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Has the robot caught up? National trends in utilization, perioperative outcomes, and cost for open, laparoscopic, and robotic pediatric pyeloplasty in the United States from 2003 to 2015

Briony K. Varda^a, Ye Wang^b, Benjamin I. Chung^c, Richard S. Lee^a, Michael P. Kurtz^a, Caleb P. Nelson^a, and Steven L. Chang^b

^aDepartment of Urology, Boston Children's Hospital, Harvard Medical School, MA, USA

^bDivision of Urologic Surgery, Center for Surgery and Public Health, Brigham and Women's Hospital, Harvard Medical School, MA, USA

^cDepartment of Urology, Stanford School of Medicine, CA, USA

Summary

Introduction—Since 2010, there have been few new data comparing perioperative outcomes and cost between open (OP) and robotic pyeloplasty (RP). In a post-adoption era, the value of RP may be converging with that of OP.

Objective—To 1) characterize national trends in pyeloplasty utilization through 2015, 2) compare adjusted outcomes and median costs between OP and RP, and 3) determine the primary cost drivers for each procedure.

Study design—We performed a retrospective cohort study using the Premier database, which provides a nationally representative sample of U.S. hospitalizations between 2003 and 2015. ICD9 codes and itemized billing were used to abstract our cohorts. Trends in utilization and cost were calculated and then stratified by age. We used propensity scores to weight our cohorts and then applied regression models to measure differences in the probability of prolonged operative time (pOT), prolonged length of stay (pLOS), complications, and cost.

Results—During the study period 11,899 pyeloplasties were performed: 75% open, 10% laparoscopic, and 15% robotic. The total number of pyeloplasty cases decreased by 7% annually; OP decreased by a rate of 10% while RP grew by 29% annually. In 2015, RP accounted for 40% of cases. The largest growth in RPs was among children and adolescents. The average annual rate of change in cost for RP and OP was near stagnant: −0.5% for open and −0.2% for robotic. The summary table provides results from our regression analyses. RP conferred an increased likelihood of pOT, but a reduced likelihood of pLOS. The odds of complications were equivalent. RP was associated with a significantly higher median cost, but the absolute difference per case was \$1060.

Correspondence to: B.K. Varda, Boston Children's Hospital, Department of Urology, 300 Longwood Avenue, Hunnewell 390, Boston, MA 02115, USA, briony.varda@childrens.harvard.edu (B.K. Varda).

Conflicts of interest

None.

Discussion—Despite advantages in room and board costs for RP, we found that the cost of equipment and OR time continue to make it more expensive. Although the absolute difference may be nominal, we likely underestimate the true cost because we did not capture amortization, hidden or down-stream costs. In addition, we did not measure patient satisfaction and pain control, which may provide the non-monetary data needed for comparative value.

Conclusion—Despite an overall decline in pyeloplasties, RP utilization continues to increase. There has been little change in cost over time, and RP remains more expensive because of equipment and OR costs. The robotic approach confers a reduced likelihood of pLOS, but an increased likelihood of pOT. Complication rates are low and similar in each cohort.

Keywords

Robotic pyeloplasty; Minimally invasive surgery; Pediatric urology; Ureteropelvic junction obstruction

Introduction

Although there has been a steady decline in pediatric pyeloplasty over the last 15 years [1], robotic pyeloplasty (RP) utilization has increased [2,3]. In fact, pyeloplasty is now the most commonly performed robotic procedure in children in the United States [4]. Reasons for this include the advantages inherent to minimally invasive surgery (e.g., small incisions, short recovery time and limited postoperative pain), as well as a distinct technical advantage over laparoscopy provided by articulating robotic wrists. In short, proponents feel RP is better for the patient than the open approach, and easier for the surgeon to perform compared with pure laparoscopy.

Despite this widespread adoption and dissemination of pediatric RP, the comparative value – which is equivalent to quality (including effectiveness, safety, and patient satisfaction) divided by the cost – has been difficult to determine primarily because of limited and varying reports on cost. One single-institution study reported equivalent costs for open and RP; however, it included an uncommonly long length of stay (LOS) for open pyeloplasties (OP) of 3.8 days [5]. In contrast, a 2009 cost comparison using the KID database demonstrated a \$2500 cost difference favoring open surgery [6], while another population-based study found a \$3500 cost discrepancy in 2010 [2]. A third study using the Nationwide Inpatient Sample found a 2.5-fold increased likelihood of excessive charges for a RP compared with the open procedure [7].

There are reasons to believe that the contemporary cost of RP has decreased since 2010, but little has been published on cost since these aforementioned studies. The periods previously assessed reflect a period of adoption wherein outcomes may have been influenced by a learning curve effect – both institutional and surgeon-related [8,9]. Proponents of RP feel that with increased experience, operative times decrease, which drives down the substantial cost associated with operating room (OR) use [10]. Further, more experienced surgeons, particularly in high-volume centers, may use costly robotic disposable equipment more judiciously. Updated information on cost for both robotic and open pyeloplasty would

determine whether or not the two procedures have reached cost parity, and as a result, comparable value.

The objectives of this study were threefold. First, we aimed to characterize national trends in utilization of open, laparoscopic, and RP from early inception to the contemporary period. Second, we aimed to compare adjusted perioperative outcomes, complications, and cost (to the hospital) for open and robotic pyeloplasty. Finally, using itemized billing data we aimed to determine the primary cost drivers for each procedure.

Methods

We performed a multi-institutional, nationally representative cohort study comparing open, laparoscopic and robotic pediatric pyeloplasties performed in the United States between 2003 and 2015.

Data source

We used the Premier Hospital Database, which is compiled and updated annually for national quality and utilization benchmarking by participating hospitals. This information is also made commercially available for research purposes. Data have been collected from over 600 hospitals. The population is sampled using survey procedures and represents 20% of all annual inpatient discharges in the United States. The database is unique in that participating hospitals provide itemized billing information, making it possible to identify anything that was billed during an inpatient stay (e.g. a specific DaVinci surgical instrument). Although both costs and charges are available in Premier, this study focuses only on costs to the hospital, which are reported by participating hospitals' billing departments specifically for value assessment. This includes information about direct costs, which is based on hospital-provided RVU data or cost-to-charge ratios. The database does not include information about clinical outcomes related to specific procedures, nor laboratory or imaging results.

Sample selection

All patients aged 18 years or younger with a procedure code for pyeloplasty (ICD9 55.87) and a diagnostic code for ureteropelvic junction obstruction (UPJO; ICD9 753.21) or hydronephrosis (ICD9 591) were abstracted.

Measures

Our exposure of interest was procedure type: open, laparoscopic, or RP. Using billing data, procedures were distinguished through regular expression matching techniques for terms specific to robotic and laparoscopic surgery equipment. Outcomes included trends in utilization, prolonged operative time (pOT; >50th percentile), prolonged LOS (pLOS; >75th percentile), complications, and total median cost. The definition for pLOS was based on prior literature [11–13], while pOT was based on the presence of a clear bimodal distribution within the data. Our covariates included patient (age, gender, race, insurance, and presence of complex chronic conditions as defined by Feudtner et al. [39]) and hospital-level characteristics (bed-size, urbanicity, region, and annual hospital volume and surgeon volume for the year the case was performed (grouped by tertiles)). Specific cost drivers were

organized into categories using billing data, and included OR use, room and board, equipment, pharmacy, radiology and miscellaneous costs (namely, respiratory, EKG, labs, therapy, and other non-categorizable costs).

Analysis

The annual number and proportion of cases were recorded and average annual growth rates (AAGR) were calculated for open, laparoscopic, and RP. The analysis was then stratified by age categories: infants (<1 year), children (1–12 years), and adolescents (13–18 years). Median annual cost and AAGRs were also calculated for each surgical approach and plotted over time.

Descriptive statistics of baseline patient and hospital characteristics adjusted for hospital sampling weights to reflect a national estimate were calculated and compared for OP and RP using chi-square or non-parametric tests. To adjust for factors influencing receipt of robotic versus open surgery, a propensity score was designed *a priori* to incorporate both patient (age, gender, race, insurance, presence of chronic conditions) and hospital characteristics (hospital size, teaching status, urbanicity, region, annual hospital pyeloplasty volume, and annual surgeon pyeloplasty volume). After weighting, balance across the cohorts was assessed by chi-square or non-parametric tests. If balance was not achieved with scoring, the unbalanced measure was included as a covariate in our regression analysis.

We then performed cluster adjusted logistic regression for our categorical outcomes and quantile regression for median 90-day costs. Each used OP as the referent and RP as the comparator. Costs attributable to specific cost categories were calculated and the proportional contribution to the overall cost was reported. The Wilcoxon rank-sum test was used to compare unadjusted individual cost categories between OP and RP.

All analyses were performed using SAS 9.4 (Cary, NC).

This study was given IRB exemption by Brigham and Women's Hospital institutional review board given the de-identified nature of the data.

Results

During the study period 11,899 pyeloplasties were performed, including 8909 OP (75%), 1172 LP (10%), and 1818 RP (15%) (Fig. 1). The total number of pyeloplasty cases decreased by 7% annually. Open and LP decreased annually by a rate of 10% and 12% respectively, while RP grew by 29% annually (Fig. 2A). By 2015, RP accounted for 40% of cases. Among the RP patients, the largest growth was among children (+45% AAGR) and adolescents (+20% AAGR), with RP comprising 84% of cases among adolescents in 2015 (Fig. 2C, D). In contrast, most infant pyeloplasties in 2015 were still performed using an open approach (85%; Fig. 2B).

The average annual unadjusted median cost was \$9508 (IQR \$5769) for OP, \$9642 for LP (IQR \$6713), and \$12,508 (IQR \$8340) for RP. The average annual rate of change in cost for each procedure was −0.52% (OP), −2.6% (LP), and −0.18% (RP; Fig. 3). In 2015, the unadjusted cost for RP was \$2733 more than OP (\$11,604 versus \$8871).

Table 1 presents baseline patient, hospital, and procedure characteristics for open and robotic surgery prior to propensity score weighting. The groups significantly differed by age, number of complex conditions, and hospital teaching status ($p < 0.001$, $p = 0.01$, $p < 0.001$). OP was rarely performed in adolescents (11%), while RP was rarely performed in infants (10%). After propensity score weighting was applied the cohorts were statistically balanced for all variables except age and number of complex conditions. These variables were therefore included as covariates in our multivariable models.

In our unadjusted analysis, the median operative time was 190 min for OP versus 240 min for RP. Median LOS was 2 days for both procedures. A larger proportion of RP cases was prolonged (80%) compared with OP (46%). In contrast, 16% of open cases and only 3.8% of robotic cases required a prolonged hospitalization. The frequency of complications was similar for each procedure (10% open and 8.6% robotic). The results of the adjusted multivariable analyses are reported in Table 2. In summary, RP significantly reduced the likelihood of a pLOS (OR 0.14 (0.05–0.38), $p = 0.001$). However, it substantially increased the likelihood of a pOT (OR 5.4 (3.1–9.2), $p < 0.001$). There remained no difference in the likelihood of complications between RP and OP (OR 0.80 (0.34–1.9), $p = 0.62$). Quantile regression demonstrated that the adjusted median cost for RP was significantly more than OP (\$11,877 versus \$10,817) with an absolute adjusted cost difference of \$1060 ($p = 0.03$).

The top three cost contributors – accounting for approximately 90% of the cost in both procedures – were OR use, room and board, and equipment costs (Fig. 4). However, room and board was significantly higher for open surgery ($p < 0.0001$), while OR use and equipment costs were significantly higher for robotic surgery ($p < 0.0001$ and $p < 0.0001$, respectively).

Discussion

The approach to pediatric pyeloplasty has dramatically shifted over the last 15 years with pediatric RP now being the most commonly performed robotic procedure in children [4]. This study illustrates these changes in utilization and includes the most contemporary information available for all three surgical modalities. We continue to see an overall decline in pyeloplasty utilization yet a sustained increase in the utilization of RP across all age groups, but particularly so among adolescents and children. Comparatively, 90-day complications are uncommon and equivalent across the procedures. Although RP confers a greater likelihood of pOT, it reduces the likelihood of a pLOS. For all modalities, costs have been stagnant over time with RP costing more to the hospital than OP. In regards to the value equation, RP matches OP for safety and efficacy [9, 14–20], but we found that the cost denominator has yet to converge.

Operative time

It might reasonably be predicted that the cost of RP could catch up to OP given the potential for improvement in surgery times and therefore decreased costs associated with OR use. Indeed, early studies of pediatric RP showed decreasing OT with increasing case volume [8,9]. However, we found that the median OT for RP was close to 1 h longer than the open procedure. Furthermore, we found a high likelihood of a pOT for RP cases. Given that OR

costs make up such a substantial majority of overall cost for these procedures, it is unlikely that robotic surgery will catch up unless more gains are made in OR efficiency. However, this may be an insurmountable task for a majority of institutions: in an economic analysis Seideman et al. estimated that with a 2-day LOS, RP would only become cost-effective (when compared with LP) if it was carried out in under 120 min [21].

Length of stay

Supporters of robotic surgery often cite a reduced LOS as an advantage to the patient and means for cost-savings [5, 9, 22–25]. In this study, the median LOS for RP and OP were equivalent. Other contemporary, multi-institutional studies have also found inconsequential differences in LOS. Further, the LOS for any type of pediatric pyeloplasty in the U.S. is currently 2 days or less [1,2,4], which leaves a small margin to demonstrate an advantage between the two approaches. We did find that RP reduced the likelihood of prolonged hospitalization, which may be of substantial importance to families when considering missing work, lost wages, and additional childcare costs. But in terms of cost to the hospital, the advantage did not lead to cost parity across the aggregate. Bowen et al. arrived at a similar finding for robotic reimplant, where, despite a significantly shorter LOS, charges for robotic surgery remained significantly higher [26]. Prolonged hospitalization in the open cohort may relate to a number of factors, including worse postoperative pain with open surgery, use of antiquated postoperative protocols for open cases, or a greater incidence of unmeasured complex cases in the open cohort.

Complications

Success rates following pediatric pyeloplasty have been reported as greater than 90% for both approaches, while complications have been reported in 0–18% of cases with additional procedures occurring in 7.6% [17,27–30]. Our rate of complications was consistent with these aforementioned studies. From this study and others, we can be relatively confident that RP provides comparable safety to OP.

Cost

Our cost analysis found a persistent cost difference between the open and robotic cohorts favoring the open procedure. Although the data from 2007 to 2011 suggested robotic surgery would catch up, the trend in cost for the entire study period ultimately remained near stagnant for both surgical approaches. A closer analysis of cost contributors demonstrated that the combined costs of OR use and equipment for RP was substantial and did not overcome a higher room and board cost associated with OP. Moreover, equipment costs associated with OP made up a distinctly minute portion of overall costs.

We recognize that calculating the true total cost for a procedure is quite difficult because there are often up front, down-stream, and hidden costs. Our study did not account for amortization costs related to the purchase of the robotic platform, which are derived from a purchase price of \$1.5–2.2 million [31], as well as on-going maintenance fees. For reference, the estimated additional cost per procedure from amortization is \$1600 [31]. We were also unable to capture the base cost of training personnel. In addition, we could not account for the reduction in revenue potential from lost OR time incurred by the pOT associated with

RP. Conversely, being able to market the robotic platform may increase patient volume and lead to an increase in revenue. However, Palmer et al. estimated that a minimum of three to five robotic cases per week were necessary to profit from robotic surgery [32], which is not the case for pediatric pyeloplasty even in high-volume institutions [5, 10, 33] (although this may be achievable in settings where the robot is shared among pediatric and high-volume adult urologists). There is one scenario in which we may have overestimated robotic costs: we cannot verify whether individual hospitals reported the cost of a single use of a reusable robotic instrument or the aggregate cost each time the instrument was used (10 uses). However, given that Premier is commissioned by individual hospitals to assess and improve value, we suspect that accounting accuracy is important to these institutions, particularly for equipment which is a substantial cost contributor.

Other components of value

By understanding comparative efficacy and cost we can make better judgments about value. Our study provides the most contemporary information about two key parameters of the value equation: perioperative outcomes and cost. Other quality measures, such as patient satisfaction, postoperative pain, and improved cosmesis must be considered as well. Although our dataset is not designed for these measures, other studies have attempted to investigate these outcomes. In regard to postoperative pain following pediatric pyeloplasty, one study found no difference in pain scores between OP and RP [8], whereas the other found a lower rate of pain medication use [17]. Despite the relative smaller size of port site incisions, a recent crowdsourced survey found that respondents would prefer both dorsal lumbotomy and flank incisions [34]. Freilich et al. compared parental satisfaction using a validated measure and found no difference in overall satisfaction rates between OP and RP [35]. Behan et al. found equivalent human capital gains after accounting for amortization costs [36]. Taken together, these studies were unable to provide strong evidence that RP provides superior patient satisfaction outcomes in children. Unfortunately, with the widespread decline in OP it will be increasingly challenging to do so.

Limitations

This project is not without limitations. In addition to those already discussed, the Premier dataset disproportionately represents private, non-academic hospitals. However, this imbalance is presumably addressed by applying sampling weights. In accordance, our findings aligned with data from multi-institutional pediatric centers in the U.S. [1,3,37]. Given that Premier is an administrative dataset, we are unable to identify misclassification from coding errors. We attempted to minimize this by combining procedure and diagnostic codes, as well as itemized billing data, to improve the sample accuracy [38]. There remains the potential for unmeasured confounding and therefore selection bias, though using a propensity score adjusts (at least in part) for the receipt of a particular surgical approach. The administrative nature also means this dataset lacks clinical detail, including indications for pyeloplasty and efficacy data. We also did not investigate complications beyond 90 days which means we were unlikely to capture procedure failures/restenosis. However, by using a 90-day postoperative period we hoped to capture stent removals (if a stent was used) and any related sequelae. Another concern is that even though RP was introduced over 10 years ago, and has since widely disseminated, our results may still reflect some surgeons' and

institutions' "learning curve" periods. But by adjusting for surgeon and hospital annual volume, we hope to have lessened this effect. Finally, we only consider cost (to the hospital) in our analysis – we do not include charges or reimbursement – therefore our results do not comprehensively capture the complexity related to healthcare financing.

Conclusion

Although pediatric pyeloplasty utilization has decreased in the U.S., RP continues to experience substantial growth. The cost for RP, however, has been stable and remains higher than the open approach. This cost difference continues to be driven by OR time and supplies, which has not been mitigated by savings in room and board. In considering the outcomes and cost for RP in this study, the associated value is not superior to OP.

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Figure 1. Number and proportion of open, laparoscopic, and robotic pediatric pyeloplasties performed in the U.S. between 2003 and 2015 ($n = 11,899$).

a) All ages **b) Infants (<1 year)** **c) Children (1-12 years)** **d) Adolescents (13-18 years)** **Figure 2.**

Proportion of open (blue), laparoscopic (red), and robotic (green) pyeloplasties performed in the U.S. between 2003 and 2015. (For interpretation of the references to color/colour in this figure legend, the reader is referred to the Web version of this article.)

Figure 3.

Annual median cost for open and robotic pediatric pyeloplasties performed in the U.S. from 2003 to 2015. Average annual rate of change in cost: OP -0.5% and RP -0.2% .

Figure 4.
The proportion of cost attributable to specific cost categories stratified by surgical approach.

Table 1

Population weighted patient and procedure characteristics prior to propensity scoring, stratified by surgical approach ($n = 11,899$).

	Open ($n = 8909$)	Robotic ($n = 1818$)	p-value
Age			
Less than 1 year	60%	18%	<0.0001
1–12 years	29%	41%	
13 year and older	11%	42%	
Gender			
Male	73%	71%	0.72
Female	27%	29%	
Race			
White	65%	74%	0.09
Black	9%	5%	
Hispanic	7%	5%	
Other	19%	16%	
Insurance			
Medicaid/Medicare	40%	31%	0.29
Private	54%	63%	
Other	6%	6%	
Complex chronic conditions			
CCC = 0	29%	7%	<0.0001
CCC = 1	69%	46%	
CCC >1	2%	46%	
Bedsizes			
000–299	32%	16%	0.14
300–499	25%	40%	
>500	43%	44%	
Teaching status			
Non-teaching	45%	67%	0.01
Teaching	55%	33%	
Urbanicity			
Rural	2%	1%	0.68
Urban	98%	99%	
U.S. region			
Northeast	23%	11%	0.43
Midwest	14%	18%	
South	46%	54%	
West	17%	17%	
Hospital annual volume			
Lowest tertile (3 cases)	18%	24%	0.19
Middle tertile	20%	20%	

	Open (n = 8909)	Robotic (n = 1818)	p-value
Top tertile (>6 cases)	62%	56%	
Surgeon annual volume			
Lowest tertile (1 case)	18%	26%	0.06
Middle tertile	28%	30%	
Top tertile (>3 cases)	54%	44%	

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Table 2

Propensity-score weighted multivariable analysis^a comparing perioperative outcomes and cost associated with robotic and open pyeloplasty.

	OR	95% CI	p-value
Prolonged LOS (> 2 days)			
Robotic	0.14	(0.05, 0.38)	0.001
Open	ref		
Prolonged OT (> 200 min) ^b			
Robotic	5.4	(3.1, 9.2)	<0.001
Open	ref		
Complications			
Robotic	0.80	(0.34, 1.9)	0.62
Open	ref		
	Open	Robotic	p-value
Median cost (USD)	\$10,817	\$11,877	0.03

^aMultivariable logistic regression for categorical outcomes, quantile regression for median cost.

^b8% of sample missing data.

Table

Propensity-score weighted multivariable-adjusted analyses for perioperative outcomes and cost associated with robotic pyeloplasty (as compared with the open approach).

	OR	95% CI	<i>p</i>-value
Prolonged LOS (>2 days)	0.14	(0.05–0.38)	0.001
Prolonged OT (>200 min)	5.4	(3.1–9.2)	<0.001
Complications	0.80	(0.34, 1.9)	0.62
	Open	Robotic	<i>p</i> -value
Median cost (USD)	\$10,817	\$11,877	0.03

LOS = length of stay; OT = operative time.