Open versus minimally invasive surgical approaches in pediatric urology: trends in utilization and complications

Mr. Rohit Tejwani[a], **Dr. Brian J. Young**[a], **Hsin-Hsiao S. Wang**[a], **Steven Wolf**[b], **J. Todd Purves**[a], **John S. Wiener**[a], and **Jonathan C. Routh**[a,*]

[a]Division of Urologic Surgery, Duke University Medical Center, Durham, NC, USA

[b]Dept of Biostatistics and Bioinformatics, Duke University, Durham, NC, USA

Summary

Objective—Minimally invasive surgery (MIS) techniques are anecdotally reported to be increasingly used, but little objective data supports this. Our objective was to assess trends in MIS utilization across various procedures in pediatric urology and to compare postoperative complication rates between MIS and open procedures.

Methods—We analyzed the 1998–2012 Nationwide Inpatient Sample. We identified children (<18 years old) undergoing open and MIS inpatient procedures and any in-hospital postoperative complications that occurred during that postoperative hospitalization. We utilized propensity score matching and multivariable logistic regression to adjust for confounding factors.

Results—We identified 163,838 weighted encounters in the "overall cohort," 70,273 of which were at centers performing more than five MIS procedures over the years studied. Use of MIS techniques increased significantly over time for several procedures, most prominently for nephrectomy (Figure). The overall rate of complications was lower in patients undergoing MIS compared with open surgery (6% vs. 11%, $p<0.001$). Specialized centers had a significantly lower overall rate of complications than unspecialized centers (9% vs. 12%, $p<0.001$). Within specialized centers, MIS had lower complication rates than open procedures (7% vs. 9%, $p<0.001$); this finding was consistent even after adjusting for other factors (OR 0.71, $p=0.02$).

Discussion—Limitations include that these data may not be generalizable to encounters not in the sample pool. As a large, retrospective, administrative database, NIS may be affected by miscoding bias – rendering our analysis sensitive to the accuracy of procedure coding in NIS. Although the accuracy level of NIS is high for an administrative database, it is possible at least some portion of our cohort may be incorrectly coded. Further, the NSQIP complications we identified may represent associated comorbidities and not true postoperative complications, as NIS

---

*Corresponding author. Division of Urologic Surgery, Duke University Medical Center DUMC 3831, Durham, NC 27710, USA, jonathan.routh@duke.edu.

Dr. Young and Mr. Tejwani contributed equally to this manuscript.

does not provide temporal relationships between different diagnosis codes. Despite these limitations, we note that the NIS database is rigorously monitored and audited for coding accuracy and, therefore, represents a reasonably reliable panorama of the characteristics of an inpatient surgical cohort. However, it is important to note that the choice of operative modality is, undoubtedly, multifactorial and patient/setting-specific.

Conclusions—There is increasing use of MIS for pediatric urology procedures, although utilization rates vary among procedures. MIS was associated with a lower postoperative complication rate than for open procedures. Higher-volume MIS centers have a lower complication rate than lower-volume centers.

Keywords

Urology; Pediatrics; Laparoscopic surgery; Minimally invasive surgery; Complications

Introduction

Initially pioneered primarily as a diagnostic modality in the 1970s, the use of minimally invasive surgery (MIS) has become increasingly common in pediatric surgical practice following significant recent technological improvements [1–3]. Pediatric urologists have embraced MIS as technological improvements have come to market, altering the treatment landscape and permitting viable MIS approaches for many common urinary tract procedures in children [4]. This change has coincided with paradigm shifts among physicians and parents favoring less-invasive surgical techniques in children when possible, driven by reported improvements in cosmetic outcomes, more expedient postoperative discharge, and faster recovery times [5–8]. Extensive MIS training is now a component of most urological residency and fellowship programs in the USA, and urological procedures account for up to 15% of all laparoscopic operations performed in children domestically [9,10].

Use of MIS, however, is not without potential trade-offs. Both laparoscopy and robotic surgery require considerable resource expenditure in training and infrastructure [11,12]. Operative times for MIS are typically longer than comparable open approaches and are highly dependent on operator proficiency [13–15]. Yet, despite these substantial differences, studies directly comparing the outcomes from MIS and open approaches in pediatric urology are limited.

We sought to describe changes in the frequency of MIS use in pediatric urology in the USA over a 14-year period using a nationwide all-payer database and to characterize differences in the frequency of reported postoperative complications in MIS and open pediatric urological surgical approaches. We hypothesized that there would be an increase in both MIS utilization and MIS-related complications (because of individual provider learning curves) over time.

Methods

Data source

The Nationwide Inpatient Sample (NIS) is an all-payer database managed by the Healthcare Cost and Utilization Project (HCUP) and sponsored by the Agency for Healthcare Research and Quality. Data in the NIS are from a 20% stratified probability sample of US hospitals based on five hospital characteristics including ownership status, number of beds, teaching status, urban/rural location, and geographic region. NIS includes post-stratification discharge weights to estimate 35 million hospital admissions per year.

Selection of patients and covariates

We selected all pediatric patients (<18 years old) between 1998 and 2012 undergoing procedures which could reasonably be performed open or with MIS and defined this as the "entire cohort." Procedures were defined by ICD-9-CM code (see Appendix 1 for codes and procedures); codes were previously validated at our institution to assure their accuracy [16,17]. We defined MIS procedures as those with a concurrent ICD-9-CM procedure code for laparoscopic/robotic assistance (54.51, 54.21, and/or 17.4x) [18–21]. We then refined our cohort to compare only hospitals that performed a minimum of five MIS cases per year to compare hospitals where enough MIS was performed presumably to minimize technical error and reduce complications. These encounters were defined as the "specialized cohort" in our analysis and included 59 of the 1,308 hospitals in the original cohort. Predictor variables were selected *a priori.* Covariates included basic patient demographics: age, gender, race, insurance payer (public vs. private), median household income, Charlson comorbidity index, treatment year, treatment modality, and hospital-level factors (teaching status and geographic region).

Outcome selection

The primary outcome was postoperative complications; these were identified by ICD-9-CM codes (Appendix 2) which most closely corresponded to the complications described by the National Surgical Quality Improvement Program (NSQIP). Rare complications (15), while included in the analysis, were excluded from data tables per AHRQ requirements. For secondary outcomes, we analyzed the prevalence of MIS techniques for individual procedures over time and modeled the predictors of receiving MIS, adjusting for covariates.

Statistical analysis

We used descriptive statistics to describe the demographics of each cohort. Wald chi-square test was used to compare discrete variables and ANOVA was used for continuous variables to take into account the stratum, clusters, and weights present in the data set.

Using the "entire cohort," we determined the overall frequency of complications and percentage of individual procedures performed using MIS. Encounters were subcategorized into four time periods (years 1998–2001, 2002–2005, 2006–2009, 2010–2011) to account for small numbers of observations in individual years. We then created heat maps (Fig. 1) to assess national trends in utilization (2012 was excluded from these maps as NIS did not

report each hospital's state for that year). States were excluded from the heat maps if they did not participate at any time in NIS.

To ensure a fair comparison within the "specialized cohort," we used propensity scores (PS) to match patients on surgery type. We adjusted for age, gender, race, Charlson Comorbidity Score, hospital bed size, hospital type, region, and year. Multiple imputation was used for missing data. We created 15 imputed data sets and exported them to R to perform propensity matching to create 15 matched data sets using the Matchit macro. As open surgery was expected to be significantly more prevalent than MIS, we used a control:case ratio of 3:1 using the "greedy" nearest neighbor method. We used PS matching jitter and love plots to assess how well the matching was performed. Matched data sets were exported to SAS and analyzed with PROC MIANALYZE. Generalized estimating equations were used to account for the complex survey design of NIS in addition to hospital clustering.

We modeled the 15 imputed, propensity-matched data sets to assess factors predictive of complications. We treated MIS vs. open as our primary predictor and adjusted for age, gender, race, Charlson Comorbidity Score, hospital bed size, hospital type/location, region, and year. Year was treated as a covariate in the model to take into account the varying rates of MIS by years that we observed in our figures. The same covariates were used to model the probability of receiving an MIS procedure.

A flowchart of this progression is provided in Appendix 3. An alpha of 0.05 and 95% confidence intervals (CI) were used as criteria for statistical significance. All analyses were performed using R version 3.1.0 and SAS 9.4 (SAS Institute, Cary, NC, USA).

Ethical approval

This protocol was reviewed by our institutional review board and deemed to be exempt.

Results

Demographics

We identified at total of 163,838 weighted encounters in the "overall cohort," 70,273 of which were at centers performing more than five MIS procedures over the years studied (Table 1). Specialized centers had higher rates of teaching institutions (96 vs. 88% unspecialized, $p<0.01$), females (56.5% vs. 54% unspecialized, $p<0.01$), admissions in the South regions (42.5% vs. 27.6% unspecialized, $p<0.01$), lower rates of large bed sizes (56.4% vs. 60% unspecialized, $p=0.01$), lower complication rates (9% vs. 11.5% unspecialized, $p<0.01$), and, on average, treated younger children (mean age 4.8 ± 0.05 vs. 5.5 ± 0.06 years, $p<0.0001$). No significant variation in other demographic categories, including race ($p=0.52$) and insurance ($p=0.08$), was observed between specialized and unspecialized hospitals.

Following exclusion of centers performing fewer than five MIS procedures, the "specialized cohort" consisted of 66,510 open and 3,763 MIS surgeries (Table 2). In this cohort, patients receiving MIS were, on average, older (7.8 ± 0.23 vs. 4.7 ± 0.05, $p<0.0001$), had higher rates

of males (51.6% vs. 43%, $p<0.0001$), and lower rates of comorbidity scores ≥ 2 (10.6% vs. 11.2%; $p<0.001$).

Use of minimally invasive surgery

Use of MIS techniques increased significantly over time for several procedures, most prominently for nephrectomy (Summary Figure). Adjusting for other covariates, hospital setting had a statistically significant association to surgery type, with patients seen at rural hospitals having lower odds of receiving an MIS procedure compared with those seen at urban teaching hospitals (OR 0.43, $p=0.39$). By contrast, urban nonteaching hospitals had higher odds compared with urban teaching to perform an MIS procedure (OR 2.44, $p=0.02$). Heat maps displaying national geographic trends in uptake of MIS are shown in Figure 1.

Postoperative complications

The overall rate of complications was lower in patients undergoing MIS compared with open surgery (6.3% vs. 10.6%, $p<0.0001$). Specialized centers had a significantly lower overall rate of complications than unspecialized centers (9% vs. 11.5%, $p<0.01$). Within specialized centers, MIS had lower complication rates than open procedures (7% vs. 9.1%, $p<0.01$); this finding was consistent even after adjusting for other factors (OR 0.70, $p=0.03$, Table 3). Complication frequency – initially similar at the start of the study period – decreased more steeply for MIS procedures over time than for open procedures (Fig. 2).

Additionally, for each point increase on the Charlson Comorbidity Index, patients had significantly higher odds of experiencing a complication (OR 1.79, $p<0.01$). Specific complications are detailed in Table 4.

Relative to patients undergoing open procedures, MIS patients had significantly lower rates of acute renal failure ($p=0.01$), urinary complications ($p<0.01$), and respiratory complications ($p<0.0001$). However, a relatively higher proportion of MIS patients experienced general postoperative renal complications relative to open patients ($p<0.0001$).

Discussion

Our analysis of 70,273 weighted encounters revealed that MIS use was associated with a significantly lower incidence of postoperative complications among children undergoing urinary tract procedures. Adjusting for age, gender, comorbidity score, and hospital-level clustering effects, children who underwent MIS procedures had a 30% reduction in their odds of developing in-hospital NSQIP-defined complications relative to those undergoing open procedures, contrary to our expectations. Children who underwent MIS at specialized hospitals were more likely to be older, male, and had slightly higher rates of private insurance than those treated with open surgery. These data further confirm what has previously been known anecdotally: that MIS use has increased significantly over the past two decades for some common pediatric urologic procedures nationwide. Rates of MIS nephrectomies, ureteroureterostomies, appendicovesicostomies, and bladder neck slings in particular have more than doubled since the year 2000, and by 2011 MIS cases accounted for 7% of the eight pediatric urologic procedures analyzed.

As noted by Lorenzo *et al.*, the concept of MIS can be tantalizing given the potential for comparable-or-better outcomes relative to open approaches with less tissue trauma and greater potential patient satisfaction [22]. MIS has been associated with comparable-or-better lengths of stay (LOS), recovery times, and postoperative morbidity and mortality in prior literature from adult and pediatric urologic case-series, and other surgical subspecialties [7–9,14,23]. Indeed, LOS and recovery time in particular may factor prominently in our observed incidence of pulmonary complications, given known risks for atelectasis, pneumonia, and upper-respiratory tract infections associated with prolonged hospitalization [24]. Better visualization within the peritoneum and retroperitoneum theoretically could permit more accurate dissection which, in turn, may further reduced procedure-related morbidity [25].

While similar at the outset of the study period, annual MIS complication rates declined more rapidly than those for open procedures, which remained mostly stable over time. Although undoubtedly, there are several potential reasons for this observation including technological improvements over the past two decades, we believe it most likely attributable to known "learning-curve" effects associated with MIS as described by Georgeson and others [1,13,26,27]. Such effects often follow the advent and dissemination of new medical technologies, as familiarity and precision increase with greater experience [27]. Early exposure and continued education geared toward operator improvement can greatly reduce the "steepness" of this curve, and adequately trained surgeons are consequently more likely to consider MIS approaches for their patients [28,29]. We note, however, that several authors have reported considerable dissatisfaction among American urological residents surveyed about MIS training during residency, with 60–85% reporting subjectively inadequate laparoscopic and robotic exposure [30,31]. Further discussion is warranted on how best to improve MIS training in graduate medical education.

Demographic differences noted between our MIS and open patient cohorts suggest a strong degree of modality-specific patient selection, particularly vis-à-vis age and comorbidities. Older children may be felt to be better candidates for MIS given larger and better-developed abdominopelvic spaces, which afford greater maneuverability of laparoscopic instruments and less risk of accidental injury. Such children are also more stable physiologically, and likely more tolerant of operative and anesthetic insults in the event of intraoperative open conversion should MIS fail. This may similarly explain why children with higher CCS scores were slightly more likely to undergo open surgery, rather than MIS.

The findings of our study must be viewed in the context of its design limitations. NIS represents a 20% stratified sample of US hospital admissions. Consequently, results derived from it may not be generalizable to encounters not in the sample pool. Non-participation by specific centers with high pediatric surgical volumes may similarly reduce the accuracy of our state-level reporting of MIS prevalence over time. We note, however, that NIS provides meticulous tracking of discharge and hospital weights to minimize sampling bias risk. Because NIS represents admission-based rather than patient-based data, it is impossible to track a given patient across time. We were unable to assess longer-term outcomes nor whether individual patients had multiple admissions. As a large, retrospective, administrative database, NIS may be affected by miscoding bias – rendering our analysis sensitive to the

accuracy of procedure coding in NIS. Although the accuracy level of NIS is high for an administrative database, it is possible that at least some portion of our cohort may be incorrectly coded. This is particularly true for our method to identify MIS cases, which relies on a concurrent ICD-9 code being present. While this same definition has been successfully used in several other reports [18–21], it is likely that this method resulted in some MIS cases being incorrectly labeled as "open." We would anticipate that miscoding bias would, in this case, have biased towards the null; in other words, systematically mistaking MIS cases for open should tend to make the two cohorts more similar. Thus, while miscoding bias is very likely to have been present in our results, we would not anticipate that miscoding bias alone would invalidate our results.

Similarly, the NSQIP complications we identified may represent associated comorbidities and not true postoperative complications, as NIS does not provide temporal relationships between different diagnosis codes. Despite these limitations, we note that the NIS database is rigorously monitored and audited for coding accuracy and, therefore, represents a reasonably reliable panorama of the characteristics of an inpatient surgical cohort.

Selection bias is likely an issue in these data. We suspect that patient selection and learning curve issues are factors that play a role in procedure choice; however, these data unfortunately cannot prove this hypothesis. In addition, the lack of accurate, contemporary ambulatory surgery datasets in pediatrics left us unable to study encounters not associated with inpatient admissions – notably patients who undergo procedures in ambulatory surgery centers, as many children undoubtedly do. Although the number of such patients not included in our cohort is believed to be relatively small, the possibility remains that such data may alter our understanding of patient and center-specific characteristics reported in this study.

However, it is important to note that the choice of operative modality is, undoubtedly, multifactorial and patient/setting-specific. Either MIS or open approaches may be more appropriate for a particular child based on anatomic/physiologic considerations, institutional resources, provider proficiency, parental preferences, and procedural costs. Further investigations more closely examining these factors as they pertain to modality choice are warranted.

Conclusions

There is steadily increasing use of MIS for pediatric urology procedures, although rates of MIS use vary widely between procedures. MIS was associated with a lower NSQIP-defined postoperative complication rate. Higher-volume MIS centers have a lower complication rate than lower-volume centers.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

References

1. Georgeson KE, Owings E. Advances in minimally invasive surgery in children. Am J Surg. 2000; 180:362–4. [PubMed: 11137688]

2. Albersen M, Cartwright R, Choyke P, Goldenberg SL, Goldman H, Lawrentschuk N, et al. Looking forward, looking back-10 years in urology. Nat Rev Urol. 2014; 11:649–55. [PubMed: 25348169]

3. Firilas AM, Jackson RJ, Smith SD. Minimally invasive surgery: the pediatric surgery experience. J Am Coll Surg. 1998; 186:542–4. [PubMed: 9583694]

4. Traxel EJ, Minevich EA, Noh PH. A review: the application of minimally invasive surgery to pediatric urology: upper urinary tract procedures. Urology. 2010; 76:122–33. [PubMed: 20303151]

5. Malkan AD, Loh AHP, Sandoval JA. Minimally invasive surgery in the management of abdominal tumors in children. J Pediatr Surg. 2014; 49:1171–6. [PubMed: 24952811]

6. Romao RLP, Weber B, Gerstle JT, Grant R, Pippi Salle JL, Bägli DJ, et al. Comparison between laparoscopic and open radical nephrectomy for the treatment of primary renal tumors in children: Single-center experience over a 5-year period. J Pediatr Urol. 2014; 10:488–94. [PubMed: 24331167]

7. Smith RP, Oliver JL, Peters CA. Pediatric robotic extravesical ureteral reimplantation: comparison with open surgery. J Urol. 2011; 185:1876–81. [PubMed: 21421231]

8. Barbosa JA, Barayan G, Gridley CM, Sanchez DC, Passerotti CC, Houck CS, et al. Parent and patient perceptions of robotic vs open urological surgery scars in children. J Urol. 2013; 190:244–50. [PubMed: 23276511]

9. Colodny AH. Laparoscopy in pediatric urology: too much of a good thing? Semin Pediatr Surg. 1996; 5:23–9. [PubMed: 8988294]

10. Passerotti CC, Nguyen HT, Retik AB, Peters CA. Patterns and predictors of laparoscopic complications in pediatric urology: the role of ongoing surgical volume and access techniques. J Urol. 2008; 180:681–5. [PubMed: 18554647]

11. Lawrence K, McWhinnie D, Goodwin A, Gray A, Gordon J, Storie J, et al. An economic evaluation of laparoscopic versus open inguinal hernia repair. J Public Health Med. 1996; 18:41–8. [PubMed: 8785074]

12. Waldhausen JH, Tapper D. Is pediatric laparoscopic splenectomy safe and cost-effective? Arch Surg. 1997; 132:822–4. [PubMed: 9267264]

13. Esposito C, Lima M, Mattioli G, Mastroianni L, Centonze A, Monguzzi GL, et al. Complications of pediatric urological laparoscopy: mistakes and risks. J Urol. 2003; 169:1490–2. discussion 2. [PubMed: 12629398]

14. Elsamra S, Theckumparampil N, Garden B, Alom M, Waingankar N, Leavitt DA, et al. Open, Laparoscopic, and Robotic Ureteroneocystotomy for Benign and Malignant Ureteral Lesions: A Comparison of over 100 Minimally Invasive Cases. J Endourol. 2014; 28(12):1455–9. [PubMed: 25390972]

15. Tobias JD. Anaesthesia for minimally invasive surgery in children. Best Pract Res Clin Anaesthesiol. 2002; 16:115–30. [PubMed: 12491547]

16. Tejwani R, Wang HS, Young BJ, Greene NH, Wolf S, Wiener JS, et al. Increased pediatric sub-specialization is associated with decreased surgical complication rates for inpatient pediatric urology procedures. J Pediatr Urol. 2016; 12:388e1–e7. [PubMed: 27363329]

17. Wang HH, Tejwani R, Zhang H, Wiener JS, Routh JC. Hospital Surgical Volume and Associated Postoperative Complications of Pediatric Urological Surgery in the United States. J Urol. 2015; 194:506–11. [PubMed: 25640646]

18. Ghani KR, Sukumar S, Sammon JD, Rogers CG, Trinh QD, Menon M. Practice patterns and outcomes of open and minimally invasive partial nephrectomy since the introduction of robotic partial nephrectomy: results from the nationwide inpatient sample. J Urol. 2014; 191:907–12. [PubMed: 24184365]

19. Kim SP, Shah ND, Karnes RJ, Weight CJ, Shippee ND, Han LC, et al. Hospitalization costs for radical prostatectomy attributable to robotic surgery. Eur Urol. 2013; 64:11–6. [PubMed: 22959352]

20. Parsons JK, Messer K, Palazzi K, Stroup SP, Chang D. Diffusion of surgical innovations, patient safety, and minimally invasive radical prostatectomy. JAMA Surg. 2014; 149:845–51. [PubMed: 24990549]

21. Parsons JK, Rangarajan SS, Palazzi K, Chang D. A National, Comparative Analysis of Perioperative Outcomes of Open and Minimally Invasive Simple Prostatectomy. J Endourol. 2015; 29:919–24. [PubMed: 25793265]

22. Lorenzo AJ, Romao RL. The Evolving Role of Minimally Invasive Surgery in Pediatric and Adolescent Urologic Oncology. Urology. 2016; 91:180–9. [PubMed: 27107196]

23. McCullough TC, Barret E, Cathelineau X, Rozet F, Galiano M, Vallancien G. Role of robotics for prostate cancer. Curr Opin Urol. 2009; 19:65–8. [PubMed: 19057219]

24. Brooks-Brunn JA. Predictors of postoperative pulmonary complications following abdominal surgery. Chest. 1997; 111:564–71. [PubMed: 9118688]

25. Camarillo DB, Krummel TM, Salisbury JK Jr. Robotic technology in surgery: past, present, and future. Am J Surg. 2004; 188:2S–15S. [PubMed: 15476646]

26. Mabrouk M, Frumovitz M, Greer M, Sharma S, Schmeler KM, Soliman PT, et al. Trends in laparoscopic and robotic surgery among gynecologic oncologists: A survey update. Gynecol Oncol. 2009; 112:501–5. [PubMed: 19138793]

27. See WA, Cooper CS, Fisher RJ. Predictors of laparoscopic complications after formal training in laparoscopic surgery. JAMA. 1993; 270:2689–92. [PubMed: 8133586]

28. Shalhav AL, Dabagia MD, Wagner TT, Koch MO, Lingeman JE. Training postgraduate urologists in laparoscopic surgery: the current challenge. J Urol. 2002; 167:2135–7. [PubMed: 11956463]

29. Shay BF, Thomas R, Monga M. Urology practice patterns after residency training in laparoscopy. J Endourol. 2002; 16:251–6. [PubMed: 12042110]

30. Duchene DA, Moinzadeh A, Gill IS, Clayman RV, Winfield HN. Survey of residency training in laparoscopic and robotic surgery. J Urol. 2006; 176:2158–66. discussion 67. [PubMed: 17070283]

31. Wang DS, Winfield HN. Survey of urological laparoscopic practice patterns in the midwest. J Urol. 2004; 172:2282–6. [PubMed: 15538249]

Appendix 1. Urologic procedure codes for study inclusion

Procedure	ICD-9 procedure code
Ureteral reimplantation	56.74, 59.3
Ureteroureterostomy	56.75
Pyeloplasty	55.86, 55.87
Nephrectomy	55.5
Partial nephrectomy	55.4
Appendicovesicostomy	57.88
Enterocystoplasty	57.87
Bladder outlet repair	59.4, 59.5, 59.6

## Appendix 2. ICD-9 codes used to identify complications

Complications	ICD-9 codes
Surgical site infection (superficial)	998.32
Surgical site infection (deep)	998.31
Peritoneal abscess	567.22
Urinary tract infection	599

Complications	ICD-9 codes
Urinary complications	997.5
Acute renal failure	584.x, 586.x
Respiratory complications	997.3
Pneumonia	481–487, 507
Post-operative respiratory insufficiency	518.5
Acute respiratory distress syndrome	518.82
Systemic sepsis	790.7, 038.x
Pulmonary emboli	415.1, 415.11, 415.19
Mechanical ventilation >96 hours	96.72
Cerebrovascular accident	997.02
Cardiac complications	997.1
Myocardial infarction	410.x
Cardiac arrest	427.5
Bleeding	285.1, 998.11
Deep vein thrombosis	453.4, 453.40, 453.9

Appendix 3. Complications according to surgical technique, entire cohort

Complication	Open (%) (n = 158,246)	MIS (%) (n = 5,593)	Total (%) (n = 163,839)	p value
SSI (deep and superficial)	135 (0.1%)	a	145 (0.1%)	0.49
Peritoneal abscess	75 (0.05%)	a	75 (0.05%)	1.00
Acute renal failure	1753 (1.1%)	30 (0.5%)	1782 (1.1%)	0.01
UTI	8,758 (5.5%)	186 (3.3%)	8,944 (5.5%)	<0.0001
Urinary complications	2,536 (1.6%)	45 (0.8%)	2,581 (1.6%)	<0.01
Respiratory complications	2,090 (1.3%)	20 (0.4%)	2,111 (1.3%)	<0.0001
Pneumonia	788 (0.5%)	a	793 (0.5%)	<0.0001
ARDS	125 (0.1%)	a	130 (0.1%)	0.94
Acute respiratory failure	568 (0.4%)	a	573 (0.3%)	0.01
Postoperative respiratory insufficiency	768 (0.5%)	a	777 (0.5%)	0.01
Systemic sepsis	889 (0.6%)	15 (0.3%)	904 (0.6%)	0.10
MI	a	a	a	1.00
DVT	44 (0.03%)	a	44 (0.03%)	1.00
Cardiac complications	303 (0.2%)	a	317 (0.2%)	0.70
Cardiac arrest	164 (0.1%)	a	164 (0.1%)	0.63
Pulmonary embolism	a	a	a	1.00
Bleeding	1801 (1.1%)	59 (1.1%)	1860 (1.1%)	0.77
Renal complications	814 (0.5%)	128 (2.3%)	942 (0.6%)	<0.0001
Ureteral complications	385 (0.2%)	39 (0.7%)	424 (0.3%)	0.06

[a] Denotes <15 occurrences. Not reported per AHRQ Data Use Agreement.
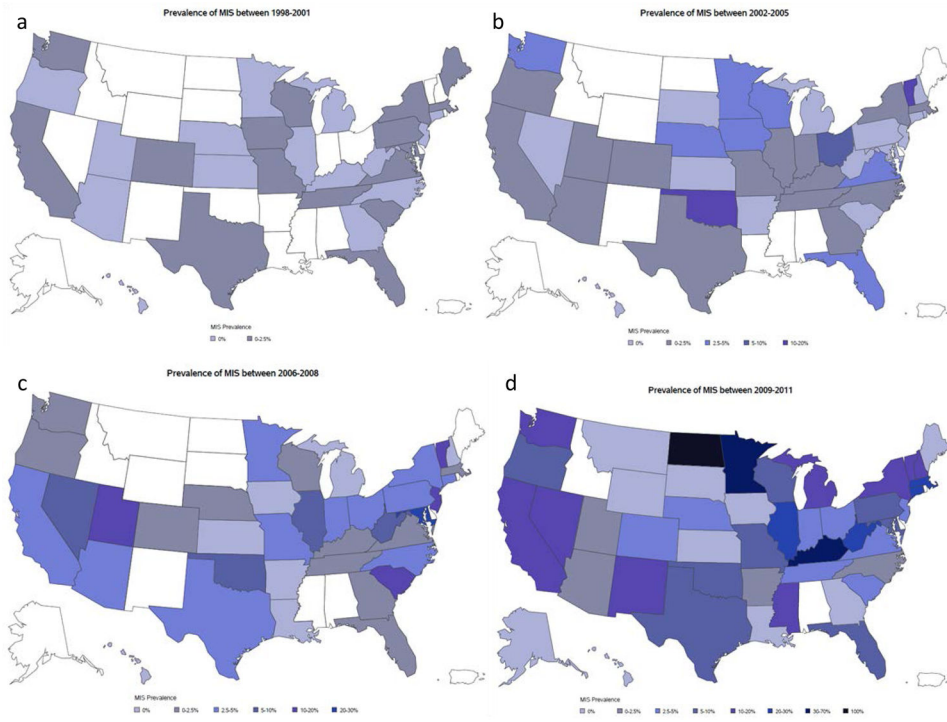
Figure 1.
Heat maps showing national trends in utilization.
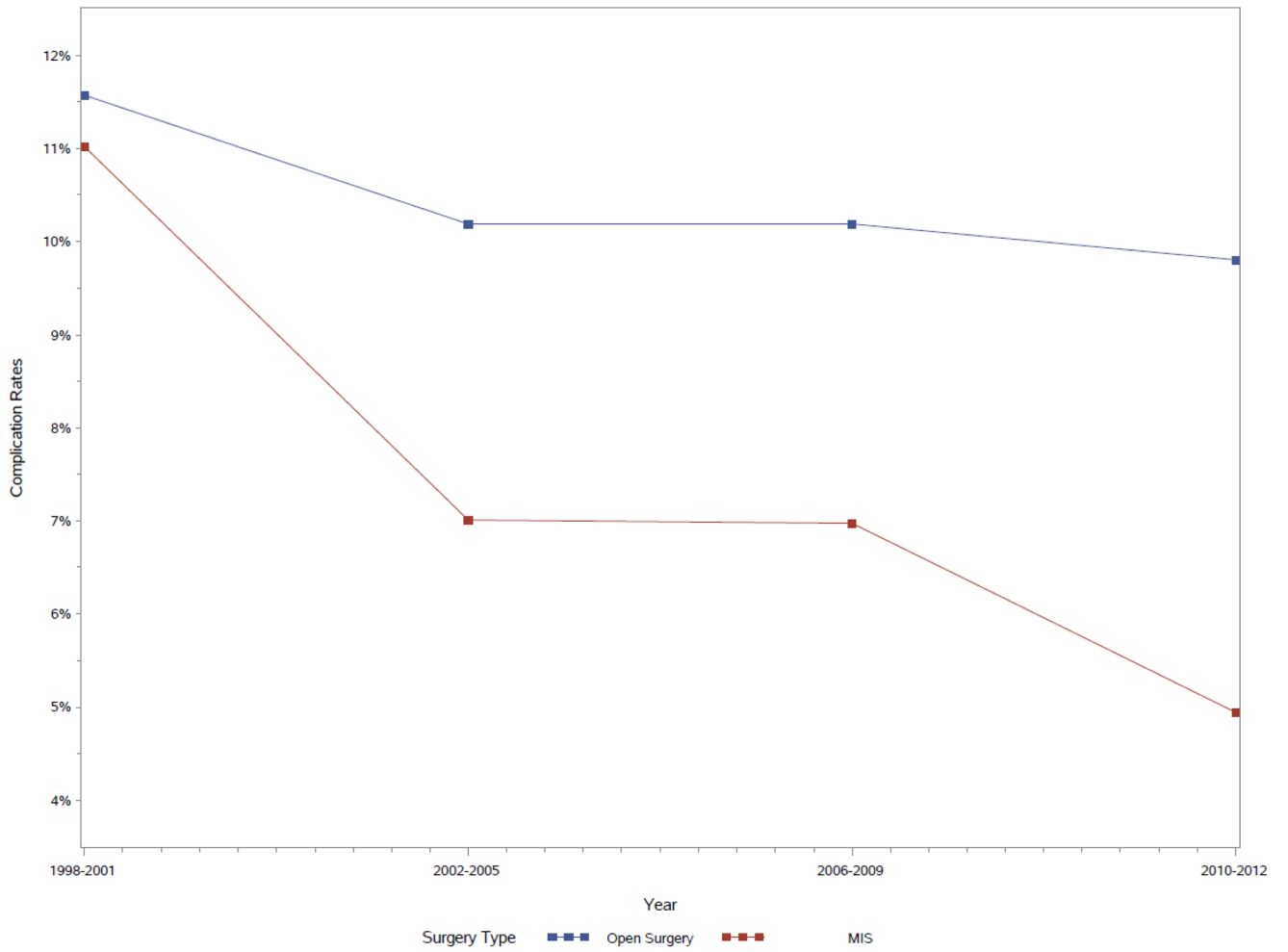
Figure 2.
Complication rates of open surgery and MIS by year.
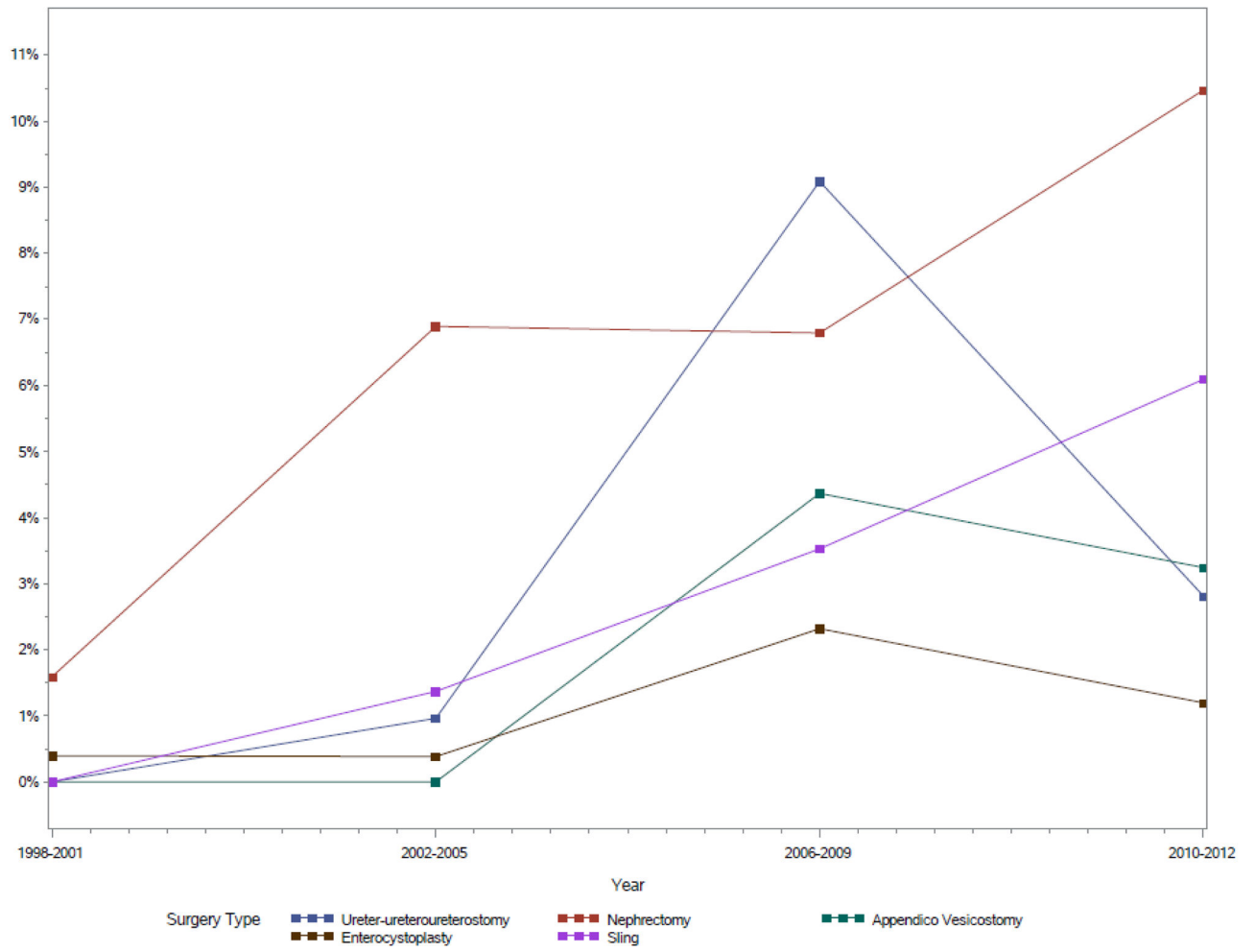
Figure.
Prevalence of MIS by procedure and year (p<0.03 for all).

Cohorts

Outcomes Measured
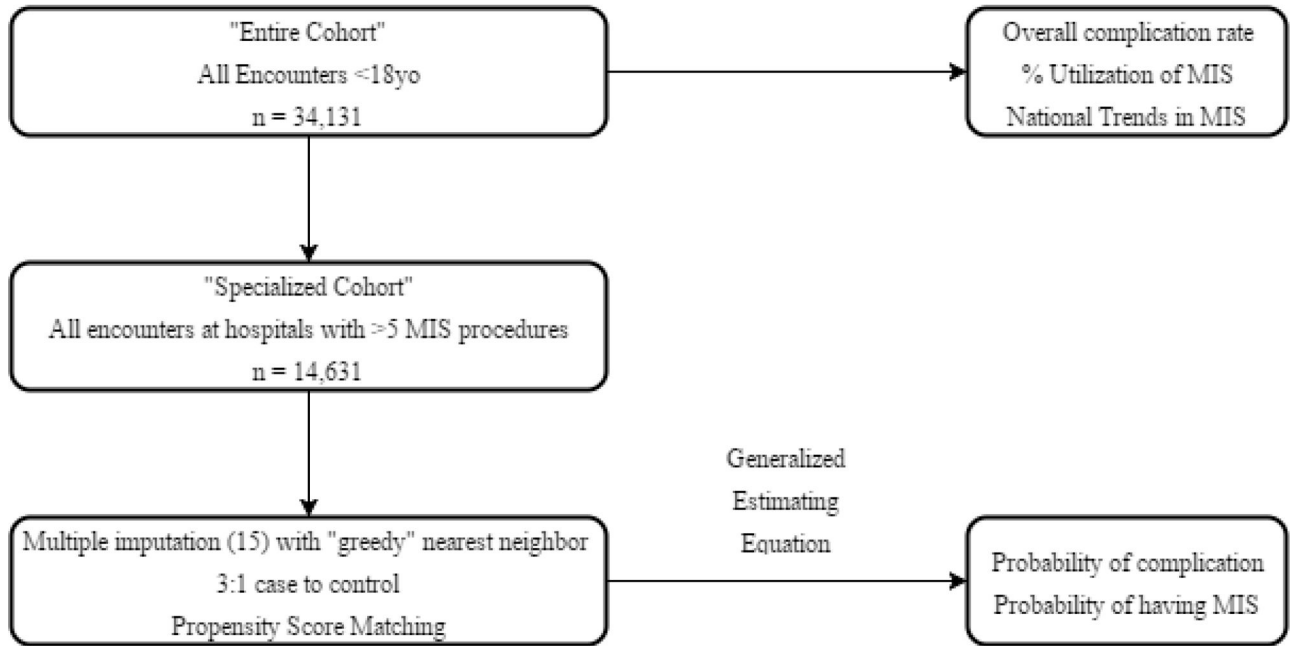
"Entire Cohort"
All Encounters <18yo
n = 34,131

Overall complication rate
% Utilization of MIS
National Trends in MIS

"Specialized Cohort"
All encounters at hospitals with >5 MIS procedures
n = 14,631

Generalized
Estimating
Equation

Multiple imputation (15) with "greedy" nearest neighbor
3:1 case to control
Propensity Score Matching

Probability of complication
Probability of having MIS

Table 1

Comparison of patient characteristics at specialized and unspecialized hospitals

| Characteristic	Total (*n*=163,838)	Specialized (*n*=70,273)	Unspecialized (*n*=93,565)	*p* value
Age in years (SE)	5.2 (0.05)	4.8 (0.05)	5.5 (0.06)	<0.0001[a]
Gender				<0.01[b]
Female	89,693 (55.0%)	39,609 (56.5%)	50,084 (53.9%)	
Race				0.52[b]
White	86,015 (67.3%)	39,980 (67.5%)	46,035 (67.3%)	
Black	8,854 (6.9%)	4,223 (7.1%)	4,631 (6.8%)	
Hispanic	21,993 (17.2%)	9,619 (16.2%)	12,373 (18.1%)	
Other	10,856 (8.5%)	5,451 (9.2%)	5,404 (7.9%)	
Insurance				0.08[b]
Public	51,510 (31.5%)	23,840 (34.0%)	27,671 (29.6%)	
Private	101,289 (62.0%)	41,772 (59.6%)	59,517 (63.7%)	
Others	10,642 (6.5%)	4,468 (6.4%)	6,174 (6.6%)	
ZIP code median income				0.29[b]
Q1	24,936 (15.6%)	11,358 (16.5%)	13,578 (14.9%)	
Q2	37,911 (23.7%)	16,733 (24.4%)	21,178 (23.2%)	
Q3	42,565 (26.6%)	17,751 (25.9%)	24,814 (27.2%)	
Q4	54,458 (34.1%)	22,807 (33.2%)	31,651 (34.7%)	
Charlson Comorbidity Index				0.12[b]
0	139,609 (85.2%)	60,232 (85.7%)	79,377 (84.8%)	
1	5,674 (3.5%)	2,359 (3.4%)	3,315 (3.5%)	
2	14,088 (8.6%)	5,980 (8.5%)	8,108 (8.7%)	
3	4,466 (2.7%)	1,702 (2.4%)	2,764 (3.0%)	
Hospital region				<0.01[b]
Northeast	33,104 (20.2%)	15,147 (21.6%)	17,957 (19.2%)	
Midwest	37,347 (22.8%)	14,848 (21.1%)	22,499 (24.0%)	
South	55,706 (34.0%)	29,848 (42.5%)	25,858 (27.6%)	
West	37,681 (23.0%)	10,430 (14.8%)	27,251 (29.1%)	
Teaching status				<0.01[b]
Rural	3,598 (2.2%)	982 (1.4%)	2,616 (2.8%)	
Urban-nonteaching	15,660 (9.6%)	1,916 (2.7%)	13,744 (14.7%)	
Urban-teaching	144,106 (88.2%)	67,143 (95.9%)	76,963 (82.5%)	
Hospital bed size				0.01[b]
Small	27,132 (16.6%)	7,789 (11.1%)	19,343 (20.7%)	
Medium	40,728 (24.9%)	22,751 (32.5%)	17,978 (19.3%)	
Large	95,503 (58.5%)	39,502 (56.4%)	56,002 (60.0%)	
Probability of at least one complication	17,042 (10.4%)	6,307 (9.0%)	10,734 (11.5%)	<0.01[b]
Surgery performed				

Characteristic	Total (n=163,838)	Specialized (n=70,273)	Unspecialized (n=93,565)	p value
Ureteroneocystosto my	83,641 (51.1%)	37,625 (53.5%)	46,016 (49.2%)	<0.01[b]
Ureteroureterostomy	2,119 (1.3%)	954 (1.4%)	1,164 (1.2%)	0.52[b]
Pyeloplasty	38,229 (23.3%)	15,375 (21.9%)	22,854 (24.4%)	<0.001[b]
Nephrectomy	28,616 (17.5%)	11,491 (16.4%)	17,126 (18.3%)	0.02[b]
Partial/heminephrectomy	6,424 (3.9%)	2,624 (3.7%)	3,800 (4.1%)	0.29[b]
Appendicovesicostomy	3,376 (2.1%)	1,443 (2.1%)	1,933 (2.1%)	0.97[b]
Enterocystoplasty	7,703 (4.7%)	3,615 (5.1%)	4,088 (4.4%)	0.07[b]
Bladder neck sling	988 (0.6%)	505 (0.7%)	483 (0.5%)	0.08[b]

[a]Weighted ANOVA.

[b]Wald chi-square.

Table 2

Demographics for specialized hospital cohort, according to procedure type

Characteristics	Total (*n*=70,273)	MIS (*n*=3,763)	Open (*n*=66,510)	*p* value
Age in years (SE)	4.8 (0.05)	7.8 (0.23)	4.7 (0.05)	<0.0001[a]
Gender				<0.0001[b]
Female	39,609 (56.5%)	1,808 (48.4%)	37,801 (57.0%)	
Race				0.10[b]
White	39,980 (67.5%)	1,861 (57.8%)	38,119 (68.0%)	
Black	4,223 (7.1%)	258 (8.0%)	3,964 (7.1%)	
Hispanic	9,619 (16.2%)	685 (21.3%)	8,934 (15.9%)	
Other	5,451 (9.2%)	413 (12.8%)	5,038 (9.0%)	
Insurance				<0.0001[b]
Public	23,840 (34.0%)	1,513 (40.3%)	22,326 (33.7%)	
Private	41,772 (59.6%)	2,093 (55.8%)	39,679 (59.8%)	
Others	4,468 (6.4%)	147 (3.9%)	4,321 (6.5%)	
Income				0.02[b]
Q1	11,358 (16.5%)	709 (19.2%)	10,649 (16.4%)	
Q2	16,733 (24.4%)	879 (23.8%)	15,854 (24.4%)	
Q3	17,751 (25.9%)	1,058 (28.7%)	16,693 (25.7%)	
Q4	22,807 (33.2%)	1,046 (28.3%)	21,761 (33.5%)	
Charlson Comorbidity Index				<0.001[b]
0	60,232 (85.7%)	3,299 (87.7%)	56,934 (85.6%)	
1	2,359 (3.4%)	198 (5.3%)	2,161 (3.2%)	
2	5,980 (8.5%)	198 (5.3%)	5,782 (8.7%)	
3	1,702 (2.4%)	68 (1.8%)	1,634 (2.5%)	
Hospital region				<0.01[b]
Northeast	15,147 (21.6%)	782 (20.8%)	14,365 (21.6%)	
Midwest	14,848 (21.1%)	857 (22.8%)	13,992 (21.0%)	
South	29,848 (42.5%)	1,055 (28.0%)	28,793 (43.3%)	
West	10,430 (14.8%)	1,069 (28.4%)	9,361 (14.1%)	
Teaching status				<0.0001[b]
Rural	982 (1.4%)	33 (0.9%)	950 (1.4%)	
Urban-nonteaching	1,916 (2.7%)	147 (3.9%)	1,769 (2.7%)	
Urban-teaching	67,143 (95.9%)	3,540 (95.2%)	63,604 (95.9%)	
Hospital bed size				<0.0001[b]
Small	7,789 (11.1%)	166 (4.5%)	7,624 (11.5%)	
Medium	22,751 (32.5%)	1,363 (36.6%)	21,388 (32.2%)	
Large	39,502 (56.4%)	2,191 (58.9%)	37,311 (56.3%)	
Probability of at least one complication	6,307 (9.0%)	265 (7.0%)	6,042 (9.1%)	<0.01[b]
Surgery performed				

Characteristics	Total (n=70,273)	MIS (n=3,763)	Open (n=66,510)	p value
Ureteroneocystostomy	37,625 (53.5%)	687 (18.2%)	36,938 (55.5%)	<0.0001[b]
Ureteroureterostomy	954 (1.4%)	56 (1.5%)	898 (1.4%)	0.81[b]
Pyeloplasty	15,375 (21.9%)	1,599 (42.5%)	13,776 (20.7%)	<0.0001[b]
Nephrectomy	11,491 (16.4%)	1,131 (30.0%)	10,360 (15.6%)	<0.0001[b]
Partial/heminephrectomy	2,624 (3.7%)	268 (7.1%)	2,356 (3.5%)	<0.01[b]
Appendicovesicostomy	1,443 (2.1%)	59 (1.6%)	1,385 (2.1%)	0.25[b]
Enterocystoplasty	3,615 (5.1%)	38 (1.0%)	3,577 (5.4%)	<0.0001[b]
Sling	505 (0.7%)	*	490 (0.7%)	0.03[b]

[a]Weighted ANOVA.

[b]Wald chi-square.

Author Manuscript

Author Manuscript

Author Manuscript

Author Manuscript

Table 3

Multivariable model predicting the odds of postoperative complications

Variables	OR (95% CI)	*p* value
Surgery type		
Open surgery	Reference	
MIS	0.70 (0.51, 0.96)	0.03
Age	1.05 (1.02, 1.08)	<0.01
Gender		
Male	Reference	
Female	1.43 (1.07, 1.90)	0.01
Race		
Other	Reference	
Caucasian	0.66 (0.48, 0.93)	0.02
CCS	1.79 (1.48, 2.15)	<0.01
Bed size		
Large bed	Reference	
Small bed	1.02 (0.57, 1.85)	0.94
Medium bed	0.57 (0.39, 0.84)	<0.01
Hospital location and type		
Urban teaching	Reference	
Rural	0.72 (0.12, 4.42)	0.72
Urban nonteaching	0.30 (0.09, 1.06)	0.06
Hospital region		
West	Reference	
Northeast	0.72 (0.42, 1.23)	0.23
Midwest	0.76 (0.47, 1.22)	0.26
South	0.71 (0.47, 1.09)	0.12
Treatment year		
1998–2001	Reference	
2002–2005	1.17 (0.25, 5.53)	0.84
2006–2009	1.18 (0.25, 5.46)	0.83
2010–2012	1.19 (0.27, 5.29)	0.82

[a] Correlation of hospitals and year of admission used.

Table 4

Complications according to surgical technique, entire cohort.

Complication	Open (%) (n = 163,447)	MIS (%) (n = 5,761)	p Value
Surgical site infection (deep and superficial)	141 (0.1%)	a	0.51
Peritoneal abscess	78 (0%)	a	—
Acute renal failure	1,813 (1.1%)	31 (0.5%)	0.01
Urinary tract infection	9,027 (5.5%)	192 (3.3%)	<0.001
Urinary complications	2,627(1.6%)	47 (0.8%)	0.01
Respiratory complications	2,156(1.3%)	21 (0.4%)	<0.001
Pneumonia	814 (0.5%)	a	0.0001
Acute respiratory distress syndrome	130 (0.1%)	a	0.95
Acute respiratory failure	587 (0.4%)	a	0.01
Postoperative respiratory insufficiency	798 (0.5%)	a	0.02
Systemic sepsis	920 (0.6%)	16 (0.3%)	0.11
Myocardial infarction	a	a	—
Deep vein thrombosis	45 (0%)	a	—
Cardiac complications	315 (0.2%)	15 (0.3%)	0.68
Cardiac arrest	170 (0.1%)	a	—
Pulmonary embolism	a	a	—
Bleeding	1,859 (1.1%)	62(1.1%)	0.8
Renal complications	841 (0.5%)	132 (2.3%)	<0.001
Ureteral complications	399 (0.2%)	40 (0.7%)	0.06

[a] Denotes <15 occurrences. Not reported per AHRQ Data Use Agreement.