this study was determined to be exempt from review by the University of North Carolina Institutional Review Board.

Results

Hospital Procedure Volume

Between 1997 and 2016, KID included 1453 pediatric UC hospitalizations associated with a TAC. After appropriate weighting, this represented a total of 2306 pediatric UC colectomies nationwide. More than 91% of KID hospitals did not perform any colectomies for pediatric UC in a sampled year. The remaining 9% (766 unique hospitals) performed the pediatric UC colectomies included in our analyses. Nearly three quarters (72%) of colectomies were performed in children aged 13 to 18 years, with a nearly equal gender split (48% female). Patients undergoing colectomy were primarily Caucasian.

A total of 730 hospitals (95.3% of those performing $\geq$1 colectomy) were low-volume centers performing fewer than 10 pediatric UC colectomies annually. During this time, 57% of colectomies occurred at very-low-volume centers performing no more than 2 pediatric UC colectomies annually. High-volume centers represented only 4.7% (36) of centers performing colectomies. These high-volume centers accounted for 475 (21%) of the estimated 2306 colectomy hospitalizations evaluated (Table 1). The median annual colectomy number at low-volume centers was 3 (IQR, 2–5), compared with a median of 13 (IQR, 11–17) at high-volume centers.

Patient and Hospital Characteristics Associated With Hospital Volume

High-volume centers were more likely to be in the Northeastern and Midwest regions of the United States as compared with low-volume centers, with high-volume centers most concentrated in the Midwest. African American and Hispanic ethnicities constituted a greater proportion of colectomies at low-volume centers. In addition, low-volume centers appeared to be composed of a larger Medicaid population and reduced private/health maintenance organization payers compared with high-volume centers. Additional patient- and hospital-level characteristics stratified by hospital procedure volume are found in Table 1.

After adjustment, regional location was associated strongly with having a colectomy performed at a

Table 1. Patient and Hospital Characteristics for Pediatric UC Hospitalizations Involving a Total Abdominal Colectomy From KID Between 1997 and 2016

	All hospitals		Annual procedure volume				
	(n = 766)		Low (n = 730)[a]		High (n = 36)[a]		
	n	%	n	%	n	%	
Colectomies in KID, n[b]	1453	100	1191	82	262	18	
National estimate of colectomies,	2306	100	1831	79	475	21	
median (IQR)[b]	4	(2–8)	3	(2–5)	13	(11–17)	
	%	95% CI	%	95% CI	%	95% CI	*P* value
Age, *y*							
≤6	5.9	4.6–7.2	5.9	4.4–7.4	6.1	3.3–8.9	
7–12	22.0	19.6–24.4	20.0	19.4–24.7	21.9	16.4–27.4	.99
13–18	72.1	69.5–74.7	72.1	69.2–74.9	72.0	66.1–78.0	
Sex							
Female	47.9	45.1–50.7	46.9	43.9–49.9	51.6	44.7–58.6	.22
Race							
Black	5.7	4.3–6.9	6.0	4.5–7.5	4.3	1.9–6.7	
Hispanic	9.2	7.7–10.6	10.1	8.4–11.8	5.5	2.9–8.1	<.01
Other	22.3	20.1–24.6	23.5	20.9–26.0	17.8	12.8–22.8	
White	62.9	60.2–65.5	60.4	57.5–63.3	72.4	66.6–78.2	
Payer type							
Medicaid	19.0	16.9–21.1	20.6	18.3–22.9	12.9	8.7–17.2	
Private/HMO	75.3	73.0–77.6	73.3	70.7–75.9	83.0	78.2–87.9	<.01
Other	5.7	4.5–6.9	6.1	4.7–7.5	4.1	1.5–6.6	
Admission type							
Elective	51.7	48.9–54.4	51.8	48.8–54.8	51.3	44.3–58.2	.88
Region							
Northeast	18.7	16.7–20.8	15.7	13.6–17.7	30.7	24.6–36.7	
Midwest	29.2	26.5–31.9	26.1	23.4–28.9	40.9	33.8–48.1	<.01
South	28.0	25.6–30.4	31.1	28.3–33.8	16.2	11.5–20.9	
West	24.0	21.8–26.3	27.2	24.6–29.7	12.1	8.2–15.9	
Hospital type							
Rural	3.4	2.3–4.4	4.2	2.9–5.5	N/A	N/A	
Urban/nonteaching	10.4	8.6–12.2	11.5	9.5–13.5	6.2	1.9–10.5	N/A[c]
Urban/teaching	86.2	84.3–88.3	84.3	82.0–86.6	93.8	89.5–98.1	

HMO, health maintenance organization; IQR, interquartile range; KID, Kids' Inpatient Database; N/A, not applicable; UC, ulcerative colitis.
[a]Low volume, <10 colectomies performed annually; high volume, ≥10 performed colectomies annually.
[b]Raw data were taken from the actual database. The national estimate reflects KID weighting of raw data to produce a national estimate.
[c]Empty cell prevented calculation.

high-volume center (Northeast vs West: OR, 4.5; 95% CI, 3.1–6.4; Midwest vs West: OR, 3.7; 95% CI, 2.6–5.2). Northeast and Midwest centers also were 3 to 4 times more likely to be high-volume centers vs centers in the South (data not shown). In addition, the category of other ethnicity showed a reduced likelihood of colectomy at a high-volume center (OR, 0.6; 95% CI, 0.5–0.8). Multivariable logistic regression results are found in Table 2.

Temporal Trends in Colectomies

Between the years of 1997 and 2016, the annual number of pediatric colectomies for UC increased from 224 to 713 in 2016 ($P = .07$) (Figure 1). However, during this period, the proportion of colectomies performed at high-volume hospitals decreased ($P = .009$) (Figure 2). In 1997, high-volume hospitals performed 34% of all pediatric UC colectomies. In 2016, the proportion of colectomies performed at high-volume centers was 22%.

Complication Frequency

A total of 472 in-hospital complications occurred during the 7 triennial periods sampled. Colectomies performed at low-volume hospitals accounted for 398 complications (of 1831 colectomies), resulting in an absolute risk of complication of 22%. This was larger than the complication frequency at high-volume centers, where the absolute risk of complications was 16% (74 complications/475 colectomies) ($P = .003$). An adjusted analysis showed a 30% reduction in complication risk at high-volume hospitals compared with low-volume hospitals (OR, 0.7; 95% CI, 0.5–0.9) (Table 3).

Among hospitalizations with surgical complications, the 5 most frequent complications are shown in Table 4.

Table 2. Multivariable Analysis, OR, and 95% CI of Colectomy at a High-Volume Center Among Pediatric UC Hospitalizations Associated With Total Abdominal Colectomy in the 1997 to 2016 KID Database

	OR	95% CI
Age, *y*		
≤6	1.1	0.7–1.8
7–12	1.1	0.8–1.4
13–18	Ref	
Sex		
Female	1.2	0.9–1.5
Male	Ref	
Race		
Black	0.7	0.4–1.1
Hispanic	0.9	0.6–1.6
Other	0.6	0.5–0.8
White	Ref	
Payer type		
Medicaid	0.6	0.5–0.9
Other	0.9	0.5–1.5
Private/HMO	Ref	
Admission type		
Elective	0.8	0.7–1.0
Nonelective	Ref	
Region		
Northeast	4.5	3.1–6.4
Midwest	3.7	2.6–5.2
South	1.2	0.8–1.7
West	Ref	
Hospital type		
Rural	N/A	N/A
Urban/nonteaching	0.8	0.5–1.2
Urban/teaching	Ref	

HMO, health maintenance organization; KID, Kids' Inpatient Database; N/A, not applicable; OR, odds ratio; UC, ulcerative colitis.

Complications at low-volume centers included ileus (22%), intestinal and hepatic postoperative complications (16%), and postoperative infection (8%). High-volume centers most frequently experienced intestinal and hepatic postoperative complications (18%), followed by ileus (16%), and postoperative atelectasis (9%; <6% of all hospitalizations with a complication). There were no statistical differences between the types of complications occurring at high- and low-volume centers.

We performed several subanalyses. Of 259 hospitalizations (11.2% of the total sample) in the age group younger than 10 years, there was no statistical association between hospital volume and complications (OR, 1.1; 95% CI, 0.5–2.5). However in the older age group, high-volume centers showed a 40% risk reduction compared with low-volume centers (OR, 0.6; 95% CI, 0.4–0.8).

The use of higher thresholds to define high-volume centers accentuated the observed volume–outcome relationships. Only 18 hospitals performed 12 or more pediatric UC colectomies annually between 1997 and 2016. By using a threshold of 12 annual colectomies to define high volume, the absolute risk of complication was 14.7% for high-volume centers vs 21.2% for low-volume centers, resulting in a risk difference of 6.5%. Only 10 hospitals performed 15 or more colectomies in pediatric UC patients annually. If the threshold was set at 15 colectomies to define high volume, then the absolute risk of complication was 11.4% vs 21.2% at low-volume hospitals (risk difference, 9.8%).

A total of 926 hospitalizations involved an open TAC vs 433 identified as laparoscopic. After adjusting for procedure type, high-volume hospitals, compared with low-volume hospitals, experienced a 30% risk reduction for in-hospital complications (OR, 0.7; 95% CI, 0.5–1.0). Supplementary Table 3 reports the results of the multivariate analysis. Procedural codes did not specify the conversion rate of a laparoscopic technique to an open procedure.

Our final subanalysis involved 791 pediatric TAC hospitalizations identified as emergent surgical admissions compared with 570 nonemergent. In the emergent group, high-volume centers showed a 50% reduction in complication risk compared with low-volume centers (OR, 0.5; 95% CI, 0.4–0.8) (Supplementary Table 4). In the nonemergent group, the risk reduction of 20% did not reach statistical significance (OR, 0.8; 95% CI, 0.5–1.2) (Supplementary Table 5).

We included 2 secondary outcomes: mortality and length of stay. Two hospitalizations resulted in death (0.14%), both occurred at low-volume centers. The median length of stay at low-volume centers was 8 days (IQR, 5–16 d), which was identical to the median length of stay at high-volume centers (IQR, 5–14 d).

Discussion

In a nationally representative sample of pediatric hospitalizations in which colectomy was performed for UC, we found that, on average, high-volume centers account for only 21% of annual colectomy hospitalizations whereas more than 57% of pediatric UC colectomy hospitalizations take place at centers performing no more than 2 of these procedures annually. This is in contrast to recent guidelines that recommend surgery for UC be performed at hospitals performing at least 10 surgeries per year. Our data also show a secular trend: the proportion of colectomies performed at high-volume centers has decreased over time between 1997 and 2016, despite an increasing volume of colectomies performed over the same period. Region was associated significantly with colectomy volume—centers in the Northeast and Midwest were more likely to be high-volume centers compared with those in the South or West. Importantly, we observed a significantly higher risk of in-hospital complications associated with colectomies performed at low- vs high-volume hospitals, indicating a volume–outcome relationship for pediatric UC surgery.

Although the adult literature clearly shows that better surgical outcomes are achieved at centers with high

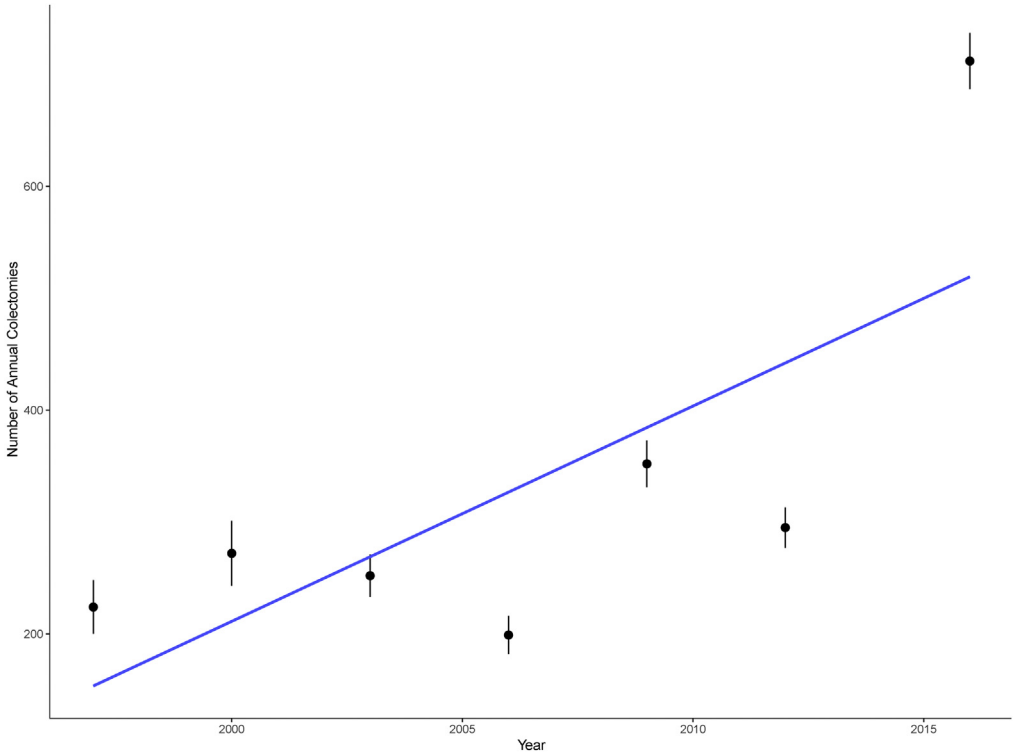

Figure 1. Temporal trend of total UC hospitalizations involving a colectomy in KID from 1997 to 2016. Spearman correlation showed a nearly significant association between total colectomy volume and time ($P = .07$). Point estimates with SDs are shown.

surgical volume,[4,18,19] low-volume centers continue to care for a large volume of UC patients. Kaplan et al[3] showed that a large proportion of adult UC colectomies take place at centers performing 3 or fewer annual UC colectomies. In that study, the investigators also found that 48% of adult UC colectomies occurred at centers performing 5 or fewer annual colectomies. Furthermore, more than 1000 of the study's sampled hospitals performed only 1 annual colectomy in the UC population. Similar trends were seen in our data in which the vast majority of pediatric colectomy hospitalizations occurred at low-volume centers, with 57% of pediatric UC colectomies occurring at centers performing only 1 to 2 surgeries per year.

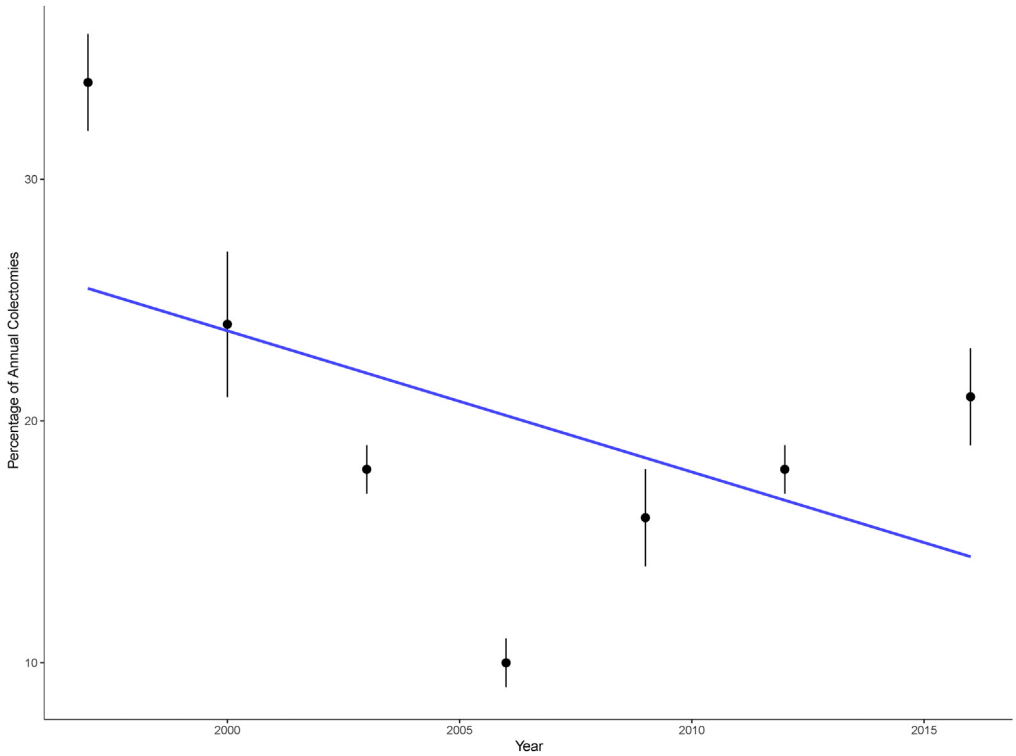

Figure 2. Temporal trend of pediatric UC hospitalizations involving a colectomy at high-volume centers in KID from 1997 to 2016. Cochrane–Armitage testing showed a significant association between time and decreasing proportions of pediatric UC colectomies performed in high-volume centers ($P < .009$). Point estimates with standard errors shown.

Table 3. ORs and 95% CIs of Acute, In-Hospital Complications Among Pediatric UC Hospitalizations With Total Abdominal Colectomies in the 1997 to 2016 KID Database

	OR	95% CI
Hospital volume		
High volume	0.7	0.5–0.9
Low volume	Ref	
Age, y		
≤6	1.2	0.8–1.9
7–12	0.8	0.6–1.1
13–18	Ref	
Sex		
Female	0.8	0.6–0.9
Male	Ref	
Race		
Black	1.0	0.6–1.8
Hispanic	1.6	1.1–2.4
Other	1.0	0.8–1.3
White	Ref	
Payer type		
Medicaid	0.9	0.7–1.3
Other	1.1	0.7–1.7
Private/HMO	Ref	
Admission type		
Elective	0.8	0.6–0.9
Nonelective	Ref	
Region		
Northeast	0.8	0.6–1.1
Midwest	1.1	0.8–1.4
South	0.9	0.7–1.3
West	Ref	
Hospital type		
Rural	1.4	0.8–2.4
Urban/nonteaching	0.9	0.7–1.4
Urban/teaching	Ref	

HMO, health maintenance organization; KID, Kids' Inpatient Database; OR, odds ratio; UC, ulcerative colitis.

Table 4. The 5 Most Frequent In-Hospital Complications for All Pediatric UC hospitalizations Involving a TAC in KID From 1997 to 2016

Complications	All hospitals	Low-volume hospitals	High-volume hospitals	*P* value
Ileus resulting from procedure	21%	22%	16%	.46
Intestinal and hepatic postoperative complications	17%	16%	18%	.20
Postoperative infection	8%	8%	7%	.71
Postoperative sepsis (many bacterial types)	7%	7%	8%	.88
Unspecified septicemia	6%	6%	6%	.95

NOTE. *P* values are from between-group comparisons of volume categories. KID, Kids' Inpatient Database; TAC, total abdominal colectomy; UC, ulcerative colitis.

In addition, we observed that the number and proportion of colectomies for pediatric UC that are performed at low-volume centers has increased over the years. Although prior studies using KID have evaluated trends in the overall number of colectomies for UC, center-level colectomy volume has not been reported. For example, deBruyn et al[11] showed a stable prevalence of pediatric colectomy among hospitalizations for pediatric IBD from 1997 to 2009. Soon et al[15] combined KID data regarding UC colectomy rates between 1997 and 2009 with population data from the US Bureau of the Census and also showed stable colectomy rates. However, these prior studies concluded with data from 2009, while our study used 2 additional triennial periods. Another significant methodologic difference between our study and these prior studies was that we used a more restricted definition of colectomy, including only those hospitalizations associated with a total abdominal colectomy (the customary procedure for UC), whereas these prior studies included partial colon resection.

The difference in the absolute risk of in-hospital complications between high-volume and low-volume centers is also clinically important. Our results show that low-volume centers experienced an absolute risk of complication of 22%, compared with 16% at high-volume centers. These frequencies of surgical complications are not atypical. Prior studies have shown overall colectomy complication rates ranging from 25% to 33%,[3,14,15] and studies in adult UC have shown higher complication rates in low-volume centers. Interestingly, individual comparison of the top 5 complications between volume categories failed to show any significant differences. This suggests a lack of unique complications inherent to either low-volume or high-volume centers.

After adjustment, the risk of complications was reduced by 30% when pediatric colectomy was performed at high-volume centers. Our subanalyses adjusting for factors such as surgical technique and emergent admissions further support the risk reduction associated with high-volume centers. Nevertheless, our data show that hospitals performing more than 10 pediatric UC colectomies annually experience better in-hospital outcomes. Risk reduction was particularly notable in the group aged 10 to 18 years, as well as for increased annual colectomy thresholds. We also noted that the lack of a significant association between in-hospital complications and hospital volume in the group younger than age 10 is likely the result of a much smaller sample size powering the subanalysis and not a suggestion that younger age groups are impervious to the influence of hospital volume on surgical outcomes.

Overall, the risk reduction showed in high-volume hospitals is important in reinforcing recent guidelines recommending that pediatric UC surgical care be limited to high-volume centers. However, our results need to be balanced with the feasibility of directing surgical care to high-volume centers. As our data show, several regions of the United States have reduced access to high-volume centers and the practicality of long-distance transport of emergent surgical cases in these areas is low. Although it

may be safer to transfer nonemergent surgical patients, our subanalysis of nonemergent surgeries showed a reduced and nonsignificant effect of hospital procedure volume on in-hospital complications in these situations. Solutions for the problem of access to high-volume centers are beyond the scope of this study, however, our results show that most pediatric UC patients do not receive surgical care at high-volume centers and therefore are experiencing suboptimal outcomes.

Our study had multiple strengths, including the use of a nationally representative sample of pediatric UC hospitalizations undergoing a TAC. Because the HCUP KID is nationally representative of geographic regions, hospital characteristics, and health insurance payers, it represents the breadth of hospital-level care provided to pediatric IBD patients. The database also includes a large enough sample size to allow adequate power and precision for our primary analyses. In addition, our use of multivariable regression analysis allowed for control of potential confounding factors including age, sex, race, payer type, admission type, region, hospital location, and teaching status in studying the association between center procedure volume and in-hospital complications.

We acknowledge several limitations in our study. As with most epidemiologic studies using administrative data, misclassification of exposure or outcomes identified by diagnosis or procedural code is possible. However, the HCUP KID has been used in previous published inpatient studies regarding pediatric IBD[11,13,15] and the HCUP-defined weighting techniques allow for valid nationwide estimates.[10] Furthermore, surgical postoperative complications have been evaluated in other administrative databases and showed a high positive predictive value.[14,20] A second limitation was the conflation of center procedural volume with surgeon experience. The database is a de-identified, discharge-level database, thus preventing analysis at the surgeon level. However, hospital procedural volume, which encompasses several factors including surgeon experience as well as presurgical and postsurgical care, has been used as a surrogate for surgeon experience in prior HCUP database studies.[3,12,18] We note that administrative data were limited in the ability to evaluate presurgical and postsurgical care individually at a clinical level. A third limitation was our inability to measure and control for disease severity, timing of presentation, provider type/subspecialty, and other clinical variables including medications, smoking status, or prior hospitalizations or surgical interventions. As a result, it is possible that unmeasured confounding exists.

In summary, we used a nationally representative sample of pediatric UC hospitalizations to show that pediatric UC surgical care in the United States is not consistent with current guidelines. This deviation results in a low proportion of pediatric UC colectomies performed at high-volume centers. Furthermore, this disparity exposes pediatric UC patients to an increased absolute risk of postsurgical complication. Efforts to redirect care to high-volume centers of excellence, when feasible, may lead to improved outcomes for pediatric UC patients in light of these center-related differences in outcomes.

Supplementary Material

Note: To access the supplementary material accompanying this article, visit the online version of *Clinical Gastroenterology and Hepatology* at www.cghjournal.org, and at https://doi.org/10.1016/j.cgh.2019.03.003.

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Reprint requests
Address requests for reprints to: Matthew Egberg, MD, MPH, MMSc, Division of Pediatric Gastroenterology and Hepatology, Center for Gastrointestinal Biology and Disease, University of North Carolina Chapel Hill, 130 Mason Farm Road, Bioinformatics Building, Office 4101, Chapel Hill, North Carolina 27599. e-mail: Matthew.egberg@med.unc.edu; fax: (919) 966-8641.

Conflicts of interest
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Supplementary Table 1. ICD-9 Diagnosis Codes for Defining Acute, In-Hospital Complications for Pediatric UC Hospitalizations With Colectomy Analyzed From 1997 to 2016 in the KID Database

ICD-9 code	Diagnosis
Procedural	
54.12, 54.61	Reopening and closure of the recent laparotomy site
Mechanical wound	
998.12	Postoperative hematoma
998.3	Disruption of wound
998.31, 998.32	Dehiscence of surgical wound
Infectious	
998.5, 998.59	Postoperative infection
998.51	Postoperative infected seroma
038	Bacteremia or sepsis
039.2	Abdominal infection
998.0, 998.02	Septic shock after trauma or surgery
Urinary	
997.5	Postoperative urinary retention/infection/failure
Pulmonary	
997.3	Postoperative atelectasis
512.2	Postoperative pneumothorax or air leak
518.4	Postoperative pulmonary edema
518.51	Acute respiratory failure after trauma or surgery
518.53	Acute and chronic respiratory failure after trauma or surgery
512.1	Iatrogenic pneumothorax
Gastrointestinal	
997.4	Postoperative intestinal and hepatic complications
560.1	Paralytic ileus
Cardiovascular	
453.40, 453.41, 453.42, 453.8, 453.9	Deep vein thrombosis
415.11	Iatrogenic postoperative pulmonary embolism
998.0	Postoperative shock (see *Infectious* section in this Table)
Surgical complications	
998.2	Accidental puncture or laceration
998.11	Hemorrhage complicating procedure
998.12	Hematoma complicating procedure
998.89	Unspecified complication of procedure, not otherwise specified
Decubitus ulcer	
707.0	Pressure ulcer
Foreign body	
998.4	Foreign body accidentally left in during procedure
998.7	Acute reaction to foreign substance accidentally left in during procedure
Complications from central venous catheter	
999.3	Central venous catheter–related complication/bloodstream infection

ICD-9, International Classification of Diseases, 9th revision; KID, Kids' Inpatient Database; UC, ulcerative colitis.

Supplementary Table 2. ICD-10 Diagnosis Codes for Defining Acute, In-Hospital Complications for Pediatric UC Hospitalizations With Colectomy Analyzed From 1997 to 2016 in KID

ICD-10 code	Diagnosis
Procedural	
0W3H	Reopening of recent laparotomy site
0W3P	Gastrointestinal bleed
Mechanical wound	
T813	Disruption of wound
Infectious	
A40	Postoperative infection sepsis (many bacterial types)
A41	Postoperative infection sepsis
A421	Abdominal infection
K6811	Postoperative retroperitoneal abscess
T814	Postoperative infection/sepsis at surgical site
Urinary	
N9989	Postoperative urinary retention/infection/failure
Pulmonary	
J9581	Postoperative pneumothorax or air leak
J9582	Acute postoperative respiratory failure
Gastrointestinal	
K913	Postoperative obstruction
K56.0, K56.7	Paralytic ileus
Cardiovascular	
I826	Acute embolism or thrombus of the superficial vessels
I828	Embolism or thrombosis of the lower extremities
I8290	Acute embolism or thrombus in unspecified vein
I82B1	Acute embolism and thrombosis of the subclavian vessels
I82C1	Acute embolism or thrombus of the internal jugular vessels
I82A1	Acute embolism or thrombus of the axillary vessels
T811	Postoperative shock
Surgical complications	
D781	Accidental puncture or laceration
I9742	Intraoperative hemorrhage
I9752	Accidental puncture or laceration of vessel
I9762	Intraoperative hemorrhage of a circulatory organ
I9788, I9789	Intraoperative circulatory complication not otherwise specified
Decubitus ulcer	
L89	Decubitus ulcer
Foreign body	
T8150	Foreign body accidentally left in during procedure
T8151	Adhesion caused by foreign body left in during procedure
T8152	Obstruction from foreign body left in during procedure
T8159	Other complications from foreign body left in during procedure
T816	Aseptic peritonitis or other acute reaction from foreign body left in during procedure
Complications from central venous catheter	
T800	Air embolism after infusion/transfusion/or therapeutic injection
T801	Vascular complication after infusion/transfusion/or therapeutic injection
T8021	Infection caused by central venous catheter
T8022	Acute infection after infusion/transfusion/or therapeutic injection
T8029	Infection after infusion/transfusion/or therapeutic injection

ICD-10, International Classification of Diseases, 10th revision; KID, Kids' Inpatient Database; UC, ulcerative colitis.

Supplementary Table 3. Multivariable Analysis, OR, and 95% CI of Colectomy at a High-Volume Center Among Pediatric UC Hospitalizations Associated With Total Abdominal Colectomy Adjusting for Procedure Type in Addition to Previous Covariates From 1997 to 2016 in KID

	OR	95% CI
Hospital volume		
High volume	0.7	0.5–1.0
Low volume	Ref	
Age, *y*		
≤6	1.3	0.8–2.4
7–12	0.9	0.6–1.3
13–18	Ref	
Sex		
Female	0.9	0.7–1.2
Male	Ref	
Race		
Black	0.9	0.5–1.7
Hispanic	1.5	0.9–2.4
Other	0.9	0.6–1.3
White	Ref	
Payer type		
Medicaid	1.1	0.8–1.6
Other	1.0	0.5–2.0
Private/HMO	Ref	
Admission type		
Elective	0.7	0.5–1.0
Nonelective	Ref	
Region		
Northeast	0.7	0.4–1.1
Midwest	1.0	0.7–1.5
South	0.7	0.5–1.1
West	Ref	
Hospital type		
Rural	1.8	0.9–3.6
Urban/nonteaching	0.6	0.3–1.2
Urban/teaching	Ref	
Procedure type		
Open	2.5	1.–3.4
Laparoscopic	Ref	

HMO, Health Maintenance Organization; KID, Kids' Inpatient Database; OR, odds ratio; UC, ulcerative colitis.

Supplementary Table 4. ORs and 95% CIs of Acute, In-Hospital Complications Among Emergent Pediatric UC Hospitalizations With Total Abdominal Colectomies From 1997 to 2016 in KID

	OR	95% CI
Hospital volume		
High volume	0.5	0.4–0.8
Low volume	Ref	
Age, *y*		
≤6	1.5	0.9–2.7
7–12	0.8	0.5–1.2
13–18	Ref	
Sex		
Female	0.9	0.7–1.2
Male	Ref	
Race		
Black	1.9	1.0–3.3
Hispanic	0.8	0.4–1.5
Other	1.0	0.7–1.4
White	Ref	
Payer type		
Medicaid	1.1	0.8–1.7
Other	0.9	0.4–1.8
Private/HMO	Ref	
Region		
Northeast	0.5	0.3–0.9
Midwest	0.8	0.6–1.3
South	0.7	0.4–1.0
West	Ref	
Hospital type		
Rural	1.6	0.7–3.7
Urban/nonteaching	0.9	0.5–1.6
Urban/teaching	Ref	

HMO, Health Maintenance Organization; KID, Kids' Inpatient Database; OR, odds ratio; UC, ulcerative colitis.

Supplementary Table 5. ORs and 95% CIs of Acute, In-Hospital Complication Among Nonemergent Pediatric UC Hospitalizations With Total Abdominal Colectomies From 1997 to 2016 in KID

	OR	95% CI
Hospital volume		
High volume	0.8	0.5–1.2
Low volume	Ref	
Age, *y*		
≤6	1.0	0.5–2.0
7–12	0.9	0.6–1.3
13–18	Ref	
Sex		
Female	0.7	0.5–1.0
Male	Ref	
Race		
Black	0.2	0.1–1.8
Hispanic	2.9	1.7–5.0
Other	1.0	0.7–1.4
White	Ref	
Payer type		
Medicaid	0.8	0.5–1.2
Other	1.4	0.7–2.7
Private/HMO	Ref	
Region		
Northeast	1.1	0.7–1.9
Midwest	1.4	0.9–2.2
South	1.2	0.8–1.9
West	Ref	
Hospital type		
Rural	1.4	0.7–2.9
Urban/nonteaching	1.1	0.6–1.7
Urban/teaching	Ref	

HMO, Health Maintenance Organization; KID, Kids' Inpatient Database; OR, odds ratio; UC, ulcerative colitis.