



A population-based cohort examining factors affecting all-cause morbidity and cost after pediatric appendectomy: Does annual adult procedure volume matter?

Cecily Bos^a, Aristithes G. Doumouras^a, Gileh-Gol Akhtar-Danesh^a, Helene Flageole^{a, b}, Dennis Hong^{a, c, *}

^a Department of Surgery, McMaster University, Hamilton, Ontario, Canada

^b Division of Pediatric Surgery, McMaster University, Hamilton, Ontario, Canada

^c Division of General Surgery, St. Joseph's Healthcare, Hamilton, Ontario, Canada

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ABSTRACT

Background: The purpose of this study was to examine factors affecting morbidity and cost after pediatric appendectomy and particularly the role of adult surgical volume.

Materials and methods: This was population-based study including all pediatric patients who underwent appendectomy for appendicitis in Canada (excluding Quebec) from 2008 to 2015. All-cause morbidity was the main outcome of interest. Cost of the index admission (in 2014 Canadian dollars) was a secondary outcome. Hierarchical linear and logistic regressions were used to model the outcomes.

Results: Overall, 41,512 patients were identified. After adjustment, younger patients (OR = 0.98/year, 95% CI 0.97–0.99, $p < 0.001$), patients with comorbidities (OR = 2.20, 95%CI 1.96–2.46, $p < 0.001$), and those with perforated appendicitis (OR = 5.95, 95%CI 5.44–6.50, $p < 0.001$) were more susceptible to morbidity. Annual pediatric appendectomy volume was a significant predictor of reduced morbidity (OR = 0.85/20 cases, 95%CI 0.76–0.93, $p < 0.001$) as was the use of laparoscopy (OR = 0.81, 95%CI 0.72–0.91, $p = 0.001$). Conversely, annual adult appendectomy volume conferred no benefit nor did pediatric surgery specialty training.

Conclusion: Outcomes after pediatric appendectomy are influenced by pediatric case volume, regardless of specialty training, but extra adult surgical volume confers no benefit.

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Introduction

Appendicitis is the most common surgical emergency in children and is an important area for quality improvement in pediatric surgery.^{1,2} The incidence of pediatric appendicitis in Canada has been reported to be as high as 82.8 per 100 000 population and rising annually.³ A recent report of case costs in an Ontario center quoted a range per case of \$4290 to \$5845.⁴ Appendicitis is one of the most costly pediatric surgical illnesses and, accordingly, it remains an important public health issue.

Due to the burden and ubiquity of pediatric appendicitis, it must be treated at both community hospitals and pediatric centers but

consensus regarding ideal management is lacking.⁵ Previous studies have reported a difference in the cases that are managed by pediatric surgeons, as compared to general surgeons without pediatric-specific training. In particular, pediatric surgeons tend to manage younger, more complicated cases.⁶ However, adult surgeons have extensive experience with the disease process in adults and it is therefore felt that they can safely treat the disease in children in most circumstances.⁷ In addition, it is feasible that adult experience may even improve pediatric outcomes as a recent study demonstrated that high volume adult surgeons had lower morbidity compared to low-volume pediatric surgeons for pediatric cholecystectomies.⁸ Though the pediatric appendectomy outcomes of adult general surgeons have been studied previously, usually in comparison with pediatric surgeons, the effect of adult volumes on pediatric appendectomy outcomes has not been well characterized.^{9,10}

Given this gap in the literature, the primary objective of this

* Corresponding author. Division of General Surgery, St. Joseph's Healthcare, Room G814, 50 Charlton Avenue East, Hamilton, Ontario, L8N 4A6, Canada.

E-mail address: perino@mcmaster.ca (D. Hong).

study was to determine how health system factors, including adult appendectomy volume, affect all-cause morbidity after appendectomy in a large population-based cohort of pediatric patients in Canada. As a secondary objective, this study aimed to examine the effect of health system factors on costs.

Materials and methods

Study Design and population

This was a population-based retrospective analysis of administrative data in which the principle objective was to determine the factors that affect all-cause morbidity and cost after appendectomy. This population-based study included patients aged 17 or younger who underwent appendectomy in Canada (excluding Quebec) from April 2008 until March 2015. This study received ethics approval from the Hamilton Integrated Research Ethics Board (HIREB).

Data sources

Patient demographics, comorbidity profiles, surgical procedures, and complications were derived from the Canadian Institute for Health Information (CIHI) Discharge Abstract Database. Quebec was excluded as its data are accessible only through the Quebec Ministry of Health and Social Services rather than directly from the Canadian Institute for Health Information. The CIHI database is highly accurate in documenting most responsible diagnoses and primary surgical procedures as well as morbidity causing a more than 24-h increase in length of stay.^{11,12}

Outcomes

The main outcomes of interest were all-cause morbidity and cost during the index admission. It has been suggested that the use of a composite outcome such as all-cause morbidity is a means of addressing the low morbidity rates in pediatric surgery.^{2,13} All-cause morbidity included any documented complication that occurred during the index admission which extended length of stay by 24 h or required a separate, unplanned procedure. This was a composite outcome that was determined by CIHI during the initial data collection process and therefore is the most comprehensive outcome afforded by the dataset. Similar composite outcomes have been shown to be more valid in explaining hospital and surgeon level variation in serious complication rates. For costs, CIHI uses a standardized costing methodology where a resource intensity weight is assigned to each hospitalized patient based on their utilization. This weight is multiplied by the average cost per weight unit for each health region for the year that the admission occurred. All costs were adjusted for inflation and reported in 2014 Canadian dollars.

Predictors

The regression factors included patient, surgeons and hospital factors. Patient level factors included patient gender, age, comorbidity status, perforated appendicitis and use of laparoscopy. Hospital level predictors included pediatric hospital status and annual hospital pediatric appendectomy volume. Surgeon variables included pediatric surgeon specialty, annual surgeon pediatric appendectomy volume and annual adult appendectomy volume.

Statistical analysis

Descriptive statistics were used to characterize the patient population. The χ^2 statistic was used to compare categorical

variables and analyses of variance (ANOVA) were used for continuous variables. Hierarchical regression models were used to determine predictors of costs and morbidity. The year, province, hospital and provider were used as cross-classified random effects. This will adjust for correlation within each of these levels. Fixed effects included gender, age, comorbidity status, perforation, laparoscopy, pediatric surgeon training, pediatric hospital status, annual surgeon pediatric volume, annual surgeon adult appendectomy volume and hospital pediatric appendectomy volume. Volume variables were analyzed as continuous variables. Additionally, we also completed a sensitivity analysis for patients under 10 years of age. Morbidity was modeled using a logistic hierarchical regression whereas costs were remodeled using a linear regression. Monte Carlo Markov Chain estimation was used for all models with 100,000 iterations after a 5000 iteration burn-in. All chains were examined for convergence. Statistical significance was set at $p < 0.05$. Data were analyzed using Stata (StataCorp version 12.1; College Station, TX) and MLwiN (Version 2.26; Centre for Multilevel Modelling, University of Bristol).

Results

Table 1 presents the univariable associations between the predictors and all-cause morbidity. Overall, 41,512 patients were identified over the seven-year period and the all-cause morbidity rate was 6.4%. Approximately 41.4% of the cohort was female and the median age was 13 years (IQR 10–15). The perforation rate was 30.4% while 8.3% of patients had at least one comorbidity identified. Laparoscopy accounted for nearly 69.1% of the procedures. Pediatric surgeons and hospitals were 28.0% and 30.3% of the cohort, respectively. Significant univariable associations with all-cause morbidity were noted for all predictors except for laparoscopy.

Table 2 presents the univariable associations between the predictors and cost. Average cost in the cohort was \$4715 (SD \pm \$2981). The most substantial differences in cost occurred for patients with comorbidities, perforation and complications which cost an average of \$2567 (95% CI \$2358 - \$2,777, $p < 0.001$), \$2806 (95% CI \$2726 - \$2,886, $p < 0.001$) and \$5144 (95% CI \$4840 - \$5,448, $p < 0.001$), respectively. Pediatric surgeons \$942 (95% CI \$862 - \$1,021, $p < 0.001$), and hospitals \$982 (95% CI \$905 - \$1,059, $p < 0.001$) were also associated with increased costs. Increasing surgeon and hospital volumes were associated with modest increases in costs while laparoscopy, increasing age and female gender were associated with decreases.

The results of the hierarchical multivariable regression are presented in Table 3. After adjustment, laparoscopy, increasing age, and surgeon pediatric case volume significantly decreased the risk of morbidity. Specifically, for each increase in 20 pediatric appendectomy cases per year, the odds of morbidity was 0.85 lower (95% CI 0.76–0.93, $p = 0.001$). Laparoscopy conferred a 0.81 lower odds of morbidity (95% CI 0.72–0.91, $p = 0.001$) while for each one-year increase in age, the odds of morbidity was 0.98 lower (95% CI 0.97–0.99, $p < 0.001$). Perforation was the most substantial predictor of morbidity, conferring a 5.95 higher odds of morbidity (95% CI 5.44–6.50, $p < 0.001$). Having a comorbidity was also associated with 2.20 times greater odds of all-cause morbidity (95% CI 1.96–2.46, $p < 0.001$). Importantly, after adjusting for volume, pediatric surgery specialists and pediatric hospitals conferred no effect on morbidity. Annual volume of adult appendectomy also did not confer a morbidity advantage. The subgroup analysis for those aged 10 years or younger did not change outcomes.

Table 4 presents the results of the cost analysis. After adjustment, the most substantial predictor of cost was having a complication which increased costs by more than \$4097 (95% CI \$4002 -

Table 1
Association between patient and health system factors and all-cause morbidity.

	No Morbidity n = 38,848	Morbidity n = 2664	Total n = 41,512	Morbidity Rate (%) 6.4	p-Value
Sex					<0.001
Male	22,673 (58.4)	1654 (62.1)	17,185	9.6	
Female	16,175 (41.6)	1010 (37.9)	24,327	4.2	
Median Age (IQR)	13 (10–15)	11 (8–14)	13 (10–15)	–	<0.001
Comorbidities					<0.001
No	35,933 (92.5)	2139 (80.3)	38,072	5.6	
Yes	2915 (7.5)	524 (19.7)	3439	15.2	
Perforation					<0.001
No	28,078 (72.3)	809 (30.78)	28,887	2.8	
Yes	10,770 (27.7)	1855 (69.52)	12,622	14.6	
Laparoscopy					0.70
No	12,022 (30.95)	815 (30.59)	12,837	6.3	
Yes	26,826 (69.05)	1849 (69.41)	28,675	0.0	
Pediatric Surgeon					<0.001
No	28,309 (72.87)	1567 (58.82)	29,876	5.5	
Yes	10,539 (27.13)	1097 (41.18)	11,636	10.4	
Pediatric Hospital					<0.001
No	27,422 (70.59)	1530 (57.43)	28,952	5.5	
Yes	11,426 (29.41)	1134 (42.57)	12,560	9.9	
Annual Hospital Pediatric Volume (Median, IQR)	55 (23–123)	72 (32–232)	53 (23–135)	–	<0.001
Annual Surgeon Pediatric Volume (Median, IQR)	11 (5–29)	16 (7–37)	11 (6–30)	–	<0.001
Annual Surgeon Adult Volume (Median, IQR)	15 (1–28)	11 (0–24)	15 (1–28)	–	<0.001

\$4193 $p < 0.001$). Perforation and having a comorbidity also had a substantial impact on costs with increases \$2133 (95%CI \$2081 – \$2184 $p < 0.001$) and \$1741 (95%CI \$1658 – \$1,824 $p < 0.001$), respectively. Pediatric hospitals (\$755, 95%CI \$253 – \$1274 $p < 0.001$) were also associated with an increase in perioperative costs. Surgeon volume and hospital volume were not associated with significant differences in cost. Laparoscopy decreased average cost by approximately 7% (\$-320, 95%CI \$-386 – \$-253 $p < 0.001$).

Discussion

The aim of this study was to determine health system factors affecting all-cause morbidity and cost after appendectomy in pediatric patients in Canada. It also distinctively evaluated the effect of adult appendectomy volume on pediatric outcomes. From this analysis, two system level factors had significant associations with morbidity. Annual pediatric appendectomy volume decreased the odds of morbidity by 15% for each 20 cases a practitioner performed annually (OR = 0.85/20 cases, 95%CI 0.76–0.93, $p < 0.001$). Additionally, the use of laparoscopy was associated with a decrease in morbidity after adjustments (OR = 0.81, 95%CI 0.72–0.91, $p = 0.001$). Conversely, annual adult appendectomy volume conferred no benefit (OR = 0.98, 95% CI 0.90–1.07, $p = 0.68$) nor did pediatric surgery specialty training (OR = 1.05, 95%CI 0.75–1.39, $p = 0.83$). Complications and comorbidities had a substantial

impact on increased costs while laparoscopy modestly decreased average costs.

In this population-based cohort the all-cause morbidity rate was 6.4% over the seven-year period. This is consistent with the 6.44% all-cause morbidity rate reported by Ingraham et al. in a 2010 retrospective review of 30,788 adult appendectomy cases from ACS NSQIP data.¹⁴ In contrast, a recent American study by Tian et al. using the Kids' Inpatient Database from 2012 reported a composite complication rate of 20%.¹³ Tiboni et al. reported a 30-day complication rate of 11% in pediatric appendicitis cases from 16 centers in the United Kingdom.¹⁵

Treatment at a pediatric hospital or by a pediatric surgeon had no significant effect on all-cause morbidity in our cohort. This has been generally seen in the literature as well. In a study of pediatric appendectomy in Texas, Putnam et al. found no difference in adverse events and readmissions between pediatric surgery specialist care and non-specialist care, however the severity of disease and length of stay were increased for children treated in pediatric centers.¹⁶ Kokoska et al. found that pediatric surgeons treated more severe disease, yet had a shorter length of stay compared to their adult counterparts.¹⁷ In a population-based study of Canadian children where general surgeons performed 81.2% of the operations, pediatric surgeons had a significantly increased length of stay; however, wound infection and readmission rates were similar to those of general surgeons.¹⁰

Table 2
Unadjusted cost difference by patient and health system factors (in 2014 Canadian dollars).

Average Cost (\$)	Cost Difference 4714 (SD = 2980)	95%CI	p-Value
Female	-149	(-206, -93)	<0.001
Age/year	-85	(-94, -75)	<0.001
Comorbidities	2567	(2358, 2777)	<0.001
Perforation	2806	(2726, 2886)	<0.001
Complication	5144	(4840, 5448)	<0.001
Laparoscopy	-290	(-356, -224)	<0.001
Pediatric Surgeon	942	(862, 1021)	<0.001
Pediatric Hospital	982	(905, 1059)	<0.001
Annual Hospital Pediatric Volume/50 cases	215	(197, 234)	<0.001
Annual Surgeon Pediatric Volume/20 cases	377	(342, 411)	<0.001
Annual Surgeon Adult Volume/20 cases	-392	(-423, -361)	<0.001

Table 3
Adjusted odds of all-cause morbidity by patient and health system factors.

	Odds Ratio	95%CI	p-Value
Female	0.92	(0.84, 1.00)	0.053
Age/year	0.98	(0.97, 0.99)	<0.001
Comorbidities	2.20	(1.96, 2.46)	<0.001
Perforation	5.95	(5.44, 6.50)	<0.001
Laparoscopy	0.81	(0.72, 0.91)	0.001
Pediatric Surgeon	1.05	(0.75, 1.39)	0.833
Pediatric Hospital	1.16	(0.68, 1.88)	0.642
Annual Hospital Pediatric Volume/50 cases	1.17	(1.06, 1.30)	0.001
Annual Surgeon Pediatric Volume/20 cases	0.85	(0.76, 0.93)	0.001
Annual Surgeon Adult Volume/20 cases	0.98	(0.90, 1.07)	0.680

Interestingly, in this study, laparoscopy was associated with significantly decreased morbidity and costs. The percentage of laparoscopic cases in this cohort was 69.1% in contrast to Cheong et al. who found a majority open approach in Canada between 2004 and 2010.¹ A Cochrane review comparing laparoscopic and open appendectomy reported various advantages of laparoscopic appendectomy for both adult and pediatric patients, including decreased surgical site infection, reduced postoperative pain, and decreased length of stay; however this review did find an increased rate of postoperative abscess after laparoscopic appendectomy.¹⁸ This is further supported by a meta-analysis of pediatric studies which favored a minimally invasive approach in pediatric appendicitis.¹⁹ Our study found a significant decrease in cost with laparoscopy for pediatric appendectomy. This is in contrast to previous studies in both adult and pediatric populations which report laparoscopy to be associated with higher operating room costs.^{19,20} This difference may be in the fact that our costing methodology includes all hospital costs, rather than just operative costs. Furthermore, length of stay data for patients in pediatric centers in this study was 3.2 days (Median 2 IQR2–4) versus 2.3 (Median 2 IQR2–3) days in community sites. We feel that the added costs are a combination of a difference in practice patterns which cause an increased LOS as well as the general cost for more specialized care.

Of particular interest is the effect of surgeon volume on outcomes as found in this study. This study found decreased morbidity in patients who were treated by surgeons with high pediatric appendectomy volumes. There was no advantage conferred by surgeons who had high adult volumes. This finding persisted with a subgroup analysis for children 10 years and younger. To date, studies analyzing the volume-outcome relationship in pediatric appendectomy have demonstrated mixed results. A systematic review examining volumes and outcomes in pediatric surgery found inconsistent findings, with surgeon-level characteristics showing a stronger associations than hospital-level characteristics.²¹ A recent study in pediatric cholecystectomy found that high volume adult

surgeons had a 68% decrease in the odds of morbidity as compared to low volume pediatric surgeons.⁸ In particular, to our knowledge, there have been no previous studies examining the impact of adult appendectomy volume on outcome after pediatric cases. In this cohort, there is no doubt that pediatric centers treat sicker and more complex patients but the majority of patients 67.3% of patients treated at pediatric centers are not perforated and have no comorbidities.

This large population-based cohort of pediatric appendicitis outcomes highlights several areas of potential target for improved outcomes. Independent of surgeon volume, pediatric specialization had no effect on decreasing morbidity. The public health impact of this study indicates that appendectomy can be safely done by adult general surgeons and these surgeons can improve their outcomes by maintaining a high volume of pediatric cases. Of note, only 20 annual cases are required to decrease the odds of morbidity of 15% so the burden for improvement is not particularly high. Accordingly, for those who plan to perform pediatric appendectomies as part of their practice, ensuring adequate exposure to pediatric cases may optimize outcomes. Additionally, surgeon volume, rather than hospital volume or designation, was the primary driver of improved outcomes and this points to a vital aspect of health system planning when considering treatment of this disease. Furthermore, it was a surgeon's pediatric volume, and not their adult volume that primarily affected outcomes after pediatric appendectomies. This is important to understand when considering ways to optimize individual surgeon outcomes and delivery of care. Finally, laparoscopy was found to be associated with significantly lower morbidity with no significant difference in cost. This finding points towards the need for continued efforts in promoting laparoscopy as standard of care in the management of pediatric appendicitis.

This study utilized the CIHI Discharge Abstract Database, which while highly accurate in documenting most responsible diagnoses and primary surgical procedures as well as morbidity causing a more than 24-h increase in length of stay, may be subject to error in recording and coding. We also only used significant morbidity in this analysis and therefore could not account for morbidity that did not increase length of stay such as mild nausea or perioperative pain. In addition, despite risk adjustment, it is impossible to equalize the patients treated by general and pediatric surgeons. The age of patients treated at pediatric centers were younger with mean age of 11.0 years at pediatric sites vs 12.7 years at community sites. The median age was 11 (IQR 8–14) at pediatric sites vs 13 (IQR 10–16) at community sites. Less than 10% of our cohort were 7 years or younger, therefore the results are largely generalizable to patients aged 8 or older. Nearly 75% of the patients were 10 years or older and without comorbidities, moreover the sensitivity analysis did not appreciably change the outcomes.

Table 4
Adjusted cost difference by patient and health system factors (in 2014 Canadian dollars).

	Adjusted Cost Difference	95%CI	p-Value
Female	-52	(-98, -7)	0.012
Age/year	-9	(-16, -2)	0.006
Comorbidities	1741	(1658, 1824)	<0.001
Perforation	2133	(2081, 2184)	<0.001
Complication	4097	(4002, 4193)	<0.001
Laparoscopy	-320	(-386, -253)	<0.001
Pediatric Surgeon	117	(-52, 285)	0.085
Pediatric Hospital	784	(254, 1307)	<0.001
Annual Surgeon Pediatric Volume/20	-15	(-97, 67)	0.367
Annual Surgeon Adult Volume/20	-40	(-100, 20)	0.097
Annual Hospital Pediatric Volume/50	21	(-26, 68)	0.196

Conclusion

Outcomes in pediatric appendectomy are influenced by pediatric case volume, regardless of pediatric specialty training or hospital setting. High adult volumes appear not to confer any morbidity advantage. Laparoscopic approach translates to lower morbidity and cost. In the ongoing effort to improve surgical patient safety and cost efficiency in pediatric appendectomy, pediatric case volumes and minimally invasive surgical approach should be considered key targets.

Conflicts of interest

The authors have no conflicts of interests to declare.

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Ethical approval

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Author contribution

Study Design: AGD, DH, CB.
Data Collection and Analysis: AGD, DH, CB.
Manuscript Drafting: AGD, DH, CB, GAD.
Critical Appraisal: AGD, DH, CB, GAD, HF.
Oversight: HF, DH.

Guarantor

Dennis Hong is the guarantor of this study.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.amjsurg.2018.12.021>.

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