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The Ileal Ureter: Over a Century of Urologic Innovation

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Introduction: Surgical techniques to repair a ureteral stricture may depend on the stricture's etiology, length, and location. Options may range from primary ureteral reimplantation for short, distal strictures, buccal mucosa onlay ureteroplasty for complex proximal or mid ureteral defects, to Boari flap or even autotransplantation for longer mid to distal ureteral defects. Replacement of the entire ureter with a segment of ileum is rare but may provide durable results when indicated. Our objective was to illustrate how the history and evolution of the ileal ureter entered the contemporary surgical armamentarium.

Sources and Methods: A comprehensive literature review was performed in conjunction with library resources in the History of Medicine section at the University of Rochester. We used PubMed to identify contemporary medical literature, ILLiad to access archived texts and historic surgical and urological textbooks to obtain additional historical information and references.

Results: We documented perhaps the first description of the ileal ureter in a canine model by Guido Tizzoni and Alfonso Foggi in 1888. Adaptations of ileal ureters over the next century, and beyond, have increased the safety, feasibility, and reproducibility of thre procedure for replacement of the ureter rendered unsalvageable by strictural disease, trauma, or malignancy.

Conclusions: Tizzoni and Foggi described the first ileal ureter in the canine model in 1888.

Keywords: Ureter, Ureteral Diseases, Reconstructive Surgical Procedures, History of Medicine

The surgical treatment of complex and long ureteral strictures failing conservative management has been a challenge for urologists given the unique vascular and structural characteristics of the ureter. Several methods to address structural disease of the ureter have been described including transureteroureterostomy, renal autotransplantation, cutaneous ureterostomies, and augmented ureteroplasty with buccal graft, each having its own associated complications. Ureteral replacement with ileum may be a 'last-resort' method for ureteral injuries but which dates to the late 19th century. (1, 2) The origin of the ileal ureter procedure and its subsequent improvements have not, however, been well documented. We aimed to review the history of the ileal ureter and its evolution.

SOURCES

A comprehensive literature review was performed in conjunction with the University of Rochester's History of Medicine librarian (LH). We used PubMed to identify contemporary medical literature, ILLiad to access archived texts, and urological textbooks to obtain additional historical information and references.

RESULTS

Origin of the Ileal Ureter

In the late 19th century, surgeons experimented with various diverting techniques to combat urinary injuries that compromised ureteral continuity.(3, 4) Uretero-intestinal anastomosis such as ureterosigmoidostomy was used during this period but was complicated by hydronephrosis secondary to distal ureteral stenosis, infection, and the later development of colon cancer. (3, 5) Ureteroileoplasty was also attempted, where the ureter was anastomosed to a segment of ileum and then the distal end of the ileal segment attached to the rectum. Bowel was chosen as a ureteral substitute because is unidirectional peristaltic characteristic would theoretically prevent reflux and subsequent hydronephrosis.(6) Yet, this led to similar concerns including malignancy and recurrent infections due to retrograde migration of bacteria from the intestinal tract. Such techniques were indicated for patients who

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had undergone cystectomy but may have been the nidus to consider ileum for ureteral substitution as well. The use of ileum to replace ureter and maintain urinary continuity was first proposed in 1888 by two Italian surgeons, Guido Tizzoni (1853-1932) and Alfonso Foggi (1848-1934), in a two-stage canine model.(5) In the first stage, a seven-centimeter segment of ileum was isolated with its attached mesentery. Each end of the segment was sutured closed and then the segment left freely in the abdomen. After a month, a cystectomy was performed and the ureters were anastomosed to the proximal end of the isolated bowel. The distal end of the ileal segment was anastomosed to the urethra. (7) Renderings of Tizzoni and Foggi's method were not well documented and were only made known through subsequent publications by colleagues of Tizzoni and Foggi. These reported that only a partial cystectomy was done, and the substituted ileum was attached to the remnant portion of the bladder as opposed to the urethra (Figure 1).(8) Regardless, their studies demonstrated the first model use of bowel to maintain urinary continuity following ureteral loss.

In 1893, Christian Fenger (1840-1902), a surgeon at Northwestern University, proposed the use of bowel in ureteral reconstruction in a personal conversation with Weller Van Hook.(9, 10) This concept was later published by Joseph Bacon (1854-unknown) in the Chicago Medical Record, who suggested isolating a small ileal segment with its maintained blood supply and anastomosing it to the ureter proximally and bladder distally (Figure 2).(9, 10) The contemporary critiques of this idea highlighted problems that still challenge urologists to this day: seeding of infection from the transposed bowel, complications of bowel manipulation, and a lengthy recovery.

First Application in Humans

The first successful *in vivo* case of an ileal ureter was reported by American surgeon George Shoemaker (1857-1922) in a woman with tuberculosis who had previously undergone unilateral nephrectomy and subsequently required surgical intervention when her solitary ureter became strictured.(11) The procedure was performed using a two-stage technique. First, the strictured ureter was replaced with an isolated segment of ileum. The proximal end was attached at the renal pelvis, and the distal end of the ileal ureter was brought to the skin as a uretero-ileostomy. In the second stage, urinary continuity was re-established as the distal end of the ileal ureter was anastomosed to the bladder. Unfortunately, the long-term outcome was not described in the case report.

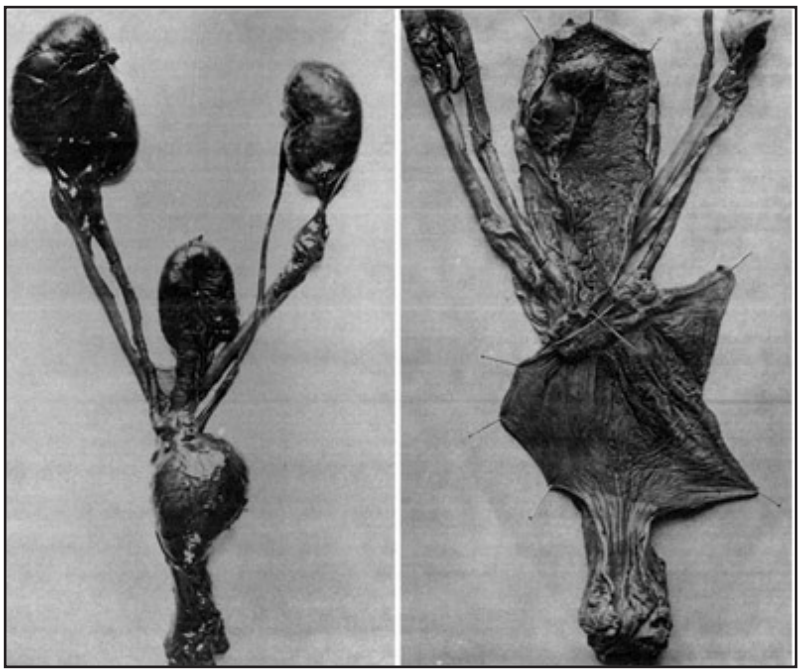

Figure 1. Depictions of the first documented use of bowel in urinary tract surgery based on the work of Tizzoni and Foggi in 1888. The photo, from the 1891 paper by Schwarz et al. describing their work, shows enlargement of an isolated segment of ileum transplanted onto bladder in the immediate post op (left) and delayed (right) in a dog models(8)

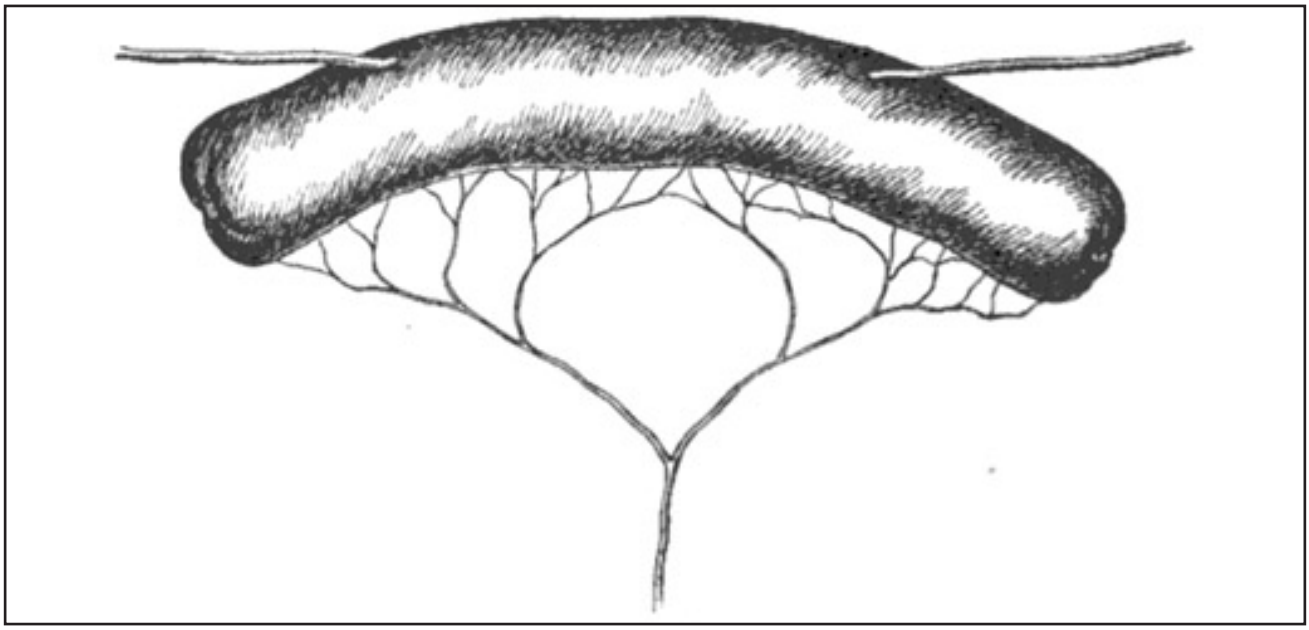

Figure 2. Joseph Bacon was the first to propose the use of small intestine in ureteral substitution in humans through isolating a small bowel segment with its maintained blood supply. Chicago Medical Recorder. 1893.(9)

Development of the Ileal Ureter after Shoemaker

Dr. Shoemaker's technique became the basis of the modern ileal ureter. Rudolf Nissen (1896-1986), a German Jewish surgeon best known for developing the Nissen fundoplication procedure, fled Nazi Germany and emigrated to Turkey, where he later became the Chief of Surgery at Istanbul University. During his tenure there (1933-1939), he described a patient with a history of bilateral obstructing renal calculi who underwent multiple ureteral catheterizations.(12) Following the last ureteral catheterization, a large "paraureteral abscess developed", which was complicated by a urine leak and ureteral fistula. Additional attempted catheterizations to reestablish ureteral continuity were unsuccessful. Thereupon, Nissen decided to complete a continent ureteral reconstruction as a last resort. Initially, a small bowel segment was isolated, and the distal end was attached to the dome of the bladder via a side-to-side anastomosis. The proximal end of the ileal segment was anastomosed to the ureter using the "Witzel technique", an anti-reflux technique in which the ureter is anastomosed in an end-to-side fashion to the ileum and then embedded in a seromucosal tunnel of the bowel using interrupted sutures.(Figure 3). The operation was successful, and the patient was followed for over six years without complications.

In 1944, French surgeon Yves-Jacques Longuet (1901-1989) operated on a woman who had previously undergone a hysterectomy and subsequently developed bilateral ureterovaginal fistulae.(13) Initial management with stents was unsuccessful due to "considerable diminution of the outflow" of the left ureter and that he found it "impossible to pass the catheter" up the right ureter. Over time, right hydroureteronephrosis developed leading to renal atrophy. A section of small bowel was isolated, and then the midpoint of this segment was attached to the bladder dome, creating a U-shaped anastomosis. The right ureter was anastomosed to the ileal segment, and then the ends of the ileal segment were anastomosed together to prevent formation of a cul-de-sac for stagnant urine. In 1950, Von K. Müller-Brandenburg, a German urologist, attached the ureters to a loop of ileum that was anastomosed to the bladder in a woman with bilateral, iatrogenic ureteral injuries secondary to gynecologic surgery for uterine malignancy.(14)

In 1953, Foret and Heugshem from Belgium used a single ureteral substitution in a 29-year-old woman with bilateral hydronephrosis secondary to distal ureterovesical stenosis. Each ureter was anastomosed end-to-end to either end of the ileal segment, and then the middle of the segment was anastomosed side-to-side to the dome of the bladder.(15)

These case reports demonstrated the diverse and innovative thought processes of reconstructive urologists during this time.

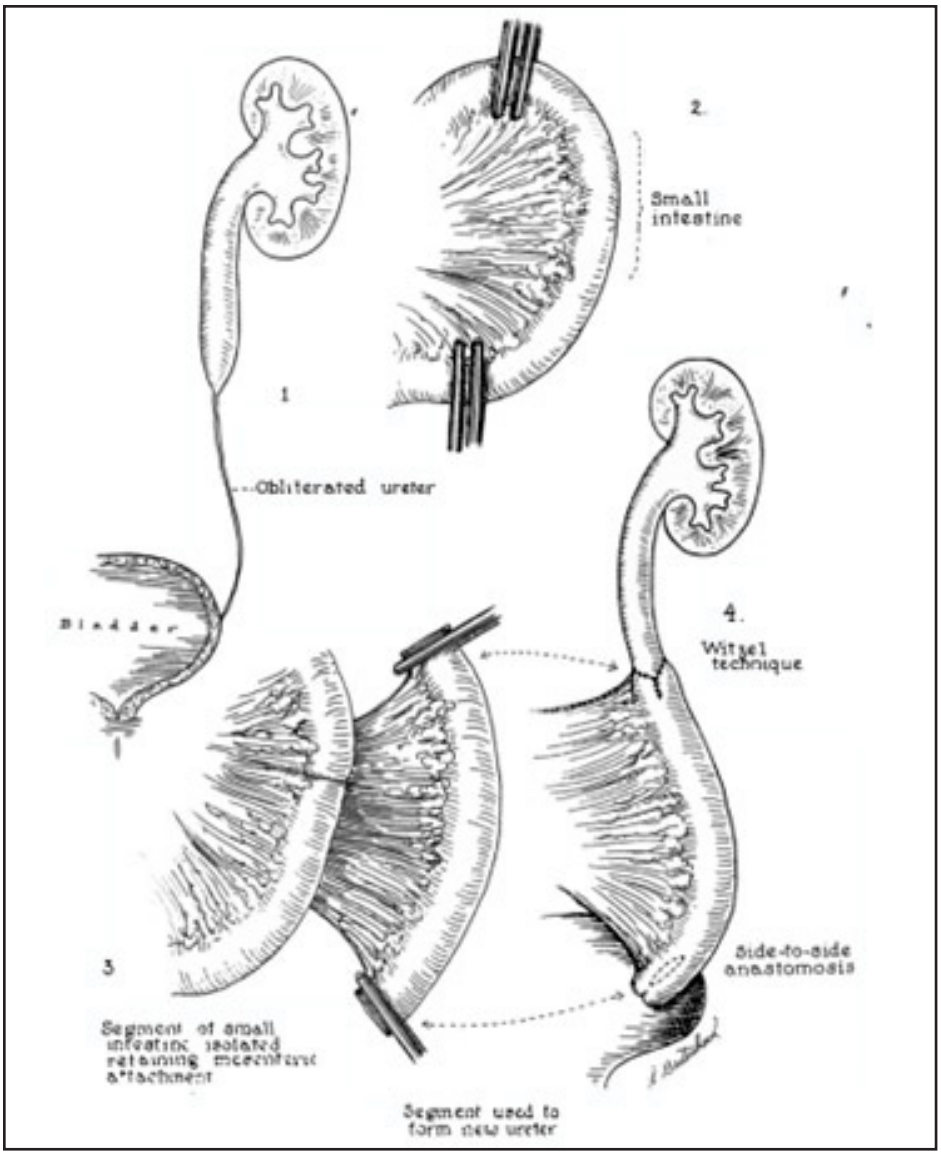

Figure 3. Following the first reported case of the ileal ureter by Shoemaker, Rudolph Nissen in 1940 was the next to describe a detailed report of using ileum in a proximal end-to-side fashion via the Witzel technique and distal side-to-side anastomosis to the bladder. From Nissen et al.(12)

The First Large Cohort Study

Charles Wells (1898-1989), a Liverpool surgeon, presented a 395-patient case series on the use of bowel in urologic surgeries, to the British Association of Urological Surgeons in 1956.(16) This study included patients with uretero-ileostomy, uretero-ileoplasty, and ileo-cystoplasty. Within the uretero-ileoplasty series, 56 patients underwent either partial or total ureteric replacement with ileum. Wells looked at several outcomes including all-cause mortality, improvement in pre-operative hydronephrosis, and general post-operative quality assessment. The mortality rate was 7.0%, with most deaths occurring in the hospital immediately post-operatively. In patients with preoperative hydronephrosis, 60% (6/10) had improvement at three to six months post-operatively,

and 66% (2/3) showed improvement after six months. General assessment at an average of 12-month follow-up showed high satisfactory outcomes. Two patients reported worse outcomes secondary to renal failure and prostatic obstruction.

Wells also reported that patients with cutaneous uretero-ileostomies had less urea and chloride reabsorption compared to patients who underwent uretero-ileoplasty and ileo-cystoplasty (Figure 4.) He concluded that the ileal mucosa had a propensity for urea and chloride reabsorption due to prolonged urine exposure to ileal mucosa in the uretero-ileoplasty and ileo-cystoplasty groups. This finding was one of the first to raise concern regarding the metabolic derangements associated with the use of bowel in ureteral reconstruction.

The UCLA Impact on the Evolution of the Ileal Ureter

In 1959, Willard Goodwin (1915-1998) and colleagues at the University of California at Los Angeles (UCLA) published a series of 16 patients who had undergone ileal ureters and described in detail the surgical technique and outcomes of each patient.(17) They reported six different technical variations of the surgery including unilateral end-to-end ileal ureters (Fig. 5). Three of 16 (19%) outcomes were deemed failures. Two of the three were due to poor preoperative renal function, leading to uremia and acidosis postoperatively requiring ileoureterostomy for urinary diversion. The third failure was due to a vesicovaginal fistula that was present prior to the surgery. In this case, the ureteral replacement was a success, but persistence of the fistula necessitated cutaneous uretero-ileostomy.

Goodwin was the first to appreciate the concern of ileo-ureteral reflux. He noted that the peristaltic effects of the ileal segment most often prevented reflux, but fluorographic and pressure studies demonstrated that high bladder pressures transmit through the ileal ureter into the kidney. Goodwin also noted the relationship between optimal ileal segment length and reflux, as patients with segments that were too long or too short resulted in excessive metabolic complications or reflux, respectively. The UCLA group reported the variety of indications for ileal ureters including extensive damage from gynecological oncologic resections, solitary kidneys, and renal calculi. These findings paved the way for urologists to utilize these techniques in the repair of damaged ureters.

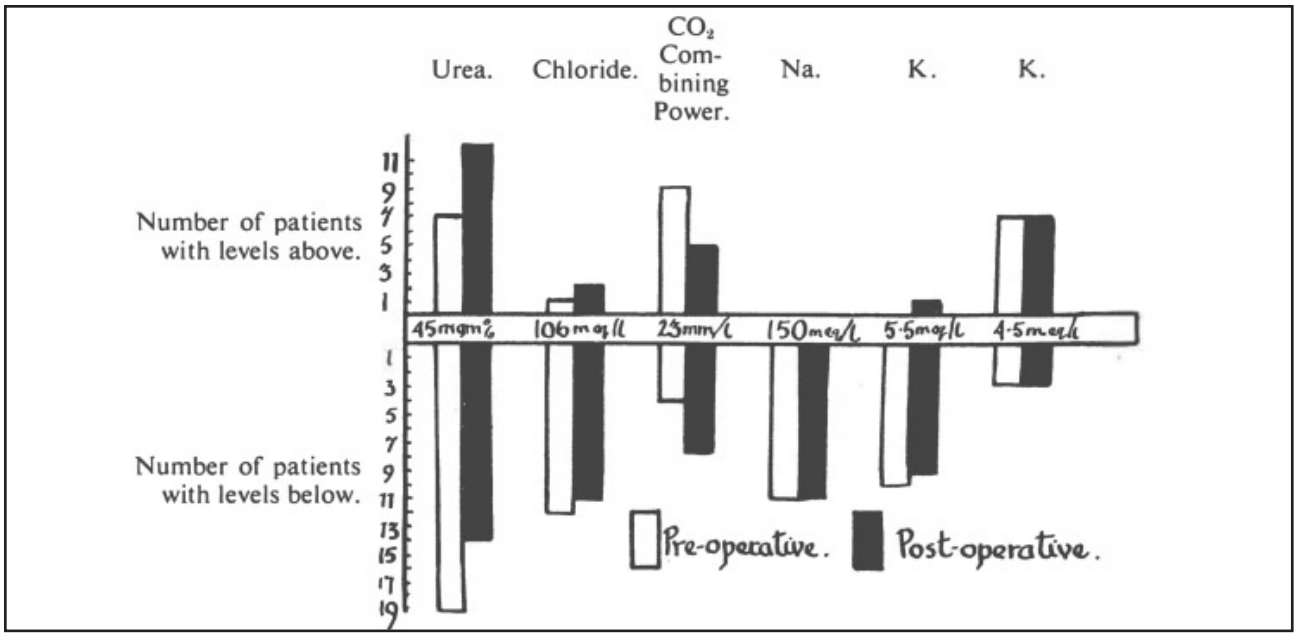

Figure 4. As the use of bowel proved a feasible option for ureteral substitution, Charles Wells published the first large cohort studies demonstrating the metabolic derangements associated with this technique such as increased urea and chloride absorption. From Wells et al.(16)

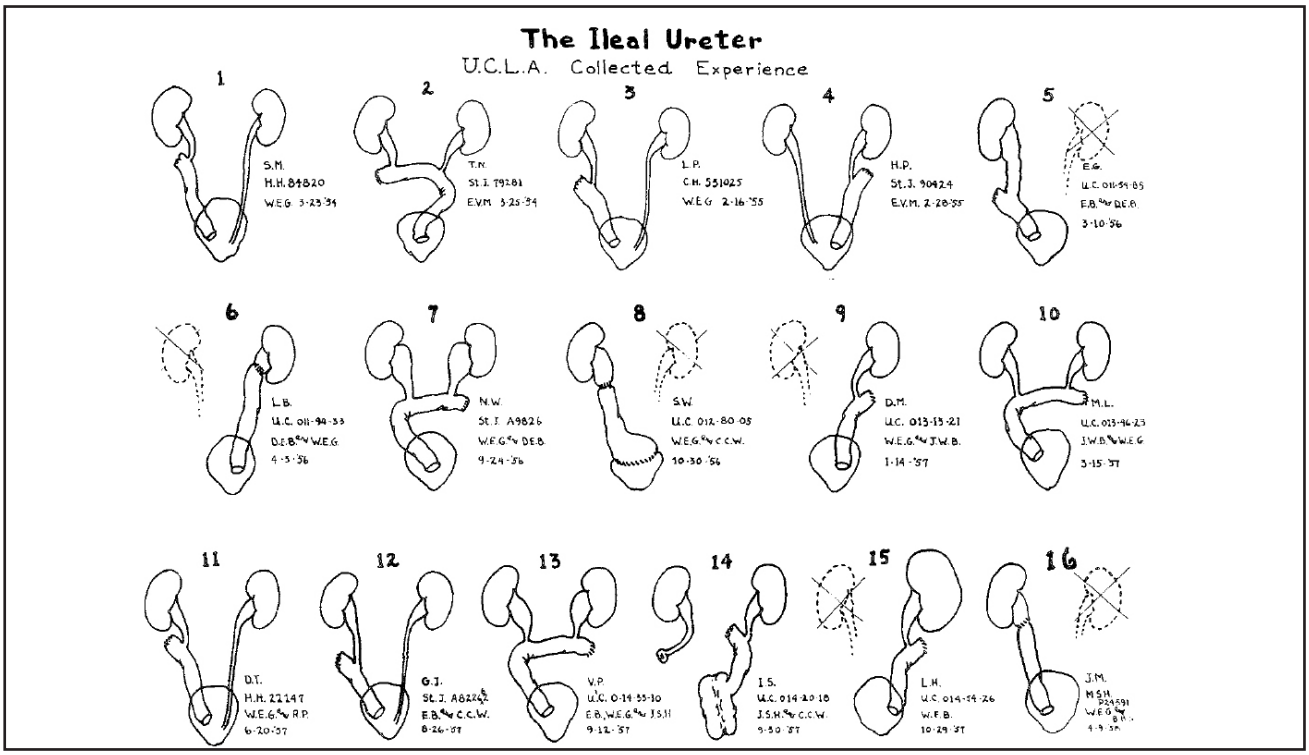

Figure 4. Willard Goodwin, a renowned urologist from UCLA, published a case series on the ileal ureter that were completed by urologists within his department. There are several variations shown, including different ureteral-bowel anastomoses and techniques for bilateral ureteral strictures. This also highlighted several technical and post-operative challenges of the use of bowel. Goodwin. J Urology. 1959.(17)

Continued Challenges of the Ileal Ureter

1) *Metabolic Derangements*: One of the major concerns regarding the use of bowel in ureteral reconstruction is its resorptive nature. In 1985, Boston urologists Michael Koch and W. Scott McDougal reported significant chloride, potassium, and ammonia reabsorption within the ileal segment.(18) Alterations in serum ammonia levels changed the body's normal buffering system, leading to acidosis. Furthermore, they found that these metabolic derangements were exacerbated in patients with preexisting renal impairment and bladder dysfunction. This established that a baseline serum creatinine greater than 2 mg/dL, and underlying inflammatory bowel disease (IBD) may be contraindications for neobladder reconstruction surgery, which remains today as a guideline. Interestingly, newer studies have shown that patients with advanced chronic kidney disease that underwent an ileal ureter had improved creatinine and eGFR despite having elevated preoperative creatinine.(19)

2) *Ileo-ureter Reflux*: Some studies postulated that reflux is present in a significant portion of ileal ureter patients but the clinical effect of reflux remains controversial.(20-22) In 1979, Richard Boxer, Donald Skinner, and colleagues at USC published that 74 of 89 (83%) patients who underwent ileal ureter had reflux, but serum creatinine was unchanged or improved in these patients upon follow up.(20) Various anti-reflux methods including the ileal-psoas tunnel(22), Yang-Monti(23, 24), and distal nipple techniques(25) have been proposed to reduce potential complications from reflux but increased the risks of ureteral obstruction.

3) *Mucous plugs:* To reduce the rate of mucous plugging, Dutch urologist Peter van Helsdingen and colleagues in 1984 used intraoperative dissection to resect the bowel mucosal layer in animal models.(26) However, this led to increased ureteral stricture rates. In 2017, Lujia Zou of Shanghai, under the guidance of Haowen Jiang and colleagues, attempted to use submucosal intestinal tissue to compensate for increased stricture risks but development ischemic inflammation.(22, 27)

Advancement of Minimally Invasive Techniques

The development of laparoscopic and robotic approaches have allowed the application of minimally invasive techniques to reconstructive urology and ureteral replacement surgery. Surgeons have described that the use of the Da Vinci robot, with its three-dimensional visualization of the surgical field, improved ergonomics, and enhanced hemostasis is applicable to ureteral replacement and ileal surgery.(28)

In 2000, Gill and associates reported the first 'straight' laparoscopic ileal replacement surgery in a patient with a solitary left kidney and a left sided ureteral urothelial carcinoma. The patient underwent left ureteral resection and ileal ureteral replacement. Total operative time was eight hours with an estimated blood loss of 200cc.(29) The first robotic-assisted ileal ureter in 2008 was reported by Joseph Wagner and colleagues from Hartford, Connecticut.(28) In this case, the robot was used for the initial ureter resection, undocked to allow for laparoscopic isolation of the ileal segment, and then redocked to the field to complete the ureteroileal and vesicoileal anastomoses. In 2014, Luis Brandao and associates in Cleveland, Ohio described the first completely intracorporeal robotic technique followed by subsequent series by other authors.(30-32) Limitations to the robotic approach included significant operative times, extended manipulation of bowel, and difficulty with bowel anastomoses which improve with surgical experience.

CONCLUSIONS:

Treatment of ureteral strictures ranges from natural orifice (i.e. transurethral) minimally invasive, endoscopic techniques to complex reconstructive surgeries with bowel substitution. The ileal ureter provides an option for long segment ureteral strictures. The modern ileal ureter utilizes techniques similar to those described more than a century ago. While the complications associated with this procedure are important to consider, they have led to novel surgical advances and continue to evolve

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