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REVIEW

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Urinary Tract Injuries in Abdominal, Laparoscopic and Robotic Surgery: a Comprehensive Review

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ABSTRACT

Background/Aim: *Urinary tract injuries (UTIs) are a significant complication in abdominal, laparoscopic and robotic surgeries. Due to the proximity of the urinary tract to critical structures, procedures like colorectal surgery, hysterectomy and prostatectomy pose risks. Minimally invasive techniques like laparoscopy and robotic surgery offer benefits but introduce unique challenges. This review explores the incidence, risk factors and management strategies for UTIs across surgical approaches.*

Materials and methods: *A systematic review of PubMed, Embase and Web of Science was conducted. Studies on abdominal, gynecological, and urological surgeries reporting UTIs were included. After screening, 17 studies published between 1990 and 2024 were analyzed. The PRISMA method was used for selection and data extraction.*

Results: *The incidence of UTI varies by surgery type: for open surgery, higher rates (0.5%–3.0%) were recorded due to invasive techniques and longer operative times, particularly in colorectal surgeries and hysterectomies. In laparoscopic surgery, a lower incidence (0.1%–1.0%) was noted, though thermal injury*

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and visualization challenges remain. Finally, in robotic surgery, incidence ranges from 0.2% to 1.5%, with enhanced precision reducing the risk of UTIs in complex surgeries like prostatectomy and hysterectomy.

Conclusion: *The primary causes of UTIs include direct trauma, thermal injury and postoperative ischemia. Advanced technologies like robotic systems and intraoperative imaging reduce risks but require surgeon expertise. Preventing UTIs in surgery involves meticulous planning, advanced intraoperative technologies and comprehensive postoperative care. Continued research into minimally invasive techniques will further reduce complication rates and improve patient outcomes.*

Keywords: abdominal surgery, laparoscopic surgery, robotic surgery, urinary tract injuries.

INTRODUCTION

Minimally invasive surgery

The urinary tract, comprising the kidneys, ureters, bladder and urethra, plays a pivotal role in maintaining homeostasis by filtering waste and excess substances from the bloodstream. Its anatomical positioning and functional significance render it particularly susceptible to trauma during various surgical procedures. Surgeries involving the abdominal, pelvic and retroperitoneal regions, such as colorectal surgery, hysterectomy and prostatectomy, pose a considerable risk of urinary tract injuries (UTIs). The advent of laparoscopic and robotic surgical techniques, while offering numerous benefits such as reduced postoperative pain, shorter hospital stays and quicker recovery times, has not eliminated these risks. Instead, these minimally invasive procedures introduce unique challenges that necessitate meticulous surgical precision and advanced intraoperative techniques (1, 2).

Urinary tract injuries can lead to severe morbidity, prolonged hospitalization, increased healthcare costs and a significant impact on the patient's quality of life. The complexity of these injuries stems from the unique anatomy of the urinary tract and its close proximity to critical structures. For instance, during colorectal surgery, the ureters are at risk due to their retroperitoneal location adjacent to the colon and rectum. Similarly, in gynecological surgeries like hysterectomy, the ureters and bladder are vulnerable because of their anatomical relationship with the uterus. Prostatectomies present a high risk of injury to the bladder neck and urethra due to their proximity to the prostate. The risk of injury is influenced by factors such as the extent of surgical manipulation, visibility of the surgical field and the surgeon's experience (3).

The primary aim of this review was to examine the underlying mechanisms, risk factors, diagnostic modalities and management strategies for UTIs across different surgical approaches with a view to optimizing clinical practice and patient outcomes. ❑

MATERIALS AND METHODS

A thorough literature search was conducted to gather data on the incidence, causative factors, preventive measures, and therapeutic interventions specific to abdominal, laparoscopic and robotic surgical techniques.

Our search strategy included a systematic review of PubMed, Embase and Web of Science databases by two independent reviewers. Disagreements were resolved after discussion. English search terms included "Urinary Tract Injury" OR "Urogenital Trauma" OR "Urinary Tract Damage" OR "Urinary Tract Trauma" OR "Genitourinary System Trauma". Review articles and meta-analyses were manually searched to identify additional articles.

Inclusion criteria were: (i) studies on patients undergoing abdominal or gynecological or urogenital surgery; (ii) studies reporting whether patients had urinary tract injuries after surgery; (iii) cohort studies and case-control studies; (iv) studies in English; (v) the latest studies when the study population was repeated.

Exclusion criteria were: (i) studies using animal models; (ii) studies unrelated to the research topic, such as studies on drug testing, etc; (iii) studies where data cannot be extracted; (iv) conference reports and presentations, dissertations, case reports.

A total of 1,219 studies were retrieved from the three databases, and four additional articles were identified from review studies. After deduplication, 456 were left. Subsequently, titles and

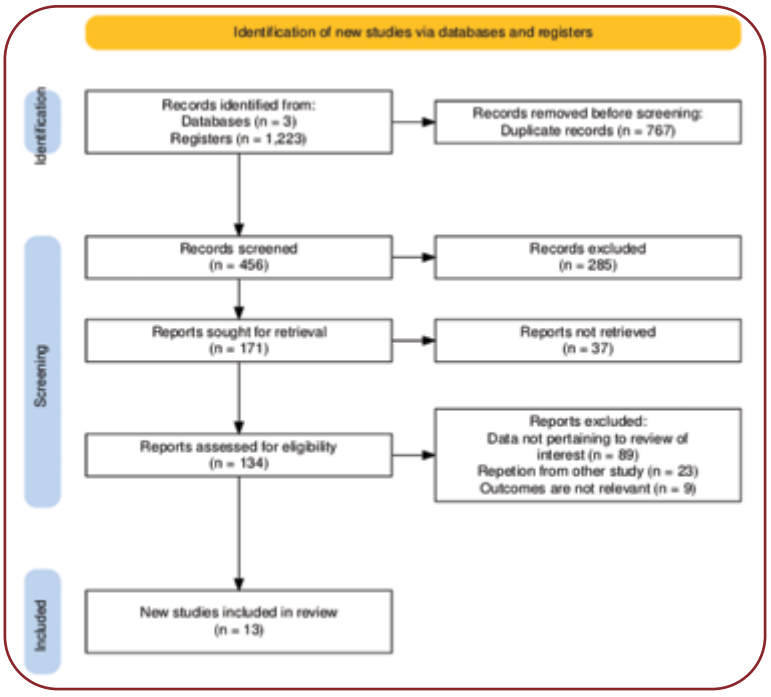

FIGURE 1. PRISMA flow diagram of study selection

abstracts and then full texts were subject to screening according to the eligibility criteria. Finally, 13 studies were included, published between Jan 1990 and Jul 2024. The selection process of the studies is summarized in the PRISMA flow chart (Figure 1). ❑

RESULTS

The incidence of UTIs in different surgical approaches is presented below.

Abdominal (open) surgery

Open surgery, involving larger incisions and direct visualization of the surgical field, has traditionally been associated with higher rates of complications, including UTIs. The incidence of UTIs in open abdominal surgeries, such as colorectal surgery and hysterectomy, is reported to be between 0.5% and 3.0% (4-7). The higher incidence is attributed to the more invasive nature of open surgery, longer operative times and greater potential for direct trauma to the urinary tract structures. The most common procedures in open surgery associated with UTIs were colorectal surgery and hysterectomy, which are further discussed below.

Laparoscopic surgery

Laparoscopic surgery, characterized by small incisions and the use of a camera and specialized instruments, has been associated with lower overall complication rates compared to open surgery. However, UTIs remain a notable risk. Studies have shown that the incidence of UTIs in laparoscopic procedures, such as cholecystectomy and appendectomy, ranges from 0.1% to 1.0% (6, 8-10). The risk is influenced by factors as presented above, such as the complexity of the surgery, the surgeon's experience and the presence of pre-existing conditions. Some common procedures in laparoscopic surgery with associated UTIs were cholecystectomy and appendectomy.

Robotic surgery

Robotic-assisted surgery, which provides enhanced precision and visualization through robotic instruments, has shown a variable incidence of UTIs. The incidence ranges from 0.2% to 1.5% (10-12), depending on the type of procedure and the experience of the surgical team (13). For example, robotic prostatectomy and hysterectomy are associated with specific risks due to the proximity of the urinary tract structures (12, 13). The use of robotic technology aims to reduce these risks by allowing finer control and more precise dissection.

Mechanisms of UTIs

The mechanisms of injuries that were found can be categorized into intraoperative and postoperative mechanisms. The intraoperative mechanisms that were found in literature are direct trauma, thermal injuries and instrument related injuries. The postoperative mechanisms include ischemia, infection and stricture formation in the ureteral structures or the bladder neck (14).

Moreover, results for different surgical approaches and comparisons are summarized below.

Laparoscopic surgery generally offers lower rates of UTIs compared to open surgery due to smaller incisions, reduced tissue trauma and shorter recovery times. However, the risk of thermal injury from electrocautery devices and difficulties in visualizing and protecting urinary structures remain concerns. Open surgery, while providing better tactile feedback and direct visualization, has higher rates of UTIs due to its invasive nature and longer operative times. The choice between laparoscopic and open surgery often depends on the complexity of the case and the surgeon's expertise (15).

Robotic surgery has emerged as a promising alternative to laparoscopic surgery, offering enhanced dexterity, precision and visualization. The incidence of UTIs in robotic surgery is comparable to or slightly lower than in laparoscopic surgery, particularly in complex procedures such as prostatectomy and hysterectomy. The robotic platform allows for more precise dissection and suturing, potentially reducing the risk of UTIs. However, the high cost and steep learning curve associated with robotic surgery are challenges that need to be addressed (15).

Compared to open surgery, robotic surgery generally shows lower rates of UTIs due to the minimally invasive approach and advanced technology. The enhanced visualization and precision of robotic instruments reduce the likelihood of accidental injuries to the urinary tract. Studies have shown that patients undergoing robotic-assisted surgeries have fewer complications and shorter hospital stays compared to those undergoing open procedures. However, patient selection and the surgeon's experience with robotic systems are critical determinants of the outcomes (10). ❑

DISCUSSION

Urinary tract injuries are a significant complication in abdominal surgeries, including colorectal surgery and hysterectomy. These injuries can lead to severe morbidity, prolonged hospitalization and additional interventions.

Colorectal surgeries, such as low anterior resection, abdominoperineal resection and colectomy, are commonly performed to treat malignancies, inflammatory bowel disease, and diverticulitis. The close anatomical relationship between the colorectal structures and the urinary tract, particularly the ureters, bladder and, in some cases, the urethra, makes these procedures prone to UTIs (16). The ureters run retroperitoneally along the posterior abdominal wall, crossing the pelvic brim and descending into the pelvis near the rectum and sigmoid colon. This anatomical proximity increases the risk of ureteric injury during mobilization and resection of the colon and rectum. The left ureter is particularly at risk due to its closer proximity to the descending colon and sigmoid. The risk of UTIs is significantly influenced by the surgical technique. Inadequate identification and dissection of the ureters can lead to inadvertent transection or ligation. Advanced techniques, such as intraoperative ureteral stenting and the use of ureteral identification devices, can reduce these risks (17). However, these techniques require careful preoperative planning to avoid associated risks. The extent and stage of colorectal disease also play a crucial role in the risk of UTIs. Advanced malignancies or extensive inflammatory disease can cause anatomical distortions and adhesions, making it challenging to identify and preserve the ureters and bladder during surgery. These cases often require more extensive dissections, increasing the likelihood of injury. Surgeon experience and expertise are critical factors in minimizing UTIs. Experienced colorectal surgeons are more adept at identifying anatomical landmarks and employing meticulous dissection techniques, thereby reducing the risk of inadvertent injury. Moreover, high-volume centers with specialized colorectal units tend to have lower rates of UTIs compared to low-volume centers (18).

Hysterectomy, whether performed for benign or malignant conditions, poses significant risks to the urinary tract due to the close anatomical relationship between the uterus, bladder, and ureters. The risk factors for UTIs in hysterectomy include patient-specific factors, the type of hysterectomy and the surgical technique employed (19). The type of hysterectomy significantly impacts the risk of UTIs. Radical hysterectomy, often performed for cervical cancer, involves extensive dissection around the bladder and ureters, thereby increasing the risk of injury. In contrast, subtotal or total hysterectomy for benign conditions typically involves less extensive dissection but still poses a risk due to the close proximity of the bladder and ureters to the surgical field. Previous pelvic surgery, such as cesarean section or pelvic organ prolapse repair, can increase the risk of UTIs during hysterectomy (20). These previous surgeries can cause adhesions and anatomical distortions, complicating the dissection and identification of urinary tract structures. Endometriosis, characterized by the presence of endometrial tissue outside the uterus, often leads to significant pelvic adhesions and distortion of normal anatomy. In patients with endometriosis, the risk of urinary tract injuries during hysterectomy is heightened due to the need for extensive dissection to remove endometrial implants from the bladder, ureters and surrounding tissues. The skill and technique of the surgeon are paramount in preventing UTIs during hysterectomy. Surgeons must be adept at identi-

fying and preserving the ureters and bladder during dissection. Techniques such as ureterolysis (freeing the ureters from surrounding tissue) and the use of intraoperative cystoscopy to ensure ureteral patency can help mitigate the risk of injury (19, 20).

Laparoscopic cholecystectomy is the gold standard for treating symptomatic gallstones and acute cholecystitis. While it is generally considered safe, the risk of UTIs, particularly involving the bladder and ureters, remains a concern due to anatomical proximity and procedural intricacies (21). During a cholecystectomy, the gallbladder is dissected from its hepatic bed, with careful attention to the cystic duct and artery. The proximity of the right ureter and bladder, especially in cases with extensive inflammation or anatomical variations, increases the risk of inadvertent injury. This is particularly relevant when converting from laparoscopic to open surgery due to complications or unclear anatomy. The risk of UTIs is influenced by the precision of the surgical technique (22). Inadequate visualization and improper handling of instruments can lead to bladder perforation or ureteral damage. The use of electrocautery devices poses a risk of thermal injury to the urinary structures, which may not be immediately apparent during surgery. Enhanced visualization techniques, such as intraoperative cholangiography, can help identify and protect adjacent structures but require skill and experience to interpret accurately. Acute cholecystitis and cholelithiasis can cause significant inflammation and adhesions, also complicating the surgical dissection and increasing the risk of UTI. Inflammatory changes can obscure anatomical landmarks, making it more challenging to differentiate the cystic duct from the common bile duct and adjacent ureter. The surgeon's experience and familiarity with laparoscopic techniques are crucial in minimizing UTIs (23). Experienced surgeons are better at anticipating anatomical variations and complications, employing meticulous dissection methods, and effectively using advanced imaging techniques to reduce the risk of injury.

Laparoscopic appendectomy is a common procedure for treating acute appendicitis. The proximity of the appendix to the urinary tract structures, especially in cases of complicated appendicitis, poses a risk for UTIs (4). The appendix is located near the cecum, and its base is often close to the right ureter. Inflammation, particularly in cases of perforated appendicitis, can cause severe adhesions and anatomical distortions, making the ureter susceptible to injury during dissection. The risk is further heightened when the appendix is retrocecal or retroperitoneal, requiring more extensive mobilization. Accurate identification of the appendix and its base is critical to avoid damaging adjacent urinary structures. Misidentification can lead to inadvertent ureteral ligation or transection. The use of advanced laparoscopic techniques, such as high-definition imaging and meticulous dissection, can mitigate these risks. However, these techniques require a high level of skill and experience (24). Complicated appendicitis, characterized by abscess formation, perforation, or extensive peritonitis, significantly increases the risk of UTIs. The inflammatory response can obscure the anatomical boundaries, making it challenging to identify and preserve the ureter and bladder during surgery. Preoperative imaging and careful intraoperative assessment are essential in these cases to minimize the risk of injury. As with cholecystectomy, the surgeon's expertise plays a pivotal role in preventing UTIs during laparoscopic appendectomy. Experienced surgeons are more adept at navigating complex anatomical scenarios and employing techniques to protect the urinary tract, such as preoperative stenting or intraoperative ureteral identification (15).

Robotic-assisted radical prostatectomy (RARP) is a common procedure for treating localized prostate cancer. While it offers superior visualization and dexterity compared to traditional open or laparoscopic surgery, the proximity of the prostate to the bladder and urethra presents inherent risks. The prostate is situated near critical urinary structures, including the bladder neck and urethra. The dissection of the prostate from these structures requires meticulous technique to avoid injury (13). The risk is increased in patients with previous pelvic surgeries, radiation therapy, or large prostate glands, which can distort normal anatomy and obscure landmarks. The surgeon's experience and proficiency with the robotic platform significantly impact the likelihood of urinary tract injuries. Inadequate training or inexperience can lead to inadvertent trauma to the bladder or urethra during dissection and suturing (25). Furthermore, technical challenges such as controlling blood loss and managing the depth of dissection can contribute to complications. Patient-specific factors, including obesity, age and comorbidities

like diabetes, can influence the risk of UTIs. Obesity, for instance, can make it more challenging to visualize and manipulate structures within the pelvis, increasing the likelihood of injury. Additionally, older patients and those with diabetes may have compromised tissue integrity and healing capacity, predisposing them to complications (26).

The intraoperative and postoperative mechanisms of UTIs, focusing on direct trauma, thermal injury, instrument-related factors, ischemia, infection, and stricture formation (5) are further discussed below.

Intraoperative mechanisms of urinary tract injuries include direct trauma, thermal injury, and instrument-related factors (8). Direct trauma to the urinary tract structures, including the bladder, ureters, and urethra, is a common cause of UTIs during surgery. This can occur due to sharp dissection, blunt injury, or inadvertent laceration. Bladder injuries can happen during procedures involving pelvic dissection, such as hysterectomy, colorectal surgery and prostatectomy. The bladder is particularly vulnerable when adhesions from previous surgeries or inflammatory conditions obscure the anatomical landmarks. Intraoperative cystoscopy can help identify bladder injuries early, allowing for immediate repair. Ureteral injuries often result from misidentification or accidental transection during dissection near the pelvic brim or close to the bladder. These injuries are more common in surgeries involving extensive pelvic dissection, such as radical hysterectomy or lymphadenectomy. Preoperative ureteral stenting can facilitate identification and reduce the risk of injury. Urethral injuries, though less common, can occur during pelvic fracture repairs or urological procedures. Catheterization and incorrect instrument placement can cause urethral perforation or rupture. Careful insertion techniques and the use of flexible instruments can mitigate these risks (27).

Thermal injuries to the urinary tract can occur during the use of electrosurgical devices, such as monopolar or bipolar cautery, and advanced energy devices like harmonic scalpels and lasers (2, 7). These injuries may not be immediately apparent but can result in delayed complications. Thermal damage occurs when the heat generated by the surgical device exceeds the thermal tolerance of the tissues, leading to coagulative necrosis (8). The extent of the injury depends on the duration of exposure and the power settings of the device. Surgeons can minimize thermal injuries by using the lowest effective power settings, limiting the duration of device activation and maintaining a safe distance from critical structures. Additionally, the use of insulating barriers and the implementation of thermal spread reduction techniques can help protect adjacent tissues (17).

The design and use of surgical instruments play a critical role in the incidence of UTIs. Factors such as instrument size, rigidity, and the surgeon's familiarity with the tools can influence the risk of injury (1, 7). Laparoscopic instruments, while offering precision, can also pose risks if improperly handled. Sharp trocar insertion can lead to bladder or ureteral perforation. The use of blunt-tip trocars and careful trocar placement can reduce these risks (5, 7). Robotic-assisted surgery involves the use of highly specialized instruments that provide enhanced dexterity and precision. However, improper calibration, excessive force application, or mechanical failure can result in UTIs. Regular maintenance of robotic systems and thorough surgeon training are essential to mitigate these risks (28).

Postoperative mechanisms of urinary tract injuries include ischemia, infection, and stricture formation. Ischemic injury to the urinary tract can occur due to compromised blood supply during or after surgery. This can lead to tissue necrosis and subsequent complications. The ureters are particularly susceptible to ischemia during extensive pelvic surgeries, where mobilization and dissection can disrupt their vascular supply. Ischemic ureteral injury can lead to strictures or necrosis, requiring complex reconstructive procedures. Bladder ischemia can result from prolonged intraoperative pressure, excessive dissection, or vascular compromise. This can lead to bladder wall necrosis, fistula formation and impaired bladder function. Ensuring adequate hydration and minimizing operative time can help prevent ischemic injuries (27, 29).

Postoperative infections are a common complication that can exacerbate UTIs. Surgical site infections (SSIs) and catheter-associated urinary tract infections (CAUTIs) are particularly relevant. Surgical site infections can occur at the site of urinary tract injury, leading to abscess formation, delayed healing and sepsis. The use of prophylactic antibiotics, strict aseptic techniques, and care-

ful postoperative monitoring are crucial in preventing SSIs. Indwelling catheters are often used postoperatively but can be a source of infection if not managed properly. Strategies to reduce CAUTIs include the use of aseptic insertion techniques, regular catheter care and prompt removal when no longer needed (28).

Strictures are a delayed complication of UTIs, resulting from fibrosis and scarring during the healing process. They can occur in the ureters, bladder neck, or urethra and lead to obstructive symptoms and impaired urinary function. Ureteral strictures can develop following direct trauma, thermal injury, or ischemia. These strictures can cause hydronephrosis, recurrent urinary tract infections, and renal impairment. Treatment options include endoscopic dilation, ureteral stenting, or surgical reconstruction. Strictures at the bladder neck are commonly associated with prostatectomy or bladder surgery. They can result in urinary retention, incontinence and recurrent infections. Management may involve endoscopic incision, dilation, or open surgical reconstruction. Urethral strictures can occur following catheterization, instrumentation, or direct trauma. Symptoms include decreased urinary flow, dysuria and recurrent infections. Treatment options range from minimally invasive procedures like dilation and urethrotomy to more complex reconstructive surgeries (30).

Urinary tract infections are significant complications that can arise from various intraoperative and postoperative mechanisms. Direct trauma, thermal injury and instrument-related factors are primary intraoperative causes, while ischemia, infection, and stricture formation are key postoperative concerns. Understanding these mechanisms and implementing preventive strategies are essential for minimizing the risk of UTIs and improving surgical outcomes. Surgical techniques, meticulous intraoperative management and postoperative care are critical components of an effective approach to preventing and managing UTIs (26).

Urinary tract infections during surgery can result from direct trauma, thermal injury, instrument-related factors, ischemia, infection and stricture formation. Direct trauma occurs due to sharp dissection or blunt injury, while thermal injuries arise from the use of electrosurgical devices. Instrument-related factors, such as the size and rigidity of instruments, also contribute to UTIs. Postoperative mechanisms include ischemia due to compromised blood supply, infections and stricture formation from fibrosis and scarring.

Effective prevention encompasses preoperative planning, intraoperative techniques and postoperative care. Preoperative imaging, including ultrasound, computed tomography (CT) and magnetic resonance imaging (MRI), aids in identifying anatomical variations and potential complications. Minimally invasive techniques, such as laparoscopic and robotic-assisted surgeries, reduce tissue trauma and enhance visualization, lowering the risk of UTIs. Advanced technologies like fluorescence imaging and intraoperative ultrasound further improve surgical precision. Postoperative monitoring for signs of UTIs and timely interventions are crucial for mitigating complications.

Technological innovations and ongoing research are pivotal in advancing surgical techniques to prevent UTIs. Minimally invasive approaches, enhanced imaging modalities, and improved energy devices contribute to reducing UTIs. The integration of artificial intelligence (AI) and robotics into surgical practice offers unparalleled precision and control. Future research in biomaterials, precision medicine and virtual reality (VR) training promises further enhancements in surgical outcomes. Artificial intelligence-driven systems can analyze preoperative imaging, provide real-time guidance during surgery and assist in postoperative analysis. Virtual reality and simulation training can improve surgical proficiency and preparedness, reducing intraoperative injuries.

CONCLUSIONS

Understanding and addressing the risk factors, mechanisms and preventive strategies for UTIs are essential for optimizing patient outcomes in abdominal, laparoscopic and robotic surgeries. The incorporation of advanced technologies, meticulous surgical techniques and comprehensive postoperative care are crucial components in minimizing the incidence of UTIs and enhancing patient safety. Continued research and innovation in surgical practices hold the potential to further reduce complications and improve overall surgical outcomes. ❑

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