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Vesico-ureteral injury during benign hysterectomy: minimally-invasive laparoscopic surgery *versus* laparotomy

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Précis

Minimally-invasive laparoscopic surgery may be associated with four-fold increased risk of ureteral injury compared to laparotomy for women with benign gynecologic disease who undergo total hysterectomy.

ABSTRACT

Study Objective: Previous studies have been inconsistent as to whether benign hysterectomy *via* minimally-invasive laparoscopic surgery increases risk of vesico-ureteral injury when compared to laparotomy. The objectives of our study were to *(i)* examine the rate of vesico-ureteral injury at benign hysterectomy by surgical approach and *(ii)* compare the risk of vesico-ureteral injury specifically between minimally-invasive laparoscopic and abdominal hysterectomy on a populational level.

Design: Retrospective population-based observational study.

Setting: The National Inpatient Sample.

Patients: 501,110 women who underwent hysterectomy for benign gynecological disease from 1/2012-9/2015 were included: total abdominal hysterectomy (TAH, *n*=284,365 [56.7%]), total laparoscopic hysterectomy (TLH, *n*=60,410, [12.1%]), abdominal supracervical hysterectomy (Abd-SCH, *n*=55,655 [11.1%]), laparoscopic-assisted vaginal hysterectomy (LAVH, *n*=45,620 [9.1%]), total vaginal hysterectomy (TVH, *n*=34,865 [7.0%]), and laparoscopic supracervical hysterectomy (LSC-SCH *n*=20,195 [4.0%]).

Interventions: A comprehensive risk assessment for vesico-ureteral injury by hysterectomy mode was performed, adjusting for patient demographics and gynecologic disease types. Propensity score inverse probability of treatment weighing (PS-IPTW) was used to compare *(i)* TLH *versus* TAH and *(ii)* LSC-SCH *versus* Abd-SCH with generalized estimating equations. In a sensitivity analysis, gynecologic disease-specific injury risk and vaginal route-specific injury risk (LAVH *versus* TVH) were assessed.

Measurements and Main Results: Vesico-ureteral injury was reported in 1,045 (0.21%) women overall. LAVH (0.28%) had the highest bladder injury rate, whereas LSC-SCH had the lowest (0.10%) (*P*<0.001). TLH (0.13%) had the highest ureteral injury rate, whereas TAH had the lowest (0.04%) (*P*<0.001). In PS-IPTW models, TLH was associated with increased risk of ureteral injury (odds ratio [OR] 3.95, 95% confidence interval [CI] 2.03-7.67, *P*<0.001) but not bladder injury (OR 1.04, 95%CI 0.57-1.90, *P*=0.897) compared to TAH. Risk of ureteral injury was particularly high when TLH was performed for endometriosis (OR 6.15, 95%CI 1.18-31.9, *P*=0.031) or for uterine myoma (OR 4.15, 95%CI 2.13-8.11, *P*<0.001). In contrast, for supracervical or vaginal hysterectomy, minimally-invasive laparoscopic approaches were not associated with increased risk of vesico-ureteral injury: LSC-SCH *versus* Abd-SCH OR 0.62, 95%CI 0.19-1.98, *P*=0.419; and LAVH *versus* TVH, OR 1.21, 95%CI 0.63-2.33, *P*=0.564.

Conclusion: The risk of vesico-ureteral injury at benign hysterectomy is overall low regardless of hysterotomy modalities but varies widely by the surgical approach. TLH may be associated with an increased risk of ureteral injury when compared to TAH.

INTRODUCTION

Hysterectomy is the most common gynecological surgery in reproductive aged women in the United States; approximately 600,000 are performed each year, the majority of which are

performed for benign indications.[1-3] In fact, one in nine women is expected to undergo a hysterectomy during their lifetime.

Minimally-invasive approaches for hysterectomy, either laparoscopic or robotic, are now regarded as common practice based on decreased length of hospital stay, postoperative pain, and a shorter overall recovery time.[4,5,6] As such, minimally-invasive approaches for hysterectomy are increasing while open procedures are decreasing. In 2002, nearly 70% of hysterectomies were performed *via* laparotomy, which decreased to approximately 50% by 2010.[3]

Lower urinary tract injury, including both bladder and ureteral injury, is a morbid complication of hysterectomy. A recent 2015 Cochrane meta-analysis found that urinary tract injury overall may be increased with laparoscopic as opposed to abdominal hysterectomy, however the authors acknowledged a low quality of evidence, and the analysis was underpowered to evaluate bladder and ureteral injuries individually.[5] Hence, further studies on vesico-ureteral injury at the time of hysterectomy are needed in surgical decision-making process.

The objectives of our study were *(i)* to examine the rate of vesico-ureteral injury at benign hysterectomy stratified by surgical approach and *(ii)* to specifically compare the risk of vesico-ureteral injury between minimally-invasive and abdominal approaches on a populational level.

MATERIALS AND METHODS

Data Source

The National Inpatient Sample (NIS) is a publically available and deidentified population-based database that is distributed as part of the Healthcare Cost and Utilization Project by the Agency for Healthcare Research and Quality.[7] The NIS database includes hospital

discharge data for more than 36 million hospitalizations per year when weighted, and it provides patient characteristics and resource-use information, such as diagnosis and intervention types, length of stay and hospital charges, as well as hospital-specific data, including location, bed size, and teaching status. Over 90% of the United States population is represented in this database during the study period when weighted. The University of Southern California Institutional Review Board deemed the study exempt due to the use of publicly available deidentified data.

Eligibility

This is a retrospective observational study examining the NIS database between January 2012 and September 2015. Women who underwent inpatient hysterectomy for benign gynecological disease were eligible for the study. Women who had a hysterectomy for an oncological indication or an unknown indication were excluded. Women who had no information on hysterectomy mode or who had a radical hysterectomy were also excluded.

Clinical Information

Among cases eligible for analysis, the following information was abstracted from the NIS database: patient demographics, disease factors, hospital information, operative types for hysterectomy, and outcome of the index admission. Patient demographics included age, race/ethnicity, medical comorbidities, obesity, primary expected payer, and median household income. Charlson Comorbidity Index was determined for each patient based on the codes for the specified medical conditions in each category and weighted appropriately to calculate a final score.[8]

Disease factors included benign uterine and adnexal pathology. Gynecological disease information included presence of uterine myomata, endometriosis, abnormal uterine bleeding, pelvic infection, uterine polyp, and/or adnexal pathology. Surgical approach was divided into the following groups: total abdominal hysterectomy (TAH), total laparoscopic hysterectomy (TLH), abdominal supracervical hysterectomy (Abd-SCH), laparoscopic supracervical hysterectomy (LSC-SCH), total vaginal hysterectomy (TVH), and laparoscopy-assisted vaginal hysterectomy (LAVH). Performance of oophorectomy was also recorded.

Hospital data included calendar year of hospitalization, hospital bed size, teaching status, and hospital region. Hospital bed size is defined by hospital geographic region, urban-rural designation, and teaching status.[9] Operative details included mode of hysterectomy (laparotomy, minimally-invasive laparoscopic, and vaginal) and type of hysterectomy (total simple, supracervical, and radical). The outcomes for analysis were perioperative vesico-ureteral injury diagnosed during the index admission.

Study Definition

During the study period of January 2012 and September 2015, the International Classification of Disease 9th revision codes (ICD-9) remained the same (Supplemental Table S1). Obesity was grouped as class I-II obesity (body mass index, 30-39.9 kg/m^2) and class III obesity (body mass index, ≥40 kg/m^2). The ICD-9 codes for bladder injury (8670 and 8671) and ureteral injury (8672 and 8673) were used to designate the presence of a vesico-ureteral injury.[10] In the NIS database, perioperative complications during the index admission for hysterectomy were recorded; there is no differentiation between intraoperative and postoperative events, and there is no information on complications that may have occurred post-discharge.

Study Objectives

The primary objective of the analysis was to examine the rate of vesico-ureteral injury by hysterectomy approach among all hysterectomies performed for benign gynecological disease. The secondary objective was to compare the risk of vesico-ureteral injury based on use of a minimally-invasive laparoscopic approach compared to laparotomy. Specifically, risk of vesico-ureteral injury was assessed in the following two cohorts: *(i)* TLH *versus* TAH, and *(ii)* LSC-SCH *versus* Abd-SCH. The fundamental rationale of this comparison was to assess the risk of vesico-ureteral injury at hysterectomy performed *via* a minimally-invasive laparoscopic approach relative to laparotomy, the historical gold standard.

Statistical Considerations

All the analyses for the study objectives were based upon the weighted values provided by the NIS program. Differences in continuous variables were assessed with the one-way ANOVA test. Differences in ordinal and categorical variables were assessed with the chi-square test.

Propensity score-based inverse probability of treatment weighting (PS-IPTW) was fitted to corroborate the background differences in the two groups comparing TLH *versus* TAH or comparing Abd-SCH *versus* LSC-SCH.[11] First, propensity score (PS) for laparoscopy use was determined by fitting a binary logistic regression model.[12] All the patient demographics, gynecologic pathology, and oophorectomy use were entered in the final model. Then, the IPTW approach assigned patients who received the laparoscopic approach a weight of 1/PS and those who received laparotomy a weight of 1/(1-PS).[11] Stabilized weights were used in the analysis, and the threshold technique was used at the 1st and 99th percentile of the weight

distribution.[11] In the PS-IPTW model, a proportional distribution of the baseline covariates were assessed for effect size, and standardized difference (SD) of 0.10 or less was considered a good-balance between the two groups.

After the PS-IPTW modeling, a generalized estimating equation model was fitted to estimate the magnitude of statistical significance for vesico-ureteral injury, expressed with odds ratio (OR) and 95% confidence interval (CI). All statistical analyses were based upon two-tailed hypotheses, and a *P*-value of less than 0.05 was considered statistical significant. Statistical Package for Social Sciences (IBM SPSS, version 24.0, Armonk, NY) was used for all analysis. The STROBE guidelines were utilized to display the performance of the observational study.[13]

Various sensitivity analyses were undertaken to assess the robustness of the study findings. First, the risk of vesico-ureteral injury was compared between the specific modes of minimally-invasive laparoscopy: conventional laparoscopy *versus* robotic-assisted laparoscopy. This comparison was undertaken in the total hysterectomy cohort. Second, the risk of vesico-ureteral injury was assessed based on the type of benign gynecological disease. The rationale of this analysis was that the surgical complexity would be different across the gynecological disease types. Third, the vesico-ureteral injury risk was assessed between the LAVH and TVH groups. Last, the vesico-ureteral injury risk was compared between the LAVH and TAH groups. This comparison was based on the post-hoc observation of the highest vesico-ureteral injury rate in the LAVH group.

RESULTS

There were 509,395 women who had hysterectomy for benign gynecological disease. Of those, 8,285 women with unknown hysterectomy type or radical hysterectomy were excluded, and the remaining 501,110 women represented the study population. The most common hysterectomy type was TAH (*n*=284,365 [56.7%]) followed by TLH (*n*=60,410, [12.1%]), Abd-SCH (*n*=55,655 [11.1%]), LAVH (*n*=45,620 [9.1%]), TVH (*n*=34,865 [7.0%]), and LSC-SCH (*n*=20,195 [4.0%]).

Patient demographics are shown in Table 1. All of the examined covariates differed significantly across the hysterectomy modes (all, *P*<0.001). Specifically, women who underwent TVH were older compared to other hysterectomy types, and those who had Abd-SCH were more likely to be black, class III obese, and have Medicaid. Women who underwent TLH were more likely to have a higher comorbidity indices and surgery at a large / urban teaching hospital. Those who underwent LSC-SCH were more likely to have a higher median household income. Women in the TAH group were more likely to have surgery in the Southern region of the United States and to have received concurrent oophorectomy.

Characteristics of gynecological disease are shown in Table 1. Women in the LAVH group were more likely to have endometriosis or abnormal uterine bleeding, whereas those in the Abd-SCH group were more likely to have uterine leiomyomas or pelvic infection. Women in the TAH group were more likely to have adnexal pathology, and those in the TVH group were more likely to have a uterine polyp.

Vesico-ureteral injury rates overall (either ureteral or bladder injury) were assessed by hysterectomy type (Figure 1). In the whole cohort, vesico-ureteral injury was reported in 1,045 (0.21%) women. Vesico-ureteral injury (either ureteral or bladder injury) rates differed

statistically significantly across the hysterectomy types (*P*-trend<0.001); LAVH (0.28%; 130 out of 45,620) had the highest bladder injury rate followed by TVH (0.24%; 85 out of 34,865) and TLH (0.24%; 145 out of 60,410), TAH (0.20%; 580 out of 284,365), Abd-SCH (0.15%; 85 out of 55,655), and finally LSC-SCH (0.10%; 20 out of 20,195).

When vesico-ureteral injury was further stratified by location of injury, LAVH (0.23%) had the highest rate of bladder injury followed by TVH (0.20%), TAH (0.16%), Abd-SCH (0.12%), TLH (0.12%), and LSC-SCH (0.05%) (*P*-trend<0.001; Figure 1). For ureteral injury rate, TLH (0.13%) had the highest rate, followed by TVH (0.06%), LAVH (0.06%), LSC-SCH (0.05%), abd-SCH (0.04%), and TAH (0.04%) (*P*-trend<0.001; Figure 1).

Patient demographics and gynecologic disease characteristics between the TLH and TAH groups were balanced in the PS-IPTW model (Supplemental Table S2). All seventeen covariates were well-balanced between the two groups (all, SD≤0.10), and 14,724 TLH cases and 11,410 TAH cases were assessed for vesico-ureteral injury (Figure 2). TLH was associated with increased risk of vesico-ureteral injury overall compared to TAH (0.31% *versus* 0.20%, OR 1.57, 95%CI 1.01-2.42, *P*=0.045). When injury sites were further stratified, TLH was significantly associated with increased risk of ureteral injury (0.16% *versus* 0.04%, OR 3.95, 95%CI 2.03-7.67, *P*<0.001) but not bladder injury (0.17% *versus* 0.17%, OR 1.04, 95%CI 0.57-1.90, *P*=0.897) compared to TAH.

When the risk of ureteral injury was further stratified based on the gynecologic disease type (Table 2), presence of endometriosis had the highest impact on ureteral injury for TLH compared to TAH (OR 6.15, 95%CI 1.18-31.9, *P*=0.031), followed by presence of uterine myoma (OR 4.15, 95%CI 2.13-8.11, *P*<0.001). The remaining three gynecological diseases

were not associated with increased risk of ureteral injury (All, *P*>0.05). Among TLH cases, robotic-assisted and conventional approaches were compared (Supplemental Table S3), and there were no differences in vesico-ureteral injury (OR 0.59, 95%CI 0.28-1.24. *P*=0.162), including ureteral injury (OR 0.715, 95%CI 0.26-1.94, *P*=0.510), between the two groups.

For the second comparison, vesico-ureteral injury was compared between the Abd-SCH and LSC-SCH groups. Differences in patient demographics and gynecologic disease types between the two groups were balanced in the PS-IPTW model (Supplemental Table S4). All of the tested covariates were well-balanced between the two groups (all, SD≤0.10), and 5,211 LSC-SCH cases and 11,593 Abd-SCH cases were assessed for vesico-ureteral injury (Figure 3). LSC-SCH was not associated with increased risk of vesico-ureteral injury when compared to Abd-SCH (0.08% *versus* 0.14%, OR 0.62, 95%CI 0.19-1.98, *P*=0.419). When injury types were specified, LSC-SCH was not associated with increased risk of bladder injury (0.06% *versus* 0.10%, OR 0.50, 95%CI 0.10-2.36, *P*=0.377) and ureteral injury (0.04% *versus* 0.04%, OR 0.82, 95%CI 0.15-4.48, *P*=0.822).

Similarly, LAVH was not associated with an increased risk of vesico-ureteral injury (Supplemental Table S5 and Figure 4): 0.29% *versus* 0.24%, OR 1.21, 95%CI 0.63-2.33, *P*=0.564. LAVH was not associated with increased risk of bladder injury (0.24% *versus* 0.19%, OR 1.27, 95%CI 0.62-2.59, *P*=0.510) or ureteral injury (0.05% *versus* 0.06%, OR 0.80, 95%CI 0.19-3.40, *P*=0.761) compared to TVH. Last, albeit statistically non-significant, the LAVH group had slightly higher rate of vesico-ureteral injury rate compared to the TAH group (0.31% *versus* 0.20%, OR 1.55, 95%CI 0.97-2.45, *P*=0.065; Supplemental Table S6).

DISCUSSION

Our findings were consistent with reported rates of urinary tract injury in prior publications.[14-17] The aforementioned meta-analysis reported a urinary tract injury rate of 0.24% and 0.1% for laparoscopic and abdominal hysterectomies, respectively among 2,140 women (OR 2.44).[5] Another study of 876 women, encompassing 584 laparoscopic and 292 abdominal hysterectomies, reported an increase in ureteral injury rates in laparoscopic cases compared to abdominal (0.9% *versus* 0%).[18] In an English study from 2015 examining 310,105 hysterectomies for benign conditions, the rate of ureteric injury was 0.6% among laparoscopic hysterectomies compared to 0.3% for open approach.[14]

A systematic review from 2014 reported an overall urinary tract injury rate of 0.73% with a specific ureteral injury rate of 0.02-0.4% and concluded that laparoscopic hysterectomy did not pose a higher risk compared to abdominal approach, however the studies included had smaller sample sizes and likely were underpowered to detect a statistical difference.[19] Finally, a Finnish study that examined 5,279 hysterectomies reported a 0.3% risk of ureteral injury with laparoscopic hysterectomy, however, the rates of vesico-ureteral injury were similar to that of abdominal hysterectomy.[20] Importantly, their study did not further stratify by route of hysterectomy and likely included supracervical approaches.

In our study, risk of ureteral injury was higher in TLH over TAH, however this was not observed when examining LSC-SCH *versus* Abd-SCH as well as LAVH *versus* TVH. Ureteral injury commonly occurs at the level of the pelvic brim, cardinal ligaments and before its insertion into the bladder; thus, we postulate that ureteral injury may occur during dissection of the cardinal ligaments or while closing the vaginal cuff during TLH.[16,21] While supracervical hysterectomy also involves the above steps with the exception of cuff closure, dissection is

required only to the level of the mid cervix and may minimize iatrogenic injury to the bladder and/or ureter.

There are several strengths in this study. First, given vesico-ureteral injuries are uncommon among all types of hysterectomy, use of a population-based national database allowed for a large enough sample size to detect significant differences in ureteral injury rates. Additionally, background corroboration with PS-IPTW enhanced our statistical rigor given that patients may be at different risk of ureteral injury based on demographic and clinical variables. This method was also particularly useful as the rate of vesico-ureteral injury regardless of hysterectomy type overall was low and other background adjustments such as propensity score matching would have limited our study size and lowered statistical power. Moreover, hysterectomy mode-specific analysis (total hysterectomy, supracervical hysterectomy, and vaginal) clearly highlighted the difference in vesico-ureteral injury risk attributed to minimally-invasive laparoscopic approaches.

Our study has a number of limitations. Firstly, while the association between ureteral injury and TLH was robust when compared to TAH, there may be additional variables that contribute to risk of ureteral injury that were not captured in this study due to limitations with a populational database such as parity, uterine size, surgical history (specifically of Cesarean delivery), surgical site adhesions, extent of endometriosis, surgeon's experience and skills, and surgical difficulty. Secondly, due to the nature of the NIS that was designed for administrative purposes rather than solely research purposes, coding misclassifications or omissions may have biased results. Unless the archived medical records are retrieved for review, the accuracy of data entry as well as the specific preoperative indication for hysterectomy is unknown. Risk of vesico-ureteral injury likely differs depending on the

hysterectomy indication. This study team acknowledged this as a major drawback in this study

Additionally, this database only includes discharge data from a single admission, thus it is unable to account for occult injuries that were not identified immediately intra-operatively or during that admission. Given prior studies have cited that up to 87% of ureteral injuries may be delayed, our study may underestimate the true number of urinary tract injuries.[22] However, this underestimation likely applies to all hysterectomy groups (non-differential outcome misclassification).

Finally, the NIS database captures inpatient admissions only, and lack of information for same-day hysterectomies results in selection bias given the increasing number of same-day minimally-invasive hysterectomies in the United States. In our dataset, only one third of cases had minimally-invasive hysterectomy between 2012-2015; this clearly reflects omission of a substantial number of same-day minimally-invasive hysterectomies, as nearly half of hysterectomies were performed *via* a minimally-invasive approach in 2010.[3] If same-day hysterectomy is presumed to *(i)* be more commonly performed *via* a laparoscopic approach and *(ii)* have lower complication rates compared to inpatient hysterectomy, it is speculated that true incidence of vesico-ureteral injury at the time of minimally-invasive laparoscopic hysterectomy would likely be lower than what we have reported in this study.

Given the findings of our study, consideration should be given to specifically discussing the increased risk of ureteral injury during the informed consent process for minimally-invasive hysterectomy. Additionally, consideration of utilization of supracervical hysterectomy in appropriate candidates with normal cervical cancer screening is reasonable given the

elevated risk of ureteral injury with total compared to supracervical hysterectomy. In case of endometriosis particularly severe type identified during laparoscopy, early decision for laparotomy conversion would be a key to avoid possible risks of ureteral injury.

CONCLUSION

While TLH is associated with a nearly four-fold increased risk of ureteral injury but no difference in bladder injury when compared to TAH, the incidence of vesico-ureteral injury overall is low for all routes of hysterectomy. Preoperatively, individualized counseling of all patients considering TLH should be performed, balancing the benefits of laparoscopy such as shorter recovery time and hospital stay with the heightened risk of ureteral injury, and taking into consideration any other patient-specific risk factors for ureteral injury. This can be particularly applicable for certain gynecologic diseases such as endometriosis as this condition exhibited the highest impact on ureteral injury with TLH.

REFERENCES

1. Whiteman MK, Hillis SD, Jamieson DJ, et al. Inpatient hysterectomy surveillance in the United States, 2000-2004. *Am J Obstet Gynecol.* 2008;198(1):34.e31-37.
2. Wu JM, Wechter ME, Geller EJ, Nguyen TV, Visco AG. Hysterectomy rates in the United States, 2003. *Obstet Gynecol.* 2007;110(5):1091-1095.
3. Wright JD, Herzog TJ, Tsui J, et al. Nationwide Trends in the Performance of Inpatient Hysterectomy in the United States. *Obstet Gynecol.* 2013;122(2 0 1):233-241.
4. Farquhar CM, Steiner CA. Hysterectomy rates in the United States 1990-1997. *Obstet Gynecol.* 2002;99(2):229-234.
5. Aarts JW, Nieboer TE, Johnson N, et al. Surgical approach to hysterectomy for benign gynaecological disease. *Cochrane Database Syst Rev.* 2015(8):Cd003677.
6. Meikle SF, Nugent EW, Orleans M. Complications and recovery from laparoscopy-assisted vaginal hysterectomy compared with abdominal and vaginal hysterectomy. *Obstet Gynecol.* 1997;89(2):304-311.
7. HCUP National Inpatient Sample (NIS). Healthcare Cost and Utilization Project (HCUP). 2001-2015. Agency for Healthcare Research and Quality, Rockville, MD. www.hcup-us.ahrq.gov/nisoverview.jsp. Accessed June 23, 2019. In.
8. Charlson ME, Pompei P, Ales KL, MacKenzie CR. A new method of classifying prognostic comorbidity in longitudinal studies: development and validation. *J Chronic Dis.* 1987;40(5):373-383.

9. HCUP NIS Description of Data Elements. Healthcare Cost and Utilization Project (HCUP). Agency for Healthcare Research and Quality, Rockville, MD. www.hcup-us.ahrq.gov/db/vars/hosp_bedsize/nisnote.jsp. Accessed June 23, 2019.
10. World Health Organization, International classification of diseases: [9th] ninth revision, basic tabulation list with alphabetic index, World Health Organization, Geneva http://www.who.int/iris/handle/10665/39473 Accessed June 23, 2019.
11. Austin PC, Stuart EA. Moving towards best practice when using inverse probability of treatment weighting (IPTW) using the propensity score to estimate causal treatment effects in observational studies. *Stat Med.* 2015;34(28):3661-3679.
12. Hadley J, Yabroff KR, Barrett MJ, Penson DF, Saigal CS, Potosky AL. Comparative effectiveness of prostate cancer treatments: evaluating statistical adjustments for confounding in observational data. *J Natl Cancer Inst.* 2010;102(23):1780-1793.
13. von Elm E, Altman DG, Egger M, et al. The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) Statement: guidelines for reporting observational studies. *Int J Surg.* 2014;12(12):1495-1499.
14. Kiran A, Hilton P, Cromwell DA. The risk of ureteric injury associated with hysterectomy: a 10-year retrospective cohort study. *BJOG.* 2016;123(7):1184-1191.
15. Teeluckdharry B, Gilmour D, Flowerdew G. Urinary Tract Injury at Benign Gynecologic Surgery and the Role of Cystoscopy: A Systematic Review and Meta-analysis. *Obstet Gynecol.* 2015;126(6):1161-1169.
16. Ibeanu OA, Chesson RR, Echols KT, Nieves M, Busangu F, Nolan TE. Urinary tract injury during hysterectomy based on universal cystoscopy. *Obstet Gynecol.* 2009;113(1):6-10.
17. Vakili B, Chesson RR, Kyle BL, et al. The incidence of urinary tract injury during hysterectomy: a prospective analysis based on universal cystoscopy. *Am J Obstet Gynecol.* 2005;192(5):1599-1604.
18. Garry R, Fountain J, Mason S, et al. The eVALuate study: two parallel randomised trials, one comparing laparoscopic with abdominal hysterectomy, the other comparing laparoscopic with vaginal hysterectomy. *Bmj.* 2004;328(7432):129.
19. Adelman MR, Bardsley TR, Sharp HT. Urinary tract injuries in laparoscopic hysterectomy: a systematic review. *J Minim Invasive Gynecol.* 2014;21(4):558-566.
20. Brummer TH, Jalkanen J, Fraser J, et al. FINHYST, a prospective study of 5279 hysterectomies: complications and their risk factors. *Hum Reprod.* 2011;26(7):1741-1751.
21. Utrie JW. Bladder and ureteral injury: prevention and management. *Clin Obstet Gynecol.* 1998;41(3):755-763.
22. Blackwell RH, Kirshenbaum EJ, Shah AS, Kuo PC, Gupta GN, Turk TMT. Complications of Recognized and Unrecognized Iatrogenic Ureteral Injury at Time of Hysterectomy: A Population Based Analysis. *J Urol.* 2018;199(6):1540-1545.

Figure Legends

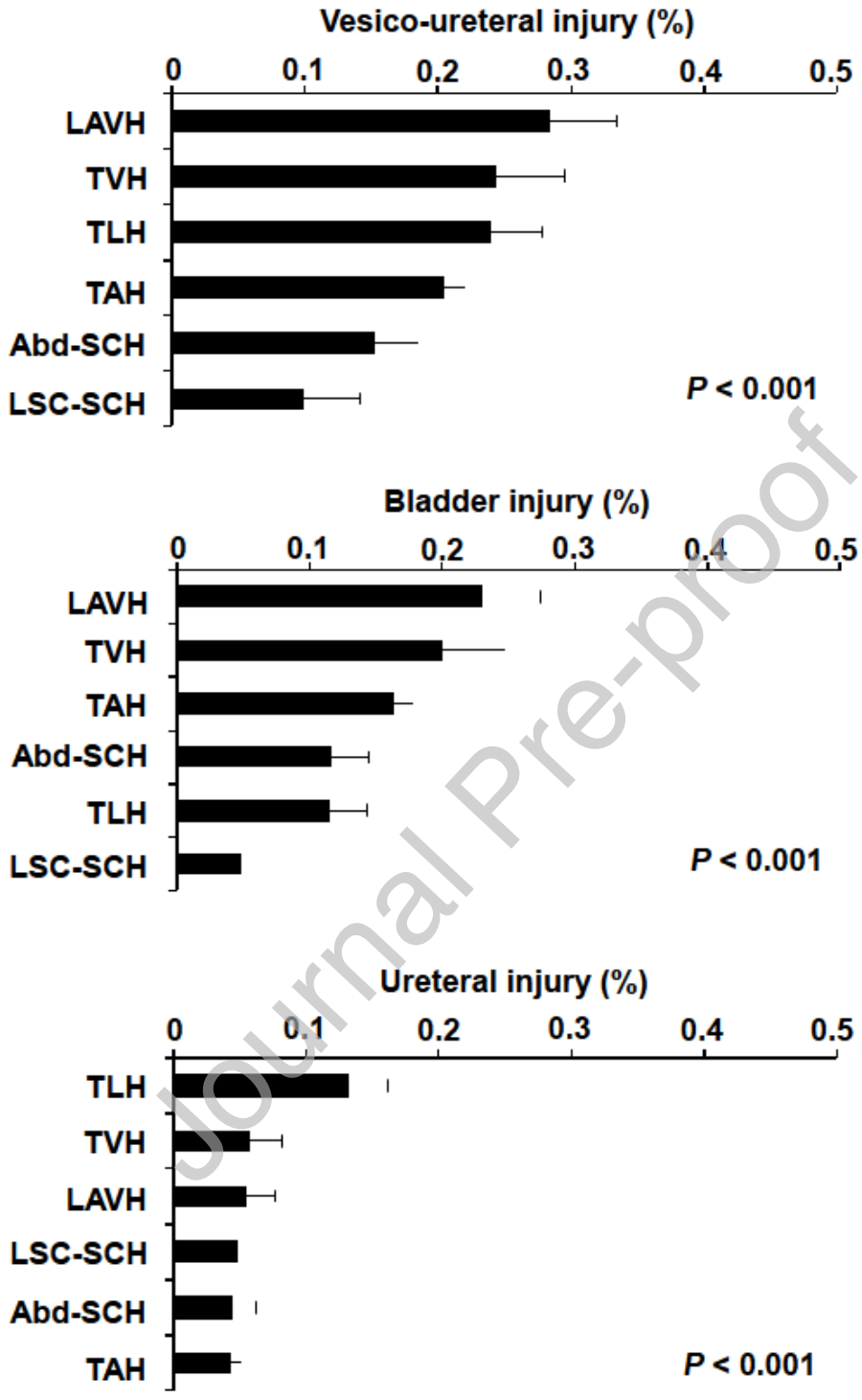

Figure 1. Vesico-ureteral injury per hysterectomy type.

Chi-square test for *P*-value. Percentage with 95% confidence interval is shown. X-axis is truncated to 0-0.5%. Abbreviations: LAVH, laparoscopy-assisted vaginal hysterectomy; TVH, total vaginal hysterectomy; TLH, total laparoscopic hysterectomy; TAH, total abdominal hysterectomy; Abd-SCH, abdominal supra-cervical hysterectomy; and LSC-SCH, laparoscopic supra-cervical hysterectomy.

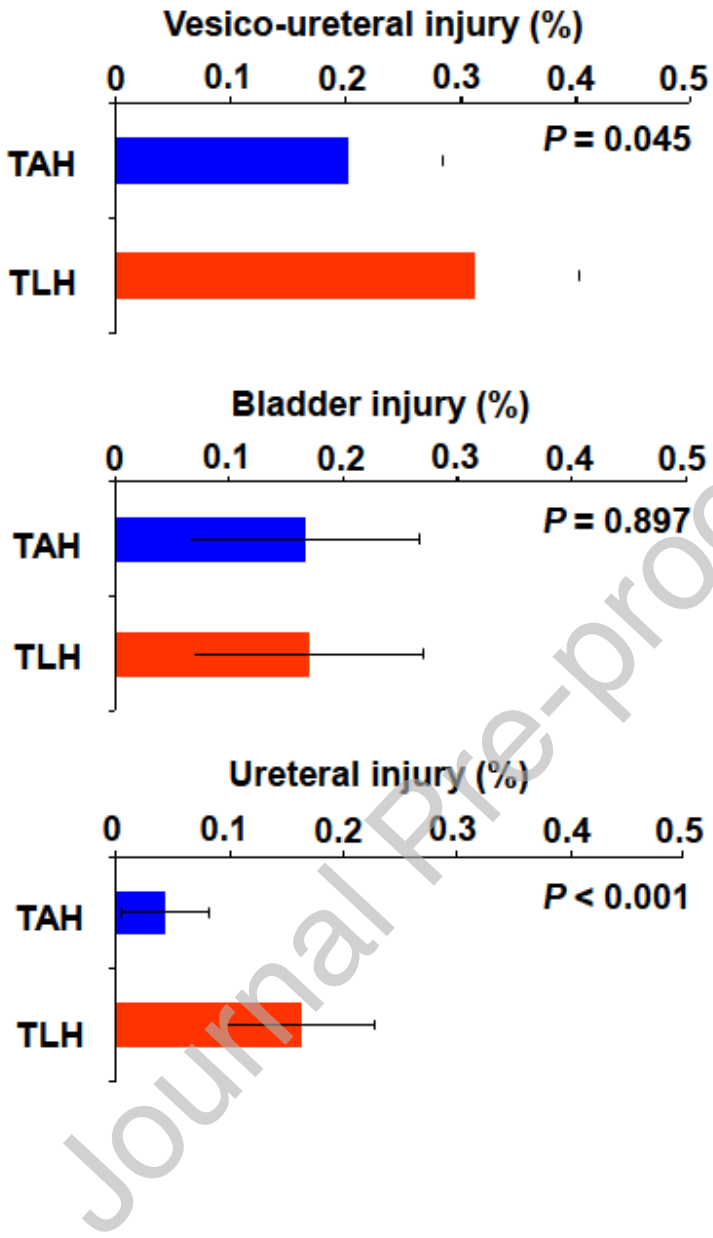

Figure 2. Vesico-ureteral injury in PS-IPTW model (TLH *versus* TAH).

A binary logistic regression test for *P*-value. Percentage with 95% confidence interval is shown. X-axis is truncated to 0-0.5%. Abbreviations: TAH, total abdominal hysterectomy;

TLH, total laparoscopic hysterectomy; and PS-IPTW, propensity score inverse probability of treatment weighting.

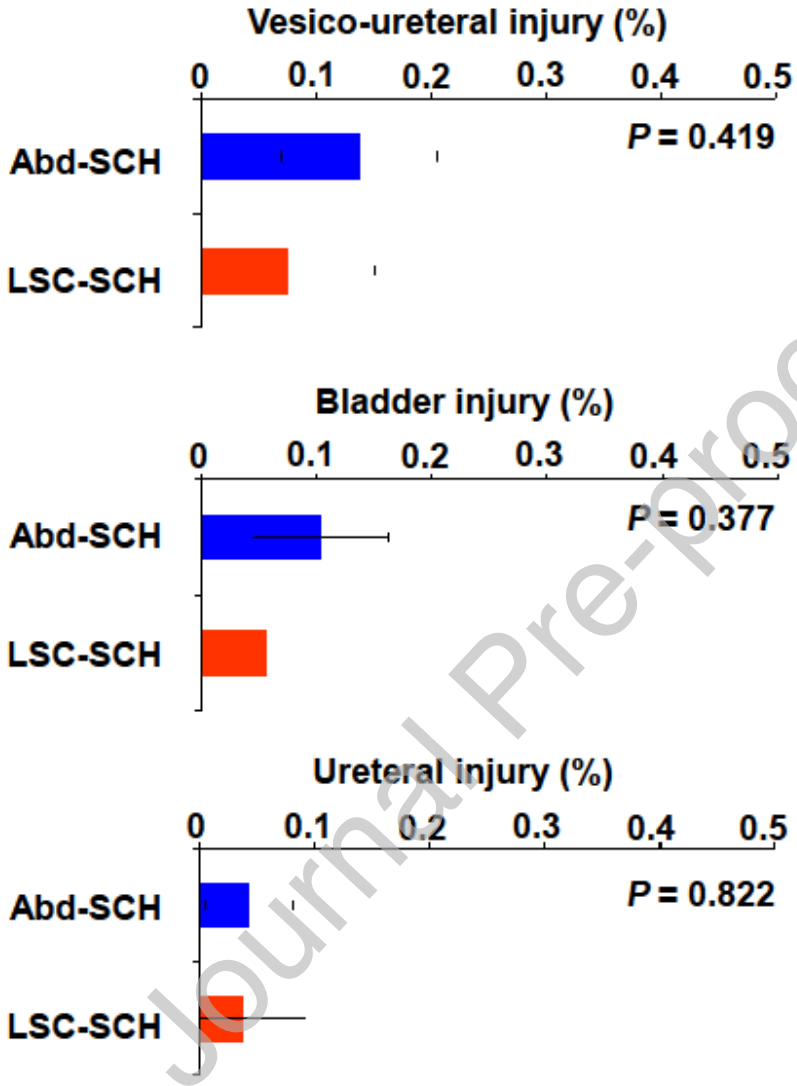

Figure 3. Vesico-ureteral injury in PS-IPTW model (TLH *versus* TAH).

A binary logistic regression test for *P*-value. Percentage with 95% confidence interval is shown. X-axis is truncated to 0-0.5%. Abbreviations: Abd-SCH, abdominal supra-cervical hysterectomy; LSC-SCH, laparoscopic supra-cervical hysterectomy; and PS-IPTW, propensity score inverse probability of treatment weighting.

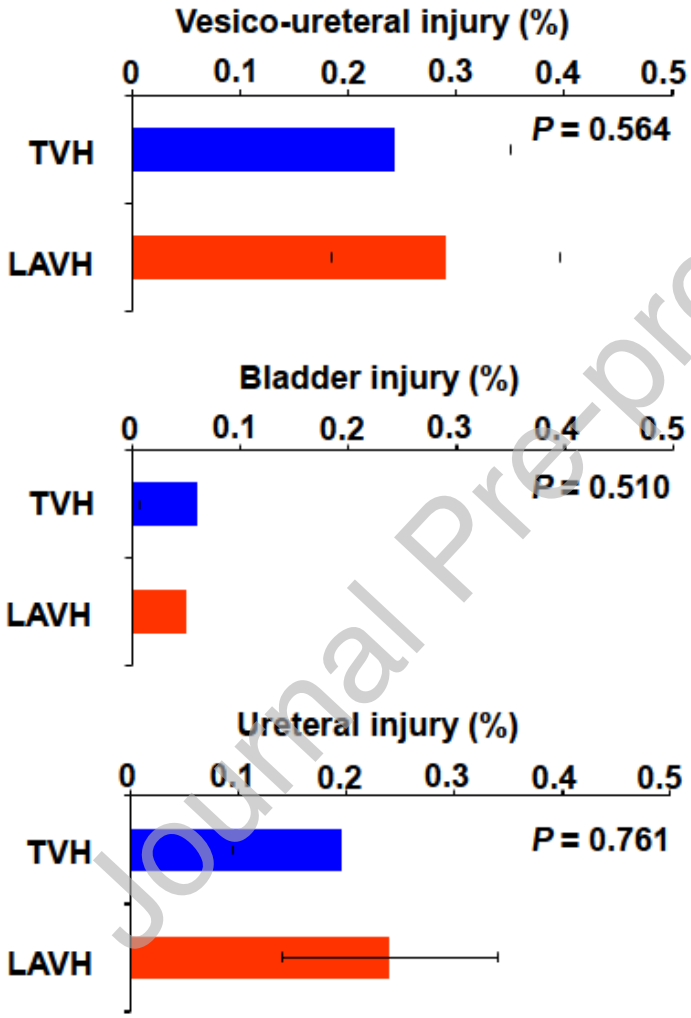

Figure 4. Vesico-ureteral injury in PS-IPTW model (LAVH *versus* TVH).

A binary logistic regression test for *P*-value. Percentage with 95% confidence interval is shown. X-axis is truncated to 0-0.5%. Abbreviations: TVH, total vaginal hysterectomy; LAVH, laparoscopy-assisted vaginal hysterectomy; and PS-IPTW, propensity score inverse probability of treatment weighting.

Table 1. Patient demographics

Characteristics	TAH	TLH	Abd-SCH	LAVH	TVH	LSC-SCH	*P*-value
Number	*n*=284,365	*n*=60,410	*n*=55,655	*n*=45,620	*n*=34,865	*n*=20,195	
Age (years)	46.8 (±8.6)	47.8 (±9.6)	45.9 (±7.2)	46.5 (±9.2)	48.2 (±10.7)	46.4 (±7.8)	<0.001
Year							<0.001
2012	80,175 (28.2%)	21,060 (34.9%)	15,940 (28.6%)	18,000 (39.5%)	13,905 (39.9%)	9,260 (45.9%)	
2013	71,150 (25.0%)	17,290 (28.6%)	14,460 (26.0%)	12,640 (27.7%)	9,745 (28.0%)	6,725 (33.3%)	
2014	76,350 (26.8%)	13,035 (21.6%)	14,460 (26.0%)	9,455 (20.7%)	6,885 (19.7%)	2,975 (14.7%)	
2015	56,690 (19.9%)	9,025 (14.9%)	10,795 (19.4%)	5,525 (12.1%)	4,330 (12.4%)	1,235 (6.1%)	
Race/ethnicity							<0.001
White	127,940 (45.0%)	31,405 (52.0%)	20,670 (37.1%)	26,175 (57.4%)	18,040 (51.7%)	10,180 (50.4%)	
Black	83,900 (29.5%)	11,470 (19.0%)	20,565 (37.0%)	7,105 (15.6%)	4,670 (13.4%)	4,150 (20.5%)	
Hispanic	38,980 (13.7%)	8,560 (14.2%)	7,480 (13.4%)	6,930 (15.2%)	6,665 (19.1%)	2,735 (13.5%)	
Asian or Pacific Islander	10,120 (3.6%)	2,285 (3.8%)	2,620 (4.7%)	1,105 (2.4%)	945 (2.7%)	895 (4.4%)	
Native American	1,185 (0.4%)	310 (0.5%)	215 (0.4%)	245 (0.5%)	120 (0.3%)	95 (0.5%)	
Other	9,730 (3.4%)	2,685 (4.4%)	2,635 (4.7%)	1,460 (3.2%)	1,305 (3.7%)	1,040 (5.1%)	
Missing	12,510 (4.4%)	3,695 (6.1%)	1,470 (2.6%)	2,600 (5.7%)	3,120 (8.9%)	1,100 (5.4%)	
Obesity							<0.001
No	239,875 (84.4%)	49,990 (82.8%)	45,845 (82.4%)	39,720 (87.1%)	30,860 (88.5%)	17,740 (87.8%)	
Obesity	28,570 (10.0%)	6,420 (10.6%)	6,010 (10.8%)	4,020 (8.8%)	2,880 (8.3%)	1,770 (8.8%)	
Morbid obesity	15,920 (5.6%)	4,000 (6.6%)	3,800 (6.8%)	1,880 (4.1%)	1,125 (3.2%)	685 (3.4%)	
Charlson Index							<0.001
0	214,490 (75.4%)	43,470 (72.0%)	44,110 (79.3%)	35,805 (78.5%)	27,685 (79.4%)	16,310 (80.8%)	
1	42,660 (15.0%)	9,375 (15.5%)	8,430 (15.1%)	6,720 (14.7%)	5,455 (15.6%)	3,055 (15.1%)	
2	14,895 (5.2%)	4,350 (7.2%)	1,900 (3.4%)	2,030 (4.4%)	1,230 (3.5%)	600 (3.0%)	
≥3	12,320 (4.3%)	3,215 (5.3%)	1,215 (2.2%)	1,065 (2.3%)	495 (1.4%)	230 (1.1%)	
Median household income							<0.001
$1-$38,999	88,670 (31.2%)	13,395 (22.2%)	14,745 (26.5%)	10,920 (23.9%)	9,085 (26.1%)	3,440 (17.0%)	
$39,000-$47,999	69,775 (24.5%)	13,055 (21.6%)	11,510 (20.7%)	11,600 (25.4%)	8,995 (25.8%)	4,095 (20.3%)	
$48,000-$62,999	65,685 (23.1%)	16,395 (27.1%)	12,625 (22.7%)	11,460 (25.1%)	8,725 (25.0%)	5,120 (25.4%)	
≥$63,000	54,580 (19.2%)	16,545 (27.4%)	15,655 (28.1%)	10,520 (23.1%)	7,380 (21.2%)	7,215 (35.7%)	
Missing	5,655 (2.0%)	1,020 (1.7%)	1,120 (2.0%)	1,120 (2.5%)	680 (2.0%)	325 (1.6%)	
Primary expected payer							<0.001
Medicare	22,440 (7.9%)	6,405 (10.6%)	2,875 (5.2%)	3,560 (7.8%)	3,985 (11.4%)	1,175 (5.8%)	
Medicaid	45,330 (15.9%)	7,425 (12.3%)	9,605 (17.3%)	6,305 (13.8%)	5,500 (15.8%)	2,235 (11.1%)	
Private including HMO	186,290 (65.5%)	42,695 (70.7%)	38,325 (68.9%)	31,885 (69.9%)	22,010 (63.1%)	15,480 (76.7%)	
Self-pay	14,985 (5.3%)	1,470 (2.4%)	1,990 (3.6%)	1,365 (3.0%)	1,330 (3.8%)	495 (2.5%)	
No charge	2,990 (1.1%)	305 (0.5%)	680 (1.2%)	380 (0.8%)	280 (0.8%)	95 (0.5%)	
Other	11,740 (4.1%)	2,055 (3.4%)	2,095 (3.8%)	1,990 (4.4%)	1,675 (4.8%)	685 (3.4%)	
Missing	590 (0.2%)	55 (0.1%)	85 (0.2%)	135 (0.3%)	85 (0.3%)	30 (0.1%)	
Hospital bed size							<0.001

Small	43,475 (15.3%)	7,470 (12.4%)	8,685 (15.6%)	7,420 (16.3%)	6,155 (17.7%)	2,995 (14.8%)	
Medium	82,965 (29.2%)	18,515 (30.6%)	17,525 (31.5%)	13,550 (29.7%)	10,830 (31.1%)	6,350 (31.4%)	
Large	157,925 (55.5%)	34,425 (57.0%)	29,445 (52.9%)	24,650 (54.0%)	17,880 (51.3%)	10,850 (53.7%)	
Hospital teaching status							<0.001
Rural	31,925 (11.2%)	3,245 (5.4%)	3,630 (6.3%)	5,500 (12.1%)	4,250 (12.2%)	1,200 (5.9%)	
Urban Non-Teaching	93,085 (32.7%)	19,470 (32.2%)	17,605 (31.6%)	17,390 (38.1%)	11,890 (34.1%)	7,210 (35.7%)	
Urban Teaching	159,355 (56.0%)	37,695 (62.4%)	34,520 (62.0%)	22,730 (49.8%)	18,725 (53.7%)	11,785 (58.4%)	
Hospital region							<0.001
Northeast	44,575 (15.7%)	12,725 (21.1%)	19,410 (34.9%)	6,530 (14.3%)	5,660 (16.2%)	6,230 (30.8%)	
Midwest	58,990 (20.7%)	12,275 (20.3%)	7,710 (13.9%)	9,555 (20.9%)	7,385 (21.2%)	2,620 (13.0%)	
South	126,455 (44.5%)	18,805 (31.1%)	17,495 (31.4%)	15,195 (33.3%)	10,765 (30.9%)	4,940 (24.5%)	
West	54,345 (19.1%)	16,605 (27.5%)	11,040 (19.8%)	14,340 (31.4%)	11,055 (31.7%)	6,405 (31.7%)	
Oophorectomy							<0.001
No	144,695 (50.9%)	32,410 (53.7%)	38,295 (68.8%)	26,440 (58.0%)	28,855 (82.8%)	14,740 (73.0%)	
Yes	139,670 (49.1%)	28,000 (46.3%)	17,360 (31.2%)	19,180 (42.0%)	6,010 (17.2%)	5,455 (27.0%)	
Uterine myoma							<0.001
No	26,755 (9.4%)	9,545 (15.8%)	3,765 (6.8%)	8,735 (19.1%)	6,690 (19.2%)	2,270 (11.2%)	
Yes	257,610 (90.6%)	50,865 (84.2%)	51,890 (93.2%)	36,885 (80.9%)	28,175 (80.8%)	17,925 (88.8%)	
Endometriosis							<0.001
No	220,030 (77.4%)	43,030 (71.2%)	43,530 (78.2%)	30,465 (66.8%)	25,285 (72.5%)	15,025 (74.4%)	
Yes	64,335 (22.6%)	17,380 (28.8%)	12,125 (21.8%)	15,155 (33.2%)	9,580 (27.5%)	5,170 (25.6%)	
Abnormal uterine bleeding							<0.001
No	155,895 (54.8%)	31,105 (51.5%)	29,415 (52.9%)	22,595 (49.5%)	18,080 (51.9%)	9,485 (47.0%)	
Yes	128,470 (45.2%)	29,305 (48.5%)	26,240 (47.1%)	23,025 (50.5%)	16,785 (48.1%)	10,710 (53.0%)	
Pelvic infection							<0.001
No	236,820 (83.3%)	51,350 (85.0%)	43,500 (78.2%)	39,500 (86.6%)	33,685 (96.6%)	17,055 (84.5%)	
Yes	47,545 (16.7%)	9,060 (15.0%)	12,155 (21.8%)	6,120 (13.4%)	1,180 (3.4%)	3,140 (15.5%)	
Uterine polyp							<0.001
No	272,135 (95.7%)	56,490 (93.5%)	53,890 (96.8%)	43,145 (94.6%)	32,405 (92.9%)	19,545 (96.8%)	
Yes	12,230 (4.3%)	3,920 (6.5%)	1,765 (3.2%)	2,475 (5.4%)	2,460 (7.1%)	650 (3.2%)	
Adnexal pathology							<0.001
No	210,830 (74.1%)	45,855 (75.9%)	43,470 (78.1%)	34,875 (76.4%)	30,470 (87.4%)	16,680 (82.6%)	
Yes	73,535 (25.9%)	14,555 (24.1%)	12,185 (21.9%)	10,745 (23.6%)	4,395 (12.6%)	3,515 (17.4%)	

Chi-square test or one-way ANOVA test for *P*-value. Percentage is per group. Abbreviations: LAVH, laparoscopy-assisted vaginal hysterectomy; TVH, total vaginal hysterectomy; TLH, total laparoscopic hysterectomy; TAH, total abdominal hysterectomy; Abd-SCH, abdominal supra-cervical hysterectomy; and LSC-SCH, laparoscopic supra-cervical hysterectomy.

Table 2. Ureteral injury risk per gynecological disease (TLH *versus* TLH).

Characteristic	OR (95%CI)	*P*-value
Endometriosis	6.15 (1.18-31.9)	0.031
Myoma	4.15 (2.13-8.11)	<0.001
Uterine polyp	2.97 (0.19-47.5)	0.442
Pelvic infection	2.90 (0.60-14.1)	0.187
AUB	2.44 (0.80-7.41)	0.117

Generalized estimating equation models were fitted on the PS-IPTW models. Risk of ureteral injury for TLH compared to TAH is shown based on presence of specific gynecologic disease. Abbreviations: TLH, total laparoscopic hysterectomy; TAH, total abdominal hysterectomy; OR, odds ratio; CI, confidence interval; and AUB, abnormal uterine bleeding.