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Chapter

Historical Perspective and Innovations in Penile Urethroplasty

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Abstract

Penile urethral strictures are common and impact on quality of life and healthcare costs. Management of penile urethral strictures is complex and depends on the physical characteristics of the stricture. Contemporary studies show no difference between urethral dilation and internal urethrotomy in terms of long-term outcomes. Overall, long-term success rates range from 20 to 30%. However, their recurrence rate is greater for men with longer strictures, penile urethral strictures, multiple strictures, presence of infection, or history of prior procedures, which make them less cost-effective. Surgical urethroplasty is associated with higher long-term success rates, averaging from 85 to 90%, mostly in virgin or noncomplex cases. Historically, modern urethral reconstruction has evolved from 1950s with the revolutionary introduction of Johanson's technique for staged urethral reconstruction. Since then, many techniques have been developed and employed for urethroplasty, depending on the location, length, and character of the stricture. Successful management of urethral strictures requires detailed knowledge of anatomy, pathophysiology, proper patient selection, and reconstructive techniques.

Keywords: anterior urethra, urethral stricture, urethroplasty, penile

1. Introduction

Urethral strictures have been common since ancient times. Knowledge was gathered about the treatment of urethral stricture disease by ancient Egyptians and other civilizations more than two millennia ago. Nonetheless, little has changed until about 60 years ago. Since then, the management of urethral strictures, including the penile urethral segment, has been in continuous and rapid evolution. Although various reconstructive techniques are available for the treatment of penile urethral stricture, no single technique has been identified as the method of choice. An understanding of the penile urethral anatomy is important for the diagnosis and treatment of penile urethral stricture disease.

Urethral strictures, in general, are associated with significant impact on patients' quality of life. Penile urethral strictures, in particular, due to their exposed anatomic location and their surgical treatment, may cause significant impact on patients' sexual function and perception of (un)satisfactory penile cosmesis.

The anatomical and physical characteristics of the penile urethra are associated with additional challenges when compared to other urethral locations, especially due to its unsuitability for anastomotic repair and its relatively thinner corpus spongiosum. The choice of penile urethroplasty technique is largely influenced by etiology, location, length of the stricture, as well as prior surgical treatments. There are a number of challenges and controversies in the surgical reconstruction of penile urethral strictures, such as the use of grafts vs. flaps, use of skin vs. oral mucosa graft (OMG) tissue for augmentation or substitution techniques, the most appropriate indications for a single or a staged (at times, multiple) reconstruction, and, lastly, the management of particularly complex cases such as panurethral stricture disease and hypospadias "cripples" to achieve the best possible outcome.

Although penile urethral strictures can be managed by any of the above-mentioned procedures individually, they can also be more adequately treated by a combined approach. Among the various procedures available for treating urethral stricture, one-stage buccal mucosal graft urethroplasty is the current standard practice. The selection of technique for penile urethroplasty for an individual patient largely depends not only on the expertise of the surgeon but also upon the stricture's etiology, pathological characteristics, and location. Therefore, contemporary reconstructive urologists working in this field should be aware of, and permanently keep themselves updated on, the numerous surgical techniques required to deal with any condition of the urethra that might surface at the time of surgery.

This review provides a brief update of the options for the surgical reconstruction of different types and sites of penile urethral stricture as well as discussing current controversies, innovations, and possible future research in urethral reconstruction of the penile urethra.

2. Anatomical considerations

Classically, the anterior urethra is divided, at the level of the penoscrotal junction inferiorly and the suspensory ligament superiorly, into bulbar and penile segments, the penile part consisting of the external meatus, fossa navicularis, and the penile shaft urethra. The penile urethra extends from the distal margin of the bulbospongiosus (or penoscrotal junction) to the external meatus. The bulbar (proximal) segment is the shorter of the two and is located in the midline between both the penile crural and the cavernosal bodies. The penile urethra (distal segment of the anterior urethra), also called pendulous, lies in a dorsal groove between the two corpora cavernosa and extends from the penoscrotal junction to the tip of the glans penis. It is surrounded in its full length by the corpus spongiosum; it is mobile and stretches during penile erection; and its length varies according to the penile length. The caliber of the anterior urethral lumen is relatively uniform, widening distally to form the fossa navicularis, and narrowing again to end at the external meatus (**Figure 1**).

Histologically, the penile (distal anterior) urethra is surrounded by five tissue layers: urethral epithelium and lamina propria (urethral mucosa), corpus spongiosum, tunica albuginea, and Buck's fascia [1]. Most of the penile shaft urethra is lined by a stratified and pseudostratified columnar epithelium, except for the distal penile urethra, including the fossa navicularis, which is lined by ciliated stratified columnar epithelium or stratified nonkeratinizing squamous epithelium. The lamina propria of the penile urethra is a fibroconnective tissue with elastic fibers and scattered, longitudinally oriented smooth muscle fibers. Multiple mucus-secreting glands drain into the anterior urethral lumen, known as Cowper's glands in the bulbar urethra and Littre's glands in the penile urethra.
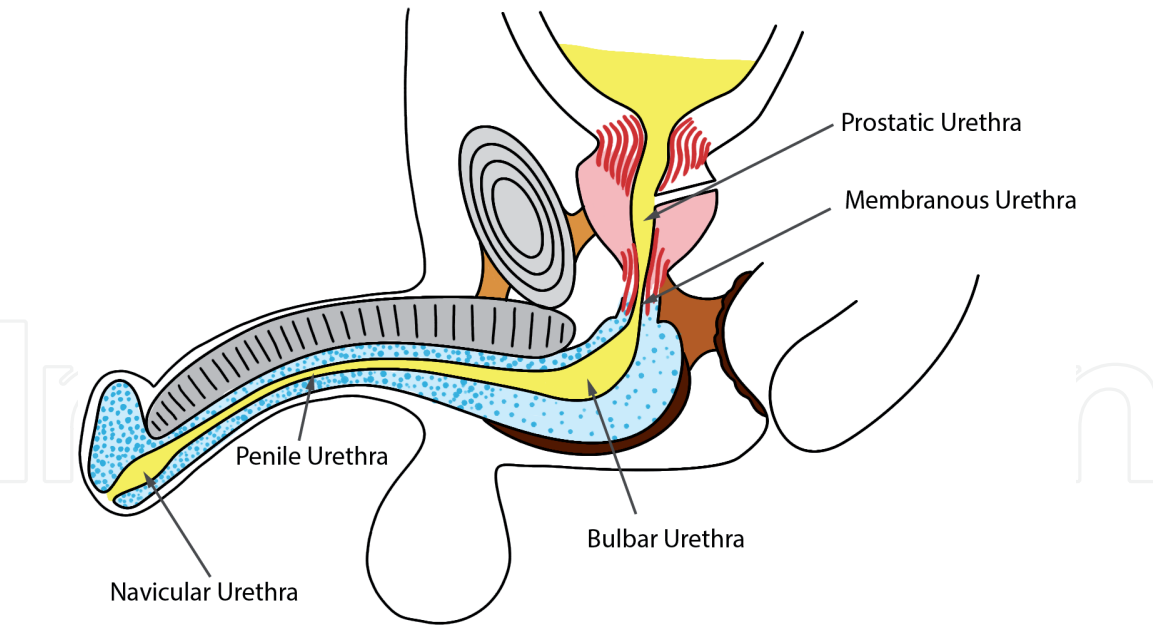
Figure 1.
Sagittal sectional view of the male urethra. The areas in blue and yellow represent the corpus spongiosum and lumen of the anterior urethra, respectively. The penile urethra extends distally from the penoscrotal junction or pubourethral ligaments (reproduced with permission from Dr. Enzo Palminteri).

The anterior urethra obtains its blood supply from the first of three penile branches of the internal pudendal artery, which in turn is a branch of the internal iliac artery. The internal pudendal artery travels through the Alcock canal and gives the inferior rectal artery, posterior scrotal artery and perineal artery, and then terminates as the common penile artery. Three branches arise from the common penile artery: the paired urethral or, most commonly, bulbourethral arteries that pierce the perineal body at a posterolateral location and supply the urethra, spongiosum, and the glans. The other branches are the paired cavernosal arteries that pierce the penile hilum to travel in the center of the erectile tissue, and the deep dorsal penile artery that travel between the crura and beneath the pubic bone to run under the Buck's fascia sending multiple circumflex branches to the corpus spongiosum and terminal branches to the glans penis, thus providing in a retrograde fashion a dual blood supply to the corpus spongiosum and urethra. It also sends cavernosal branches to contribute to the hemodynamics of the erection (**Figure 2A** and **B**). The venous

A

B
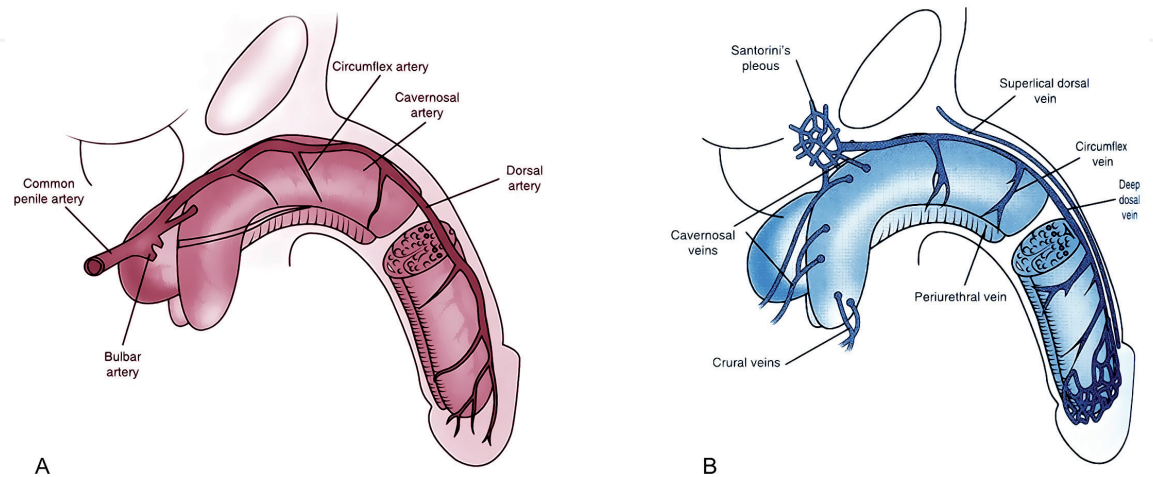
Figure 2.
Schematic illustration of vascularization of the penis and urethra: (A) arterial blood supply and (B) venous blood drainage.

drainage is through the emissary veins into the circumflex branches of the deep dorsal penile vein as well as through the urethral and bulbar veins into the internal pudendal vein. The anterior urethra is innervated by the urethrobulbar nerve, a branch of the perineal nerve derived from the pudendal nerve. The bulbocavernosus nerve, which is a branch of the pudendal nerve, gives off two branches that penetrate the rhabdosphincter at the three and nine o'clock positions. The pudendal nerve, gathering fibers from the second, third and fourth sacral spinal nerve, is both motor to the urethral rhabdosphincter and sensory to the urethra and glans penis (**Figure 3**). The lymphatic drainage of the anterior urethra is via the superficial and deep inguinal nodes, whereas the lymphatic drainage of the more proximal (the bulbar, membranous, and prostatic) urethra can take three routes: to the external iliac nodes, to the obturator and internal iliac nodes, or to the presacral nodes [2].

Understanding the penile anatomy and, in particular, the penile skin arterial blood supply is an important resource for penile urethral surgical reconstruction. The penis is covered with an elastic layer of skin that has no subcuticular adipose tissue: the dartos fascia, a layer of loose areolar subcutaneous connective tissue in the penis and scrotum. It lies immediately beneath the penile skin, allowing the skin to move freely over the shaft of the penis and is contiguous with Colles fascia in the perineum. The dartos, also with no adipose tissue, slides freely over the underlying Buck's fascia and is an extension of Scarpa's fascia of the abdominal wall, carrying superficial nerves, lymphatics, and blood vessels, which make this fascia extremely useful in bringing blood supply and preventing fistulation in urethral reconstruction. Beneath the dartos fascia lies the Buck's fascia, which surrounds the tunica albuginea of the two corpora cavernosa and the corpus spongiosum.

The development of fasciocutaneous penile skin island flaps, either as a vertical flap (as in Orandi flap) or as a circular transverse flap (as in McAninch/Quartey flap), takes advantage of the natural anatomical, relatively avascular cleavage planes between the skin and the dartos fascia and another between the dartos fascia and Buck's fascia.

The blood supply to the penile skin and anterior scrotal wall comes from the external pudendal arteries, whereas the inferior and posterior aspect of the scrotum
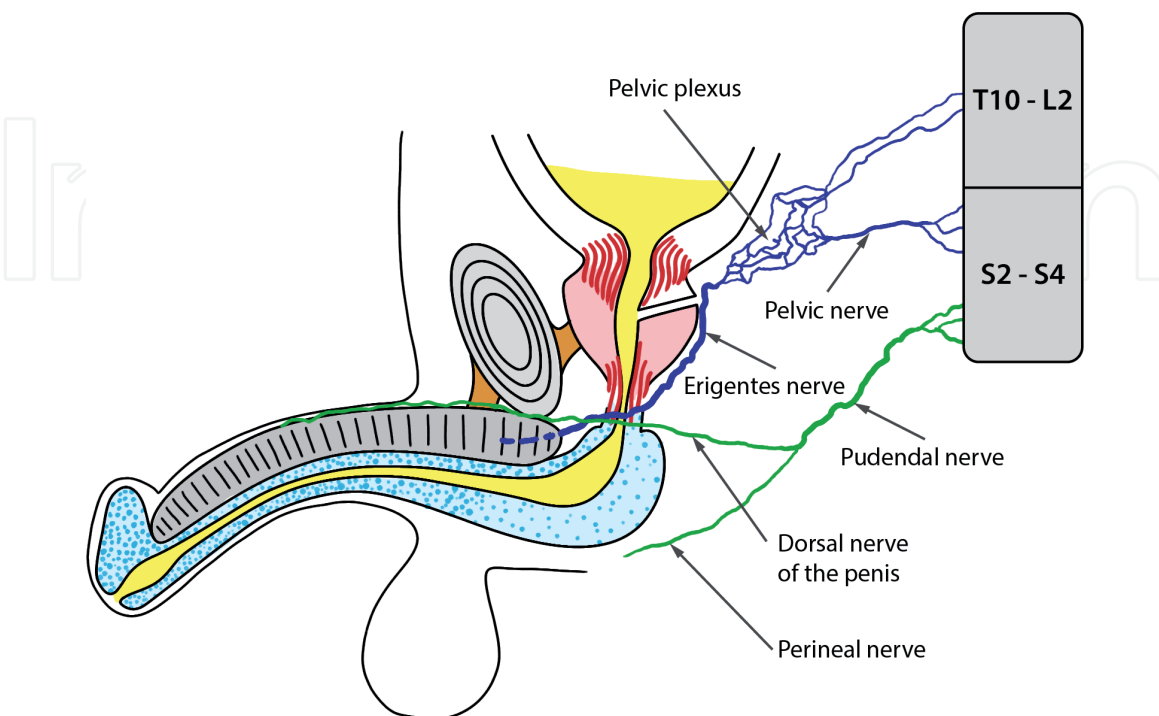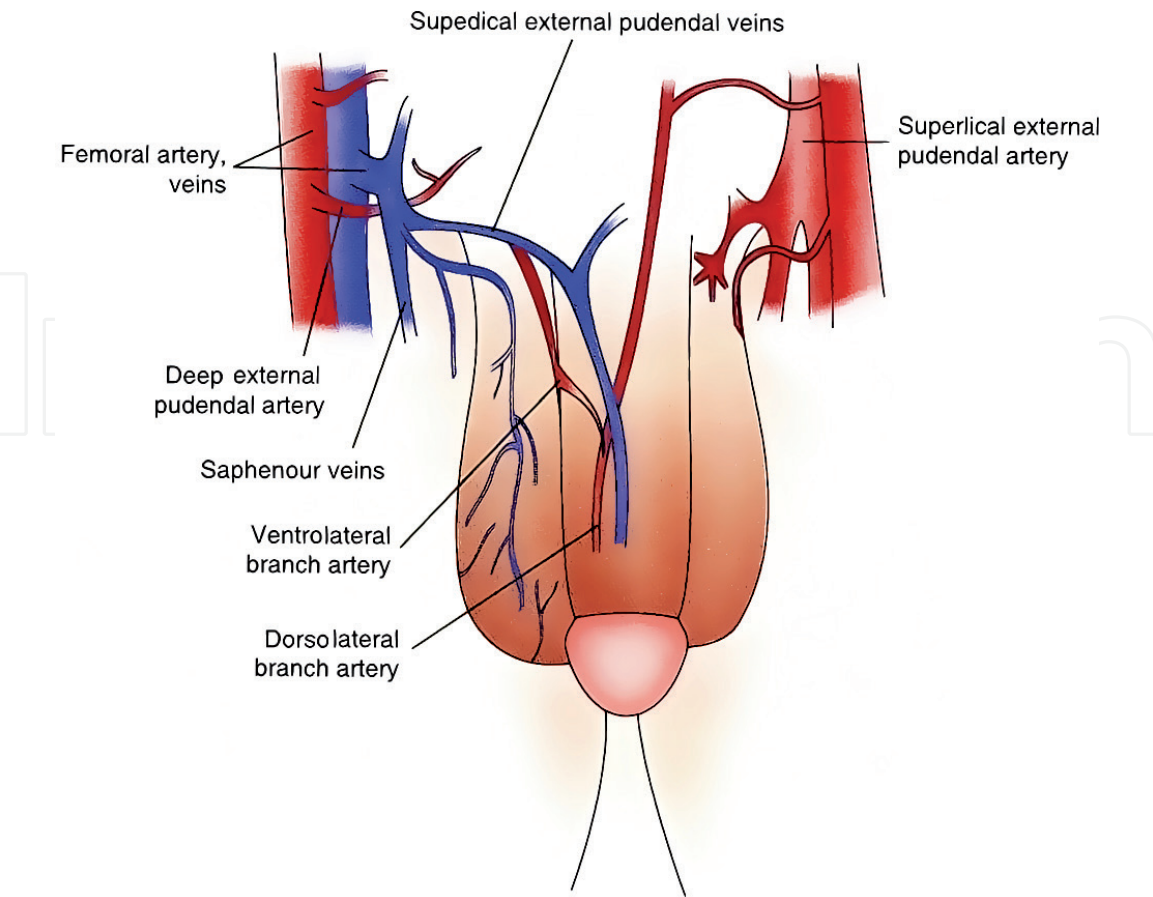

Figure 3.
Schematic illustration of autonomic and somatic innervation of the penis and urethra (reproduced with permission from Dr. Enzo Palminteri).

derives its blood supply from the posterior scrotal arteries, which are branches of the perineal artery, which in turn is a further branch of the internal pudendal artery (**Figure 4**). The superficial/superior branches of the external pudendal artery travel from medially and across the femoral triangle and within Scarpa's fascia to enter the base of the penis. After giving off anterior scrotal branches, they arborize to form an arterial network within the dartos fascia. Also, at the base of the penis, branches from the axial penile artery form a subdermal plexus to supply the distal penile skin and prepuce. Because the communicating vessels between the subcutaneous and subdermal arterial plexuses are minimal, a relatively avascular plane can be developed between the dartos and Buck's fascia. This fascial plexus, that is considered axial, is the true blood supply to the penile island skin flaps used in urethroplasty and, therefore, they can be mobilized widely and transposed aggressively and reliably.

The venous drainage of the penis includes the superficial dorsal vein, the deep dorsal vein, and the crural veins. The superficial dorsal vein drains the skin of the penis and empties into the superficial external pudendal vein and then into the saphenous vein. The deep dorsal vein begins at the base of the glans and retro coronal area and then travels deep to the Buck's fascia between the paired deep dorsal arteries. Along its course, it receives circumflex veins from the spongiosum until it passes under the pubic bone to join the periprostatic venous complex. The cavernosal veins drain into a subtunical venous plexus; then through emissary veins, they join the circumflex veins, which in turn empty into the crural vein and the periprostatic plexus or the internal pudendal veins. The lymphatic drainage of the penis is primarily to the superficial inguinal nodes.

A detailed understanding of the anatomy of the anterior urethra is a critical prerequisite for the accurate diagnosis and successful management of urethral strictures.

Figure 4.
Schematic illustration of the superficial arterial supply and venous drainage of the penis and scrotum.

3. Etiology

The etiology of contemporary urethral stricture disease involves a traumatic, iatrogenic, inflammatory, and idiopathic origin [3, 4]. Pathophysiology differs with age. The major causes of anterior urethral stricture in children are more likely to be trauma, mainly straddle injury, and complications from hypospadias surgery. Congenital and idiopathic strictures may also occur in children. In adult patients, most urethral strictures have an iatrogenic origin, mainly traumatic catheterization or transurethral manipulation or instrumentation. In the <10-year-old age group, strictures are mainly localized in the penile urethra, whereas in the >10-year-old age group, the bulbar urethra is the most common location [5].

In the past, inflammatory urethral strictures were predominantly associated with gonococcal urethritis, which has been effectively eradicated with penicillin-based antimicrobial agents. However, the emergence of resistant strains of *Neisseria gonorrhoeae* may be responsible for resurgence in these cases. Lichen sclerosus (LS, also and erroneously known as balanitis xerotica obliterans) is another inflammatory and challenging cause of urethral stricture disease, which usually involves genital skin, often progressing to panurethral stricture disease, and is associated with comorbidities, such as diabetes and obesity, which may aggravate surgical treatment [6, 7].

Stricture etiology is of particular significance in the penile urethra, as they tend to be more diffuse in nature (averaging 6.1 cm), especially if associated with LS, and shorter in the bulbar urethra (averaging 3.1 cm). Urethral strictures can be classified by their most common urethral location. Strictures involving the external meatus and fossa navicularis are predominantly inflammatory and iatrogenic in origin in 33–47% [3]. In the series reported by Fenton et al., globally, the etiology of anterior urethral strictures was idiopathic in 34%, iatrogenic in 32%, inflammatory in 20%, and traumatic in 14% [3].

Iatrogenic strictures are typically associated with instrumentation, such as transurethral resection, prolonged catheterization, and cystoscopy, totaling 90% of all penile strictures. Prior hypospadias repair and radical prostatectomy contributed to 6.3 and 3.2%, respectively [3, 8]. Such strictures are mainly the result of an ischemic injury secondary to traumatic urethral manipulation or instrumentation, particularly when a large bore catheter or resectoscope is used. Therefore, whenever relatively prolonged catheterization is necessary, smaller caliber/Fr catheters are recommended. For more extended periods of time, a suprapubic catheter is a better option.

Malignant strictures should be approached in a different clinical context and most likely require mutilating radical surgery.

Urethral dilatation
Internal urethrotomy
Laser urethrotomy
Grafts
Flaps
Combination of grafts and flaps
One-stage urethroplasty
Staged urethroplasty

Table 1.
Management options for penile urethral strictures.

4. Diagnostic evaluation

Clinical evaluation: the diagnosis of penile urethral strictures, like any other type of stricture, regardless of location, is based on a suggestive clinical history and physical examination. The main symptoms are related to obstructive voiding or urinary tract infection, or both. Some patients may less often present with urinary retention. Weak stream, incomplete bladder emptying, and a hyperactive bladder are usually the most prevalent complaints of patients with anterior urethral stricture [9]. If questioned carefully, most patients who present in chronic retention may state that their symptoms have been present for a long time, which they have tolerated fairly well and, therefore, have been neglected. In some occasions, the diagnosis is brought up to the urologist's attention because of difficult urethral catheterization for any reason, often in the operating theater before an operation that requires routine urethral catheterization. In about 1.3%, renal failure is the initial presentation of a urethral stricture [9].

Any relevant past history of urethral instrumentation, hypospadias surgery, and genital trauma should be obtained. Obstructive voiding symptoms should be assessed with a validated questionnaire. Presence of risk factors and comorbidities that may provoke ischemia or impair wound healing should be probed for. These include obesity, diabetes mellitus, severe peripheral vascular disease, cigarette smoking, long-distance bicycle riding, horseback riding, and sexually transmitted infections.

Physical examination should include palpation of the penile shaft for nodules or dense urethral scarring or constriction. The urethral meatus should be examined for narrowing and the surrounding glans for signs of LS. The penis should be examined to assess whether the patient has been circumcised, or there is sufficient shaft skin to allow development of a penile skin flap. The bladder should be assessed for potential detrusor hypocontractility, distention, and presence of an abdominal scar from a previous suprapubic cystostomy.

Uroflowmetry: this test provides a quantitative estimate of the severity of obstruction. A flattened, "en plateau" voiding pattern along with elevated postvoid residual urine volume signals the degree of urethral narrowing and efficiency of voiding and bladder emptying (**Figure 5**). More formal urodynamic studies (pressure-flow studies) are rarely indicated or necessary, except for complex cases or when the anatomic location of obstruction is needed in presence of concomitant prostatic obstruction.

Radiographic contrast studies: contrast studies of the urethra are the cornerstone of the imaging diagnosis. The combination of dynamic retrograde urethrogram and voiding cystourethrogram allows accurate assessment of stricture length and location (**Figure 6**). Dynamic retrograde urethrogram has been rated the gold standard of urethral stricture evaluation with a specificity and sensitivity of 90% [10].

Ultrasonography/sonourethrography: ultrasonography has a limited role in the evaluation of the male urethra. It may be useful to detect concomitant lesions such as calculus, trauma-induced soft tissue injury, or Peyronie's plaques that may coexist with urethral stricture disease. Sonourethrography, introduced in the mid-1980s, was reported to be a more accurate tool for the diagnosis and characterization of strictures, particularly in the bulbar urethra [11]. In addition to providing accurate information of the urethral stricture characteristics, sonourethrography allows assessment of the health and integrity of the soft tissues surrounding the strictured urethra. This modality represents an adjunct to contrast-enhanced studies and can increase the accuracy of anterior stricture length and spongiofibrosis as well as the inner diameter of the urethral lumen and, thus, improve surgical planning [12].

Endoscopy: endoscopic evaluation of a urethral stricture has a limited role as it allows only the identification of the most distal portion of the urethra. It does not determine
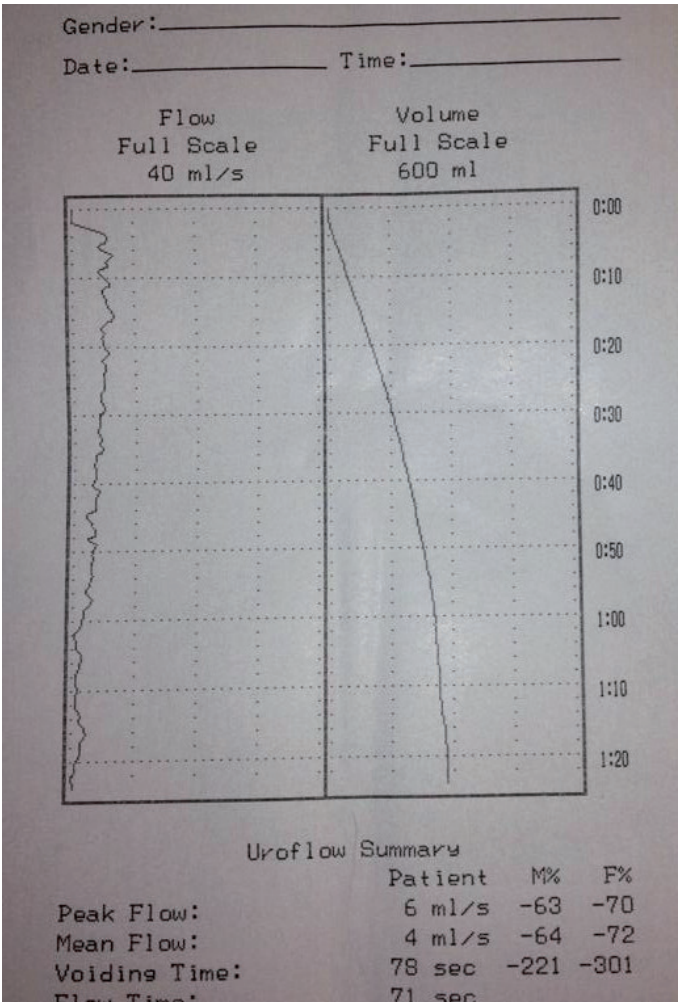
Figure 5.
"En plateau" obstructive uroflow in a patient with anterior urethral stricture.

Figure 6.
Retrograde urethrogram of long, irregular, "saw-toothed" penile urethral stricture typical of lichen sclerosus.

the length of the stricture nor can it assess the proximal stricture extremity and the corresponding proximal urethra. However, it may help to determine the amount of distal urethral elasticity, or when the insertion of a guide-wire through the stricture is necessary or deemed safe, or in a rare case of suspicion of urethral carcinoma.

5. Preoperative planning and intraoperative decision-making

Any appropriate treatment plan needs accurate identification of the stricture characteristics: location, length, depth, and thickness of fibrotic tissue (spongiofibrosis). It is critical that both the proximal and distal ends of a urethral stricture are completely and accurately assessed with endoscopy and bougienage during reconstruction as to not miss any diseased segment of the urethra. Both patient and urethral reconstructive surgeons must understand completely the goal(s) of treatment before a decision is made. The decision to choose urethroplasty over another approach to a specific urethral stricture depends on patient expectations, goals, and comorbidities. In elderly or frail patients, an expectant or conservative management is more likely to be offered. Therefore, treatment options and their individual potential outcomes in terms of cure, or simply palliation, and complications should be carefully discussed with the patients and their family. On the other hand, urethral reconstructive surgeons need to keep themselves updated and abreast regarding the vast array of treatment options and their precise and specific indications and, therefore, should be flexible enough to intraoperatively adapt and/or adopt a different strategy for a specific scenario, which was not anticipated preoperatively. Thus, it is only legitimate and ethical to embark on urethral reconstruction if one can master and offer the patient all necessary surgical options to treat his specific urethral problem. It is very important to bear in mind that the penile urethra is the most exposed segment of the male urethra, and any surgical procedure or technique should achieve not only a satisfactory functional outcome but also a cosmetic one.

6. Management options

The key techniques include mainly urethral dilatation, endoscopic urethrotomy, anastomotic repairs (rarely in the penile urethra), substitution repairs (ventral, dorsal, double-faced), free grafts of skin (full thickness and split thickness skin), oral mucosa, lingual mucosa, bladder mucosa, retroauricular skin (Wolf's graft), and skin flap repairs (circumferential, longitudinal and variants) from penile and (less commonly) scrotal skin, as well as the use of adjunctive maneuvers such as the use of advancement flaps for additional blood supply or defect coverage (**Table 1**).

Urethral dilatation: several methods for urethral dilatation exist: dilatation with a balloon, filiform and followers, urethral sounds (metallic or nonmetallic), or self-catheter dilatation. Urethral dilatation is carried out by gradual progressive stretching of the urethral lumen to a maximal diameter of 24 Fr. However, if performed aggressively, it will lead to further urethral trauma and scarring. It should be regarded as a palliative procedure and rarely as a curative one. It is mainly indicated in very select cases of strictures of the external meatus and fossa navicularis. It should be avoided in patients with LS as it often worsens the inflammatory process. Repeat dilatation should be avoided as it does not treat the underlying dense spongiofibrosis associated with more complex strictures.

Internal urethrotomy: also called direct vision internal urethrotomy (DVIU), it was first described by Sachse [13]. It consists of a cold-knife incision of the scar tissue allowing its release and healing of the underlying tissue by secondary epithelialization around a urethral catheter and thereby increasing the diameter of the urethral lumen. Apparently, only superficial strictures benefit from this treatment option when the incision is carried out through all thickness of the scar. Its success depends mostly on stricture length and degree of spongiofibrosis [14, 15]. It is best indicated for short strictures (<1.5 cm in length). Heyns et al. have suggested that if the stricture has not recurred within the first 3 months after a single DVIU (or dilatation), the stricture-free

rate is 50–60% for up to 4 years of follow-up evaluation [16]. Recurrence rates vary in the penile and bulbar urethra: 84 and 58%, respectively [17]. Like dilatation, repeat urethrotomy is known to be associated with worse outcomes [15–18]. The failure rates of these minimally invasive strategies are poor and well documented, ranging from 9% after 1–3 years of follow-up [18]. At ≥4 years, the chance of stricture-free status is nearly 0% [19]. Open urethral reconstruction should be considered in case of recurrence after these minimally invasive attempts, unless the patient prefers intermittent self-catheterization as a chronic treatment plan. Nonetheless, despite the limitation of these minimally invasive procedures, they may become more useful if new generations of currently experimental modalities for scar modulation prove successful [20].

Laser urethrotomy: it utilizes several types of lasers, including CO_2, argon, potassium titanyl phosphate (KTP), neodymium-doped yttrium aluminum garnet (Nd:YAG), holmium, and excimer lasers. They use different technologies and different depths of tissue penetration.

A meta-analysis of outcomes and complications of laser versus cold-knife urethrotomy compared unfavorably regarding laser: 12 versus 6.5%, respectively [21]. Laser urethrotomy may look appealing for the anterior urethra but with no definitive benefit over cold-knife urethrotomy.

Grafts: excision and primary reanastomosis, onlay grafting, and the use of flaps have been used for anterior urethral reconstruction. However, anastomotic urethroplasty rarely has a place in the penile shaft urethra due to the high risk of penile chordee or curvature, which impacts on erectile function and cosmesis. In the penile urethra, graft urethroplasty is traditionally used as it does not cause urethral tension. Several types of tissue can be used as onlay/inlay grafts: skin (full-thickness or split-thickness grafts), bladder mucosa, oral mucosa (buccal, labial, or lingual), and rectal mucosa. Historically, preputial skin grafts were the mainstay of grafting material until oral mucosa became popularized in the early 1990s [22, 23]. The crucial factor for grafting success is that the local tissue must have a healthy blood supply for normal graft taking. Single-stage graft urethroplasty uses the rich blood supply of spongiosal tissue ventrally or dorsally to support the graft, with overall success rates approaching 75–90% in the penile urethra, depending on stricture length [24, 25]. Little is found in the literature regarding both bladder epithelial grafts and rectal mucosal grafts, mainly due to lack of data about the process of take of these grafts.

Oral mucosal graft is currently the graft of choice, owing to their short harvest time, easy harvest technique, and the physical characteristics including resistance, durability, immunogenic properties, excellent vascularity, hairlessness, low oral morbidity, concealed donor site and high success rates [24, 25]. For these reasons, over the past 20 years, oral mucosal grafts have shown better handling characteristics and long-term stricture-free outcomes, and have replaced both penile skin grafts and flaps. However, patients with long and complex urethral abnormalities or with contraindications to oral mucosal graft use, such as those with leukoplakia, systemic skin disease of the oral cavity or history of chronic tobacco chewing may still necessitate split or full thickness skin grafts.

One controversy in anterior urethral grafting is related to dorsal or ventral placement of the graft on the urethra. Some urethral surgeons favor dorsal placement in both bulbar and urethral strictures, whereas others opt for ventral placement [26–31]. Although several studies have demonstrated comparable success rates for dorsal and ventral onlay grafting, the author of this chapter favors the use of dorsal placement of the graft in the penile urethra because the spongiosal vascularity in the ventral urethra is thinner and the graft support is less reliable when compared to the dorsal urethral surface.

Flaps: detailed knowledge of the blood supply to the penile skin and corpus spongiosum is mandatory for successful tissue harvest and transfer (see Section 2). Rather

than rely on the recipient site for survival, flaps depend on their native blood supply containing pedicle for transfer. Flaps can be classified by their blood supply, harvest technique or their method of transfer. Several types of flaps have been used in urethral reconstruction: penile skin, hairless scrotal skin, gracilis muscle, and the forearm or upper arm as free flaps or (microvascular free-transfer flaps). Popularized in the past, scrotal skin flaps are random rotational flaps that can be used for urethral and genital reconstruction [32–36]. However, their use for urethral reconstruction was associated with unacceptable long-term complications. They were predominantly used for repair of complex bulbar urethral strictures as these flaps were difficult to reach the penile urethra because of their short pedicle. They are practically abandoned.

Various penile skin flaps have been described, which can be raised ventrally or dorsally on the penile shaft and taken longitudinally or circumferentially [37–39]. These flaps are fasciocutaneous in nature and are based on dartos fascia pedicle. The ventral, longitudinal flap, as described by Orandi, is best suited for penile shaft urethral strictures that do not reach the base of the penis or any part proximal to the penoscrotal angle because hair-bearing skin will inevitably be involved in the reconstruction. On the contrary, the transverse, circumferential preputial/distal penile skin flaps are long enough to bridge defects of the entire penile urethra and most of the bulbar urethra for example in panurethral defects. Ideally, flaps should be hairless, adapted to a moist environment, with a reliable vascular pedicle, mobile, and cosmetic. In general, anterior urethral reconstruction with the use of flaps has become less prevalent due to the increased popularity of oral mucosa grafts. A rise in prevalence of genital and urethral LS has also contributed to the near abdication of the use of flaps. Nonetheless, island skin flaps still find an important indication in reoperative cases with extensive spongiofibrosis and ischemic urethral mucosal plates where chances of graft take are minimal. These circumstances occur after irradiation, severe trauma, or infection.

One-stage vs. two (multiple)-stage reconstruction: in the past, most penile urethral strictures were repaired through a staged approach [40–43]. However, because of advancements with pediatric hypospadias surgery, adult noncomplicated penile urethral strictures are now more commonly repaired with single-stage procedures. In 1995, Bracka described a two-stage urethral reconstruction, which enables a versatile approach to surgical reconstruction of previously failed, complex penile urethral strictures, especially hypospadias cripples [42]. The Johanson marsupialization was developed and subsequently reserved for penile urethral strictures [43].

Repairs in adults who failed hypospadias repair in childhood pose a particular reconstructive challenge because of dense scarring, tissue inelasticity, inflammation, impaired blood supply, and penile and urethral shortening from previous, often multiple, operations [44–47]. Penile urethroplasty should be performed in a single stage, whenever feasible, to avoid discomfort and disability to the patient from a multistage repair. Most strictures associated with trauma, infection, or instrumentation, where the penile skin, dartos fascia and spongiosum are not significantly damaged, can be approached through a single-stage procedure. On the other hand, presence of local infection or inflammation associated with a specific underlying disease process obliterated urethral segments with dense surrounding fibrosis, and a history of prior interventions, especially prior flap or hypospadias repairs, are contraindications for single-stage repairs and, therefore, should not be advised. The two-stage reconstruction involves surgical opening of the stricture, augmentation, or substitution (more commonly with use of oral mucosa grafting) of the diseased urethral segment and creation of temporary urethrostomy for drainage (first stage), followed between 4 and 6 months later by neourethral tubularization (second stage). Therefore, it should be confined to situations where it is inappropriate to maintain the axial integrity of the urethral plate and a full circumference urethral reconstruction is mandatory.

7. Urethral reconstruction by stricture location

In order to facilitate description and discussion of the various surgical procedures used for adult penile urethral reconstruction, we will group them according to stricture location in the urethra: (1) external meatus and fossa navicularis and (2) penile shaft urethra. Furthermore, a separate section will be devoted to procedures used for previously failed repairs or reoperative procedures (**Table 2**).

7.1 External meatus and fossa navicularis

Strictures involving exclusively the external meatus may be treated with **dilatation** if the stricture is not obliterative or the scarred tissue is minimal, the urethral lumen is still patent and elastic. It is considered palliative and should be attempted only once. Strictures associated with LS rarely respond to conservative options, such as dilatation, urethrotomy, and meatotomy.

Meatotomy/meatoplasty: either ventral or dorsal, meatotomy can be used for select meatal strictures. A ventral or dorsal midline incision is performed sharply, and the resultant mucosal edges are everted and reapproximated to the glans using 4–0 or 5–0 absorbable sutures. The dorsal side should be avoided, which can bleed profusely by cutting into the highly vascularized spongiosal tissue of the glans. The ventral approach usually leaves the patient with a slight degree of hypospadias that is usually well tolerated. The goal is to create a patent 22–24 F urethral lumen, particularly in cases of LS. Adjuvant topical therapy may be helpful. Meatal strictures that need meatoplasty usually require concomitant reconstruction of the fossa navicularis.

In 2004, Malone described a technique to relieve stenosis of the external urinary meatus resulting from LS [48]. The procedure is rapid and easy to perform on an outpatient basis, providing good cosmesis and functional voiding without spraying. The meatotomy is carried out dorsally avoiding a hypospadiac meatus. If the stricture extends into the fossa navicularis, oral mucosa graft reconstruction is performed. The final result is a slit-shaped with good caliber meatus at the tip of the glans. The procedure has been successfully reproduced by others [49].

Longitudinal skin flap techniques: initially reported in the early 1960s, it is based on the Y-V principle and used for short strictures of the meatus and fossa navicularis [50, 51]. Good outcomes can be achieved with these techniques, especially in patients with strictures resulting from instrumentation such as a large bore catheter or transurethral resection and those that are not associated with LS. The use of genital skin in LS patients has a high failure rate.

Several variants have been reported. Cohney in 1963 described a penile flap procedure based on a circumferential elevated random penile skin flap. The distal urethra is well open, but the patient is left with a less appealing cosmetic result and a retrusive meatus (**Figure 7A** and **B**). Blandy-Tresidder in 1967 developed a flap procedure based on dartos fascia vascularity. It also provides good functional outcomes, but only modest improvement of the cosmetic final appearance. The meatus is usually left at the coronal level (**Figure 7C** and **D**). The Brannen flap repair [52], a modification of Blandy's procedure, was described in 1976 to try to create a better cosmetic appearance of the glans and distal penile segment [53]. However, some mechanical problems associated with the flap advancement make this procedure inefficient and, therefore, offer marginal improvement in terms of cosmesis (**Figure 7E** and **F**). Designed to create a cosmetically normal meatus and glans penis, De Sy in 1984 further modified the Blandy and Brannen techniques using an advancement midline skin island flap [54]. However, the proximal portion of the flap is de-epithelialized leaving a distal skin island on dartos fascia (**Figure 7G** and **H**). Again, the mechanics of the flap advancement is inefficient.
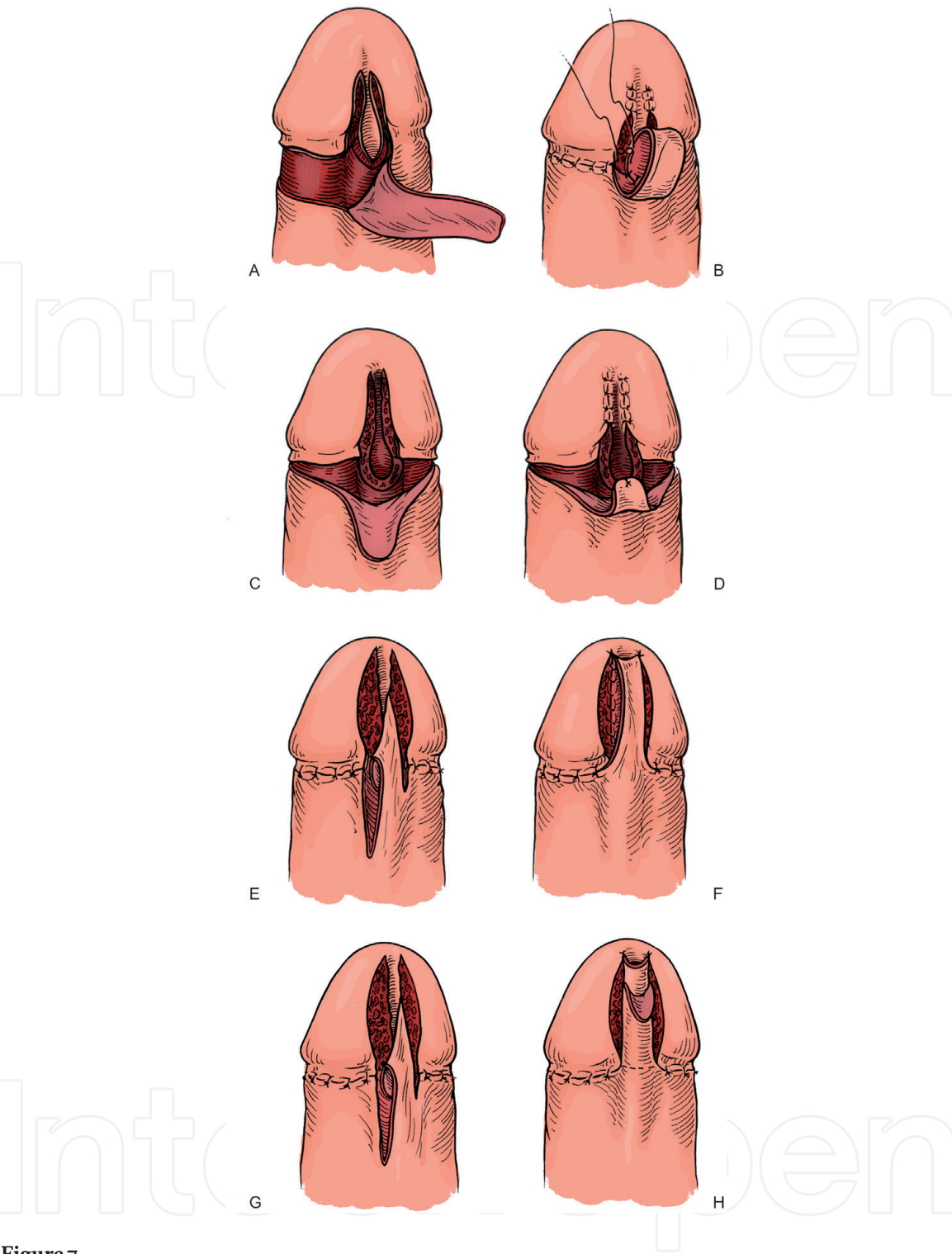
A. Ext. meatus and fossa navicularis

- Meatotomy/meatoplasty
- Longitudinal skin flap techniques
  - Cohney [50]
  - Blandy-Tresidder [51]
  - Brannen [52]
  - De Sy [53]
- Transverse ventral/circumferential fasciocutaneous skin island flaps
  - Jordan [54]
  - McAninch [39]
- Graft techniques
  - Tubularized full-thickness skin graft (Devine, 1979)
  - Inner prepuce [41]
  - OMG [41]
- Combination of grafts and flaps [65]
- Endourethroplasty techniques
  - Nandé (1998)
  - Nikolavsky et al. [64]
- Staged techniques
  - Bracka [41]
  - Jordan (2009)
- Tubularized incised plate urethroplasty
  - Snodgrass [58]

B. Penile shaft urethra

- Flap reconstruction
  - Orandi flap [37]
  - Quartey flap [67]
  - Mcflinch flap (1993)
  - Turner-Warwick flap (1993)
- Graf reconstructions
  - Dorsal OMG onlay (Barbagli, 1996)
  - Dorsal OMG inlay by ventral urethrotomy [59]
  - Penile inversion and one-sided dorsolateral OMG graft tech [75]
- Staged reconstructions
  - Johanson's techniques [40]
  - Mesh graft urethroplasty [77]
  - Staged OMG urethroplasty
- Tissue engineering/stem cell therapy

Table 2.
Urethral reconstruction by stricture location.

Figure 7.
Schematic illustration of several techniques for surgical reconstruction of strictures of the urethral meatus and fossa navicularis. (A, B) Cohney's meatoplasty: an eccentric, transversely oriented, subcoronal flap is developed, and the urethrotomy is extended to normal urethra. The transverse flap is rotated into the urethrotomy defect. (C, D) Blandy's meatoplasty: creation of a midline flap. Urethrotomy is extended till normal urethral lumen. The flap is advanced into the urethrotomy defect. (E, F) Brannen's meatoplasty: a longer midline dartos-based flap is developed and is then widely advanced. (G, H) De Sy's meatoplasty: a midline flap similar to Brannen' technique is mobilized. The proximal portion of the flap is de-epithelialized leaving a distal skin island attached to a dartos pedicle. The de-epithelialized surface of the flap is anastomosed, and the ventral glans is reapproximated over the reconstruction (from Jordan and McCammon [96]).

Transverse ventral fasciocutaneous skin island flap: as initially described by Jordan, this is a broad-based penile skin island flap oriented transversally on the ventral penile skin and elevated on a dartos fascia pedicle [55]. Minimal flap advancement is required, and the cosmetic appearance is virtually normal (**Figure 8**). McAninch modified this technique avoiding any disruption of the ventral glanular
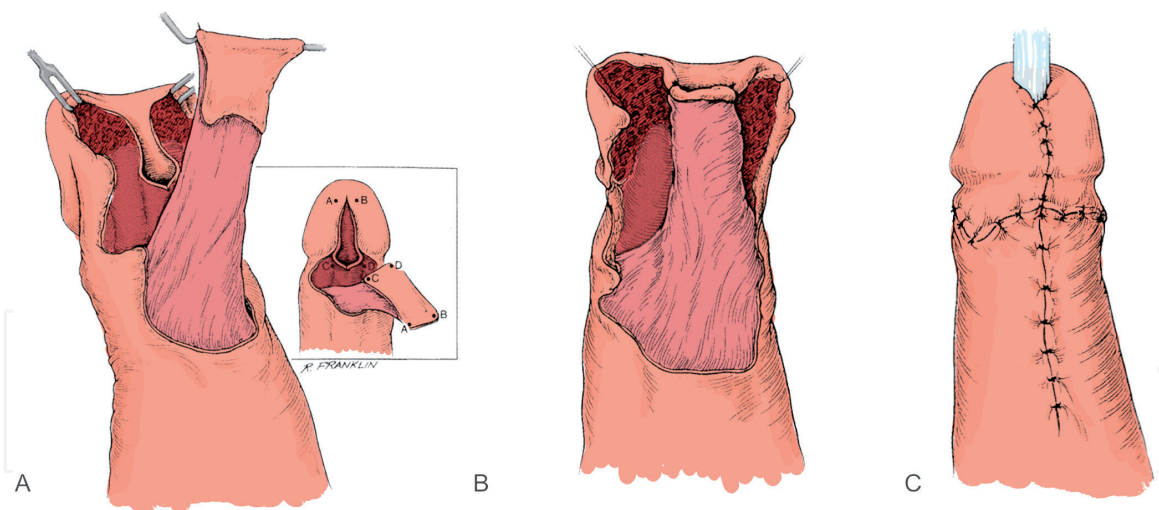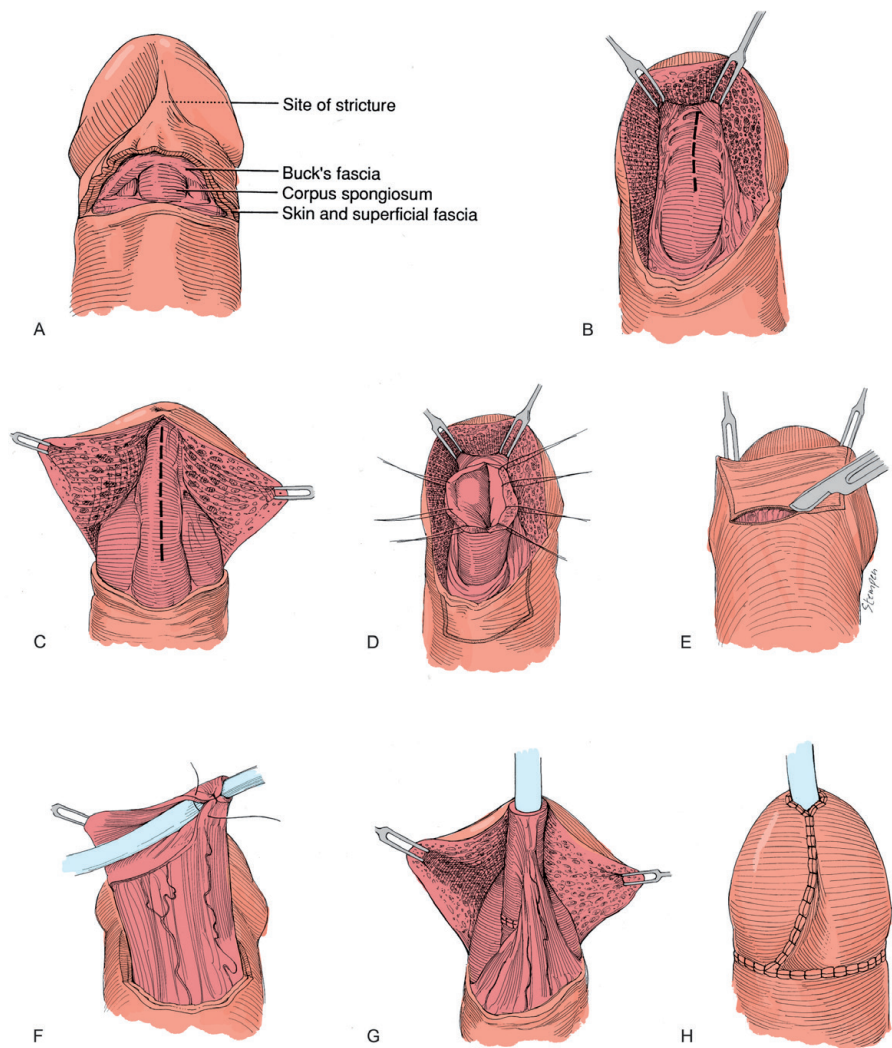
Figure 8.
Schematic illustration of Jordan's ventral transverse skin island flap procedure. (A–C) After urethrotomy is made till normal urethra, a ventral skin island flap is elevated above Buck's fascia, and the lateral glans wings are exposed. The skin island is rotated, transposed, and inverted into the urethrotomy defect. The glans wings are sutured ventrally. Inset shows details of the rotation, transposition, and inversion of the flap (from Jordan and McCammon [96]).

integrity, which he assumed to provide a superior cosmetic result. This would be of paramount importance to the patient, overshadowing the functional success of the reconstruction. In his technique, the glans is exposed in either a glans-cap or a glans-wings fashion (**Figure 9**) [56, 57].

Graft techniques: penile skin grafts were first employed and preferred tissue for urethroplasty before the advent of oral mucosa. Devine described a procedure using a tubularized full-thickness skin graft to reconstruct the external meatus and fossa navicularis [58]. Bracka reported in 2008 that the inner prepuce can be used for postischemic or infectious scarring as it is thin, flexible, with a reliable take, adapted to a moist environment and with no potential for hair growth (**Figure 10**) [43]. If not available, then postauricular skin graft is an acceptable alternative if oral mucosa cannot be harvested. However, due to its physical and biological characteristics, abundance, easy harvesting with minimal impact on the concealed donor site, and low oral morbidity, oral mucosa has become the most popular material for substitution or augmentation in urethral stricture repair. Oral mucosa can be used in strictures related to LS. It can be used in a single or staged procedure. Single-stage procedures are appropriate if the urethral plate is salvageable. In 1994, Snodgrass described a technique for the correction of pediatric hypospadias, which involved incision of the urethral plate followed by tubularization and secondary healing of the incised plate [59]. Although it produces good results in children, this procedure has not been associated with similar results in adults, often requiring inlay OMGs to increase the urethral lumen diameter [60]. Endourethroplasty techniques emerged in the early 1980s [61]. A few variants were reported later [62, 63]. However, due to inherent technical difficulties and complications of surgical reconstruction of distal penile and fossa navicularis strictures, these procedures have not become popular. Recently, Nikolavsky et al. has introduced a novel surgical technique for the reconstruction of distal urethral strictures using OMG through a transurethral approach with encouraging initial results (**Figures 11** and **12**) [64]. They designed this novel and elegant surgical concept in order to avoid the complications, technical difficulties, and limitations of the previous procedures used in this urethral area. The surgical procedure is applicable to the entire distal penile urethra, avoids an external ventral skin incision, preserves the glans penis, and employs oral mucosa for grafting, thus
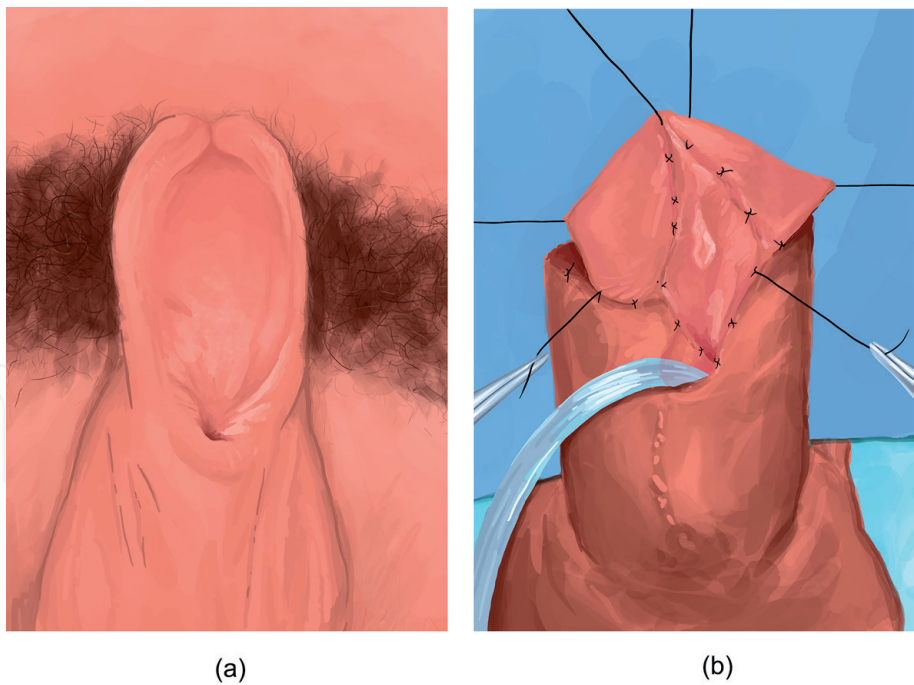
Figure 9.
Fasciocutaneous distal penile flap urethroplasty as described by McAninch. (A–H) Urethral exposure followed by ventral longitudinal urethrotomy. The fossa navicularis is exposed with either a glans-cap or a glans-wings technique. A fasciocutaneous distal, transverse, ventral penile flap is developed. The urethral stricture can be corrected by either a ventral onlay or a neourethral tube. The glans wings or cap is sutured to cover the flap reconstruction (from Armenakas and McAninch [97]).

achieving both excellent functional and cosmetic results. This procedure is especially indicated for patients affected by LS-related distal strictures, where only oral mucosal grafts are advised.

Combined flap and graft technique: in 2011, Gelman and Sohn described a procedure combining a dorsal onlay graft with a ventral onlay flap for a subset of patient with ischemic, obliterated distal strictures who had already failed urethral repair, or who had a history of hypospadias [65]. This procedure is particularly useful in strictures associated with compromised urethral plates due to ischemia and dense scarring from previous repairs and when a two-stage procedure is not desired (**Figure 13**).

Staged techniques: these techniques are best suited for patients who have failed hypospadias repairs or the urethral plate is deficient or densely scarred, or if there is involvement of LS. These techniques may be considered more versatile than flap repairs and are preferred in patients with LS. The modern staged urethral reconstruction described by Bracka in 1995 is a versatile approach to difficult anterior urethral reconstructions [41–43]. In Bracka's procedure, the diseased urethra is excised entirely and the urethral plate is replaced by an OM onlay graft (**Figure 10**). Jordan later described a similar technique [66].

(a) (b)

Figure 10.
Two-stage distal urethra reconstruction as described by Bracka. (a–b) Marsupialization of the urethra and placement of the oral mucosal graft after excision of the diseased urethral mucosa at the first stage. Aspect of the graft 6 months later, which is then prepared for tubularization at the second stage.

(a) (b) (c)

(d) (e)
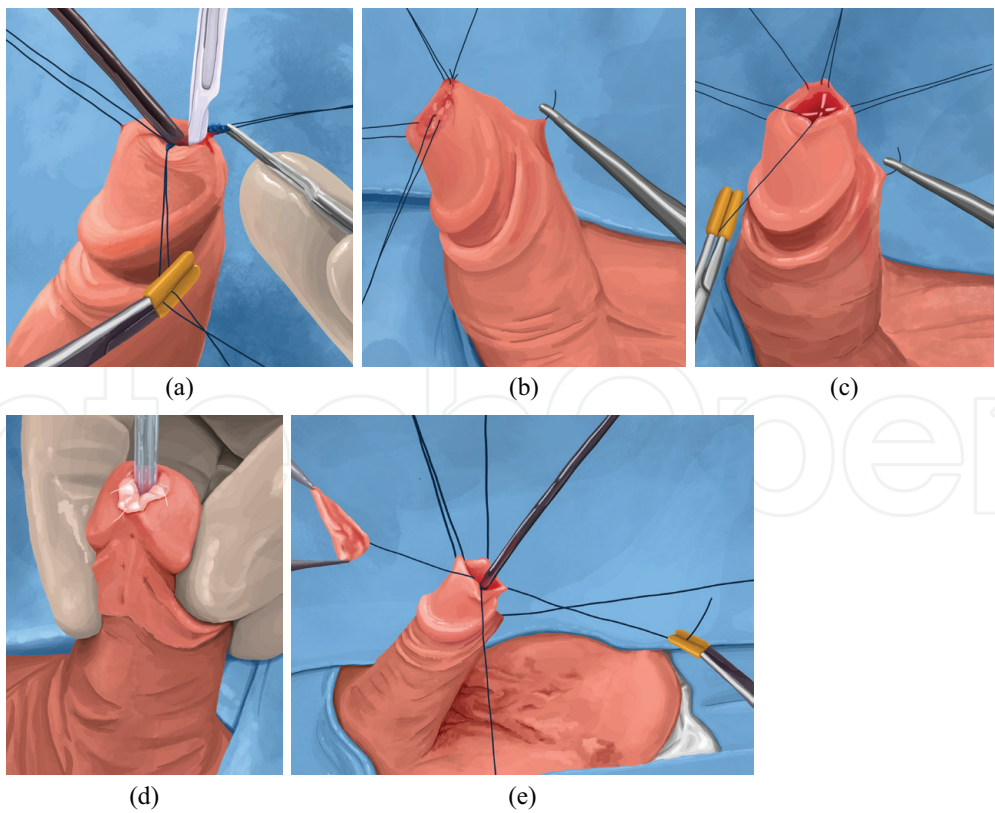
Figure 11.
Transurethral ventral buccal mucosa graft inlay urethroplasty for reconstruction of fossa navicularis and distal urethral meatus as described by Nikolavsky. (a-e) Transurethral ventral shallow resection of scar tissue. Placement of double-armed suture through buccal graft and through apex of urethrotomy (inside out). External apical suture tying, meatal BMG edge fixation, and additional inside-out quilting of the graft with double-armed sutures (reproduced with permission from Springer Science + Business Media Dordrecht, Ref. [62]).
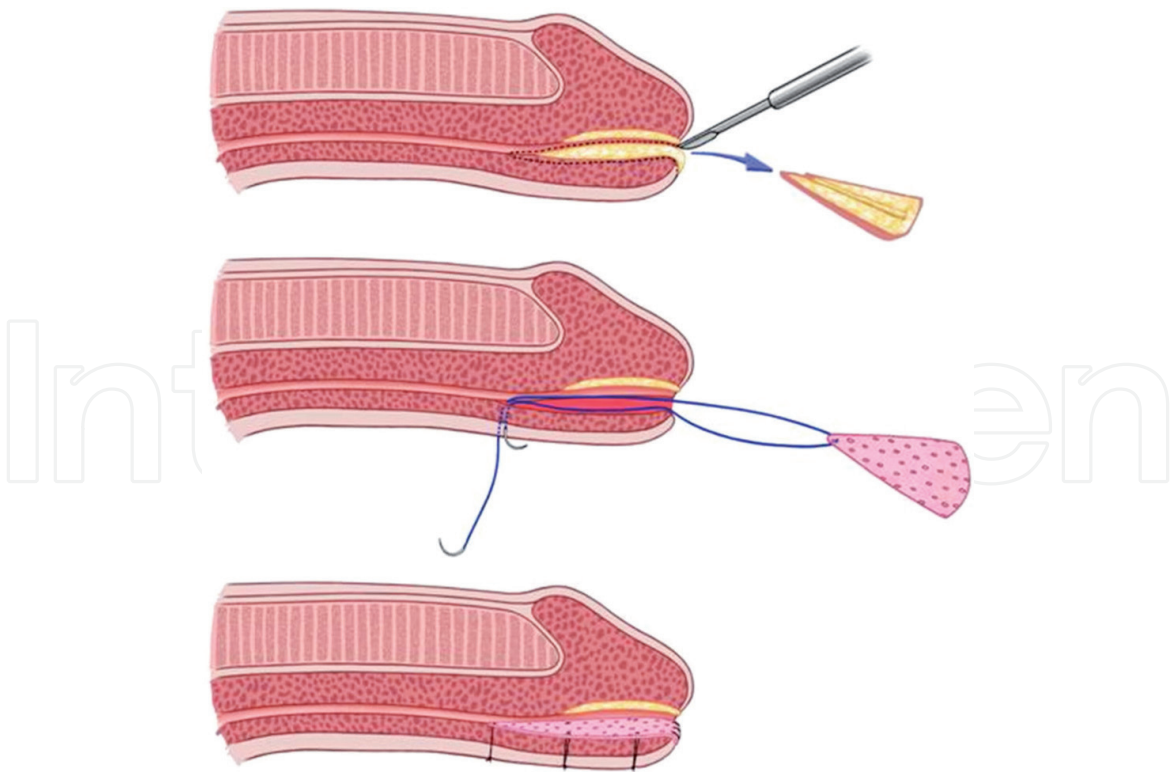
Figure 12.
*Intraoperative demonstration of the procedure described in **Figure 11** (reproduced with permission from Springer Science + Business Media Dordrecht, Ref. [62]).*
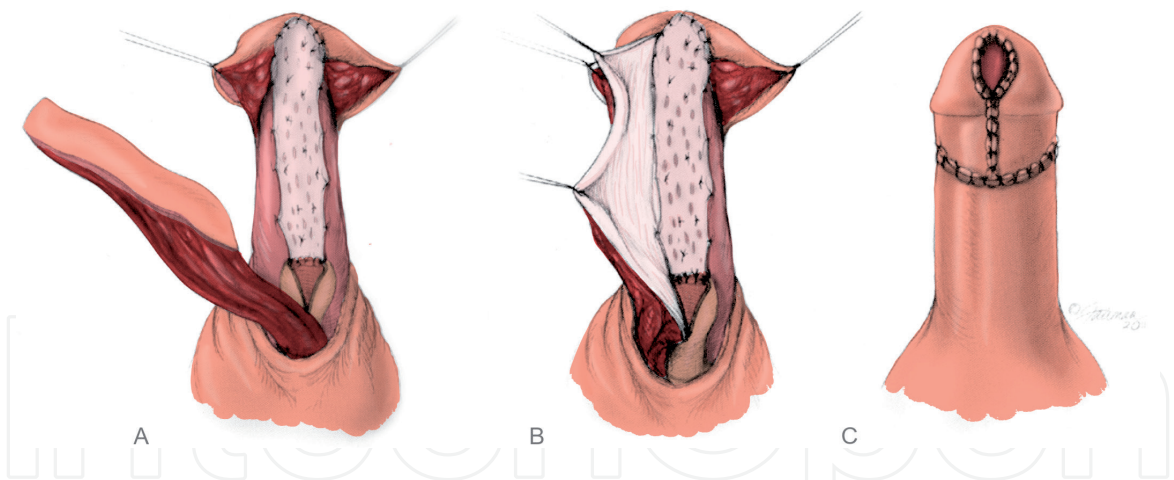
Figure 13.
Schematic illustration of single-stage, combined flap graft technique as described by Gelman. (A–C) Oral mucosal graft is placed and quilted dorsally followed by closure of the urethrotomy defect by a penile skin flap (from Gelman and Sohn, Ref. [63]).

7.2 Penile shaft urethra

For penile shaft urethral strictures, a stricturotomy and onlay or inlay patch graft, or alternatively a flap reconstruction, can be used for simple strictures. More complex cases may eventually require total excision of the strictured area and circumferential reconstruction with OM grafts or penile skin flap. In more complex situations, such as after previous failed repairs and compromised or obliterated urethras, a staged reconstruction is preferable. Penile urethral strictures are rarely cured by dilatation or DVIU. If either of these procedures fail once, the chance of a better outcome with a second attempt is almost nil, making urethroplasty the only

curative option. Anastomotic urethroplasty should be avoided in the penile urethra, even in short strictures, as ventral curvature usually occurs.

Patient advanced age and comorbidities may steer the urologist away from open surgery. In these circumstances, periodic urethral (self)-dilatation or definitive urethrostomy should be strongly considered.

Flap reconstructions: penile skin island flaps may be elevated in a longitudinal or transverse, circumferential fashion, and variants.

Orandi flap: the Orandi flap is a longitudinal, ventral, fasciocutaneous island penile flap that is appropriate for single-stage reconstruction of strictures of the penile shaft urethra [37]. Inclusion of the distal bulbar urethra in the reconstruction may be hampered by hair-bearing skin of the more proximal part of the flap. Careful planning of the flap is critical before skin incision to avoid jeopardizing the flap design and its blood supply. The flap must be handled meticulously with the use of atraumatic surgical tools and eventually loupe magnification. It then must be mobilized gently to preserve its arterial and venous blood supply. The type and size of suture material is paramount to minimize tissue reaction.

With the penis on stretch, a longitudinal nonhair-bearing skin island is marked on the ventral aspect of the penis. The description of the surgical technique is outlined in **Figure 14**. The penis is snugly dressed to avoid hematoma. Drains are rarely required. Patients are kept on strict bed rest for 3–5 days to minimize swelling. Intravenous antibiotics are administered for at least 48 h, followed by oral antibiotic prophylaxis for one additional week. Erections should be avoided. The use of a suprapubic catheter for urinary drainage is not mandatory but preferable, which should be kept for 2 weeks. The urethral catheter is left plugged to act as a stent only. After 2–3 weeks, the urethral catheter is removed and the patient is sent home with the suprapubic tube occluded, allowing the patient to resume urethral voiding. The suprapubic tube is removed after a few days of normal urethral voiding. If a
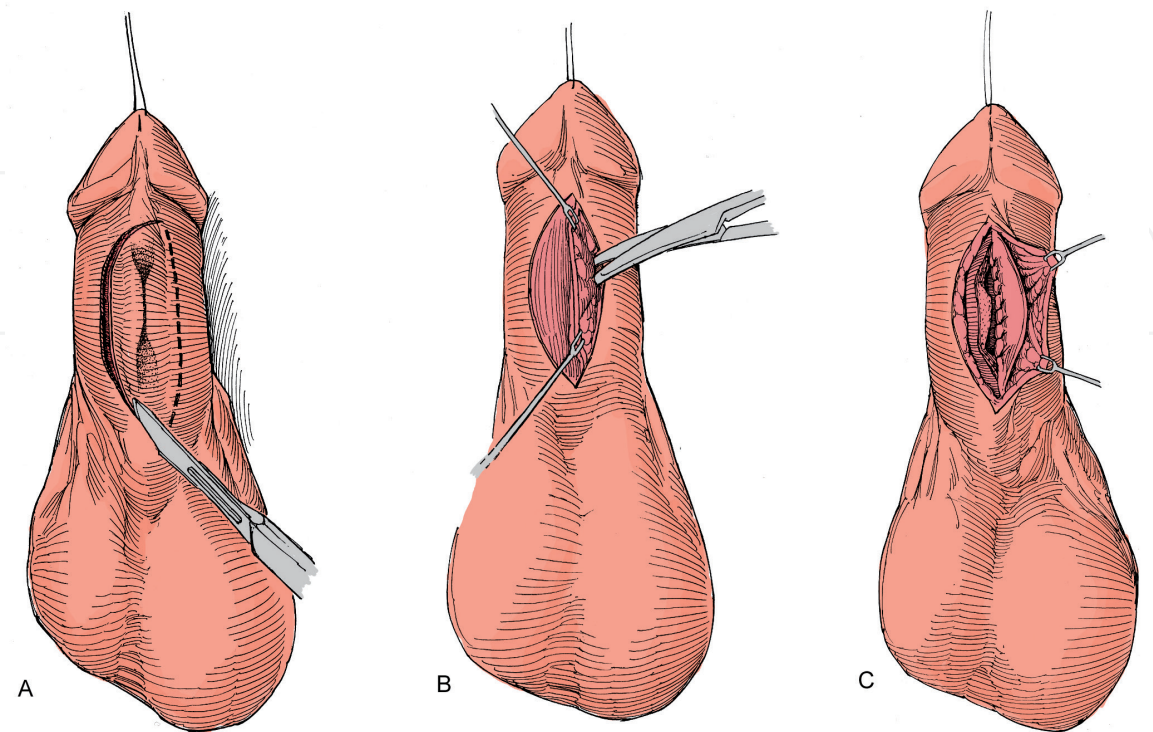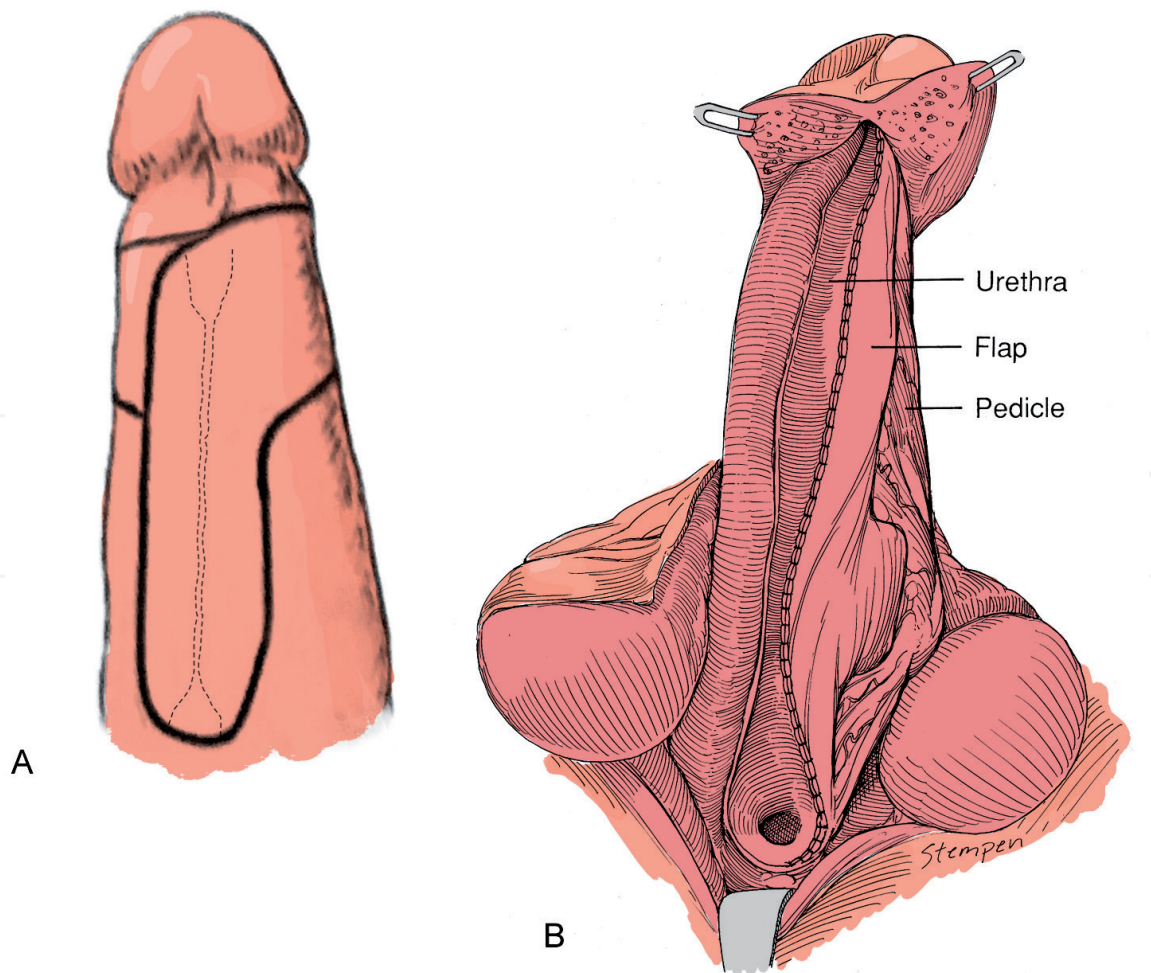

Figure 14.
Orandi flap procedure. (A–C) Deep skin incision is made over the strictured urethra. Dotted line indicates skin incision. Dartos pedicled flap is created lateral to the superficial skin incision, which will cover the urethrotomy defect. The skin is closed in the midline (from Elliott and McAninch [98]).

fistula develops, the urethral catheter is not reinserted and the suprapubic diversion is maintained for another week. If still persistent, then it should be repaired after 4–6 months.

The Orandi flap is a reliable and relatively easy flap to harvest. It is a useful solution for a single-stage reconstruction of penile urethral strictures.

Quartey flap: in 1983, Quartey described a one-stage flap urethroplasty technique using a transverse distal penile or preputial island of skin as a flap, which is supplied axially by the superficial external pudendal vessels for penile urethral strictures with possible extended application to the entire penile and bulbar urethra and even difficult posterior urethral strictures [67, 68]. He described the possibility of this island of skin being used either as a patch or as a tube. In very long strictures, the complete circumference of the distal penile skin can be extended ventrally and proximally toward the base of the penis in the hairless area. This flap design granted it the term "hockey stick island flap" (**Figure 15**).

McAninch flap: in 1993, McAninch reported the initial circular fasciocutaneous penile skin flap for the reconstruction of extensive anterior urethral strictures [39]. This flap is a variant of the flap described by Quartey 10 years earlier with the difference that this fasciocutaneous flap uses Buck's fascia as a paddle to carry the vascular pedicle to the distal flap skin. It can provide a hairless flap up to 15 cm in length, making this flap, like Quartey's flap, extremely versatile. It can be used in uncircumcised as well as circumcised men. The width of the flap varies from 2.0 to 2.5 cm, depending on the stricture characteristics. With the penis on traction, the distal incision is

Figure 15.
Quartey flap procedure. (A, B) Hockey stick skin island flap is fashioned. The length of the flap may be tailored as needed. After ventral longitudinal urethrotomy, the flap is anastomosed similar to the Orandi technique.

carried down deeply beneath the pedicle just beneath Buck's fascia, but superficial to the dorsal neurovascular bundle (dorsally), circumflex vessels (laterally), and urethra (ventrally). The proximal incision extends proximally to the base of the penis through a dissection plane beneath the skin and subdermal or dartos fascia (**Figure 16**). The flap and pedicle can be divided either ventrally or dorsally and rotated to cover the urethral area as an onlay flap. This flap also allows reconstruction of complex strictures of various lengths in a single stage even in circumcised patients. The cosmetic and functional results are excellent in experienced hands.

Turner-Warwick flap: described by Turner-Warwick, this is a bilateral, longitudinal, ventral-based pedicle skin flap supported by right and left ventrolateral branches of the external pudendal artery. Although it may be employed in penile urethral stricture repair, this flap is most useful in bulbar urethral reconstruction [69].

Graft reconstructions: historically, grafts have been used for reconstruction of anterior urethral strictures since the early 1960s [70]. Several different types of graft material have been used with favorable results since then, but in the modern era, oral mucosa has become the graft of choice for its excellent graft characteristics and ease and low morbidity of harvest.

Dorsal OMG onlay technique (Barbagli): ventral onlay grafts are usually discouraged on the corpus spongiosum if the penile urethra is thin, not allowing spongioplasty maneuvers to support the graft and optimize graft take. Therefore, a dorsal onlay approach is used in this urethral segment. The urethra can be exposed either through a circular, subcoronal incision followed by penile shaft degloving, or a ventral midline incision, the latter one being favored by the author of this chapter for its associated lower local morbidity. After identifying the obstruction of a soft 20F Nelaton catheter or Bougie-a-Boule, the urethra is mobilized circumferentially off of the corpora cavernosa along the stricture length. The urethra is rotated 180° for preparation of the dorsal urethrotomy after placing marking stitches at both ends of the stricture. The graft is quilted to the corpora cavernosa, and the edges of the graft and urethrotomy are sewn together. Barbagli et al. have suggested the use of fibrin glue for one-stage penile graft urethroplasty. The authors reported that this new adjunct was safe and effective, with limited complications and satisfactory preliminary outcomes [71].

Dorsal OMG inlay through a ventral sagittal urethrotomy (Asopa): in 2001, Asopa described the technique of dorsal OMG inlay through a ventral sagittal urethrotomy approach as an alternative to the Barbagli technique for the repair of penile strictures (**Figure 17**). The advantages are a simpler dissection, no mobilization of the urethra, and preservation of the urethral blood supply through circumflex and
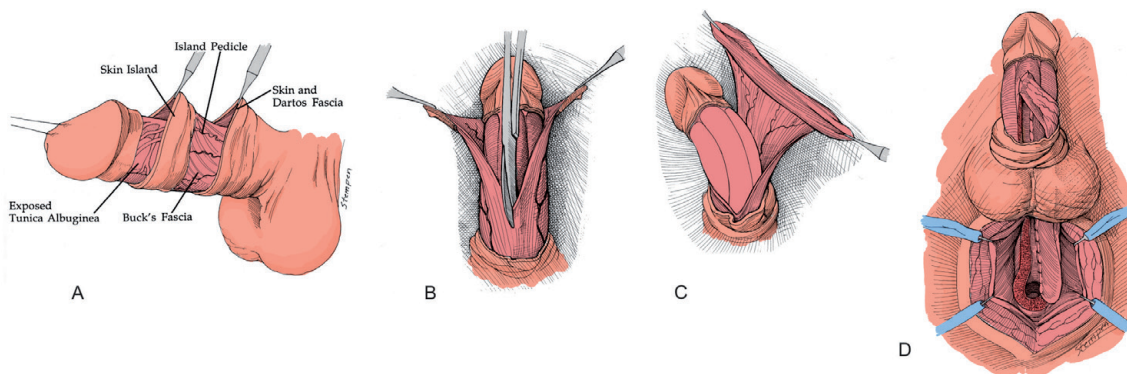
Figure 16.
McAninch fasciocutaneous circular distal penile island flap. (A–D) Flap harvesting followed by ventral division of flap and pedicle, and then, it is rotated and anastomosed to the urethrotomy defect (from McAninch [99]).
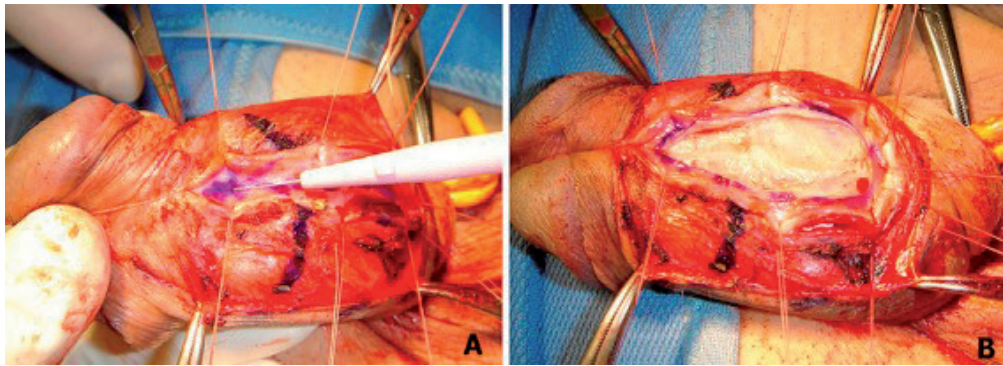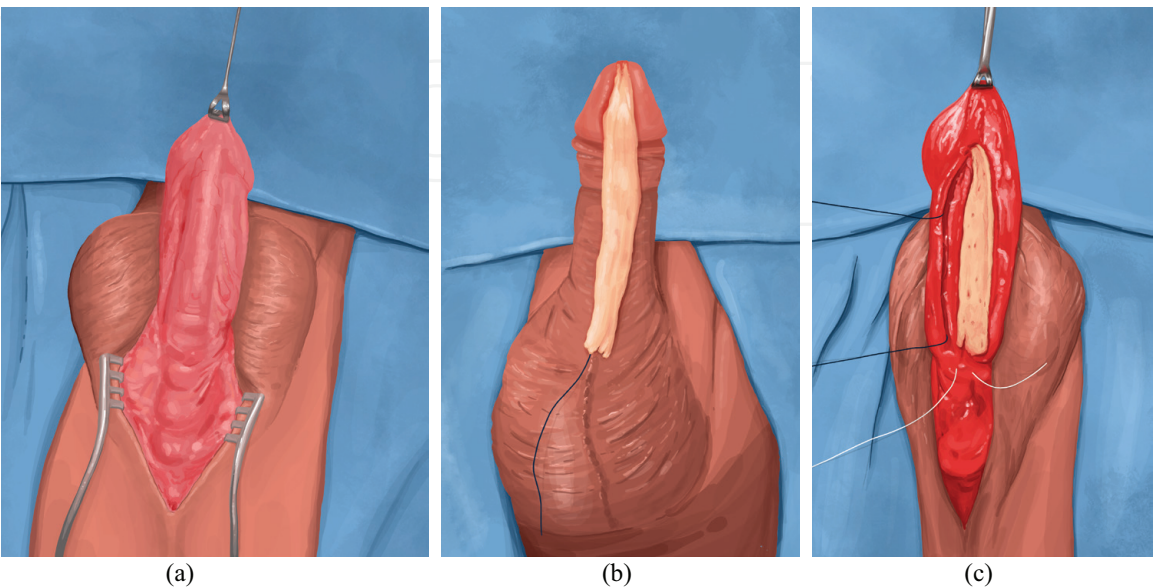
Figure 17.
(A-B) Asopa technique used in long penile urethral stricture approached through a ventral incision.

perforating vessels [72]. However, it involves an extra urethrotomy, which may potentially lead to additional urethral trauma. In the bulbar urethra, it can be used in combination with a second ventrally placed graft. Again, either a degloving or a ventral midline incision can be used. An alternative perineal approach for exclusive penile urethral strictures has been recently adapted from the Kulkarni perineal approach to panurethral stricture repair (**Figure 18**) [73, 74]. This perineal approach avoids the morbidity and less optimal cosmetic results of a penile incision and scar, allowing the performance of penile graft urethroplasty through either Barbagli's dorsal onlay or Asopa's dorsal inlay or Kulkarni's one-sided dorsolateral approach with equivalent functional results.

Penile inversion and one-sided dorsolateral OMG graft technique (*Kulkarni*): Kulkarni first described the technique of perineal approach with penile inversion to expose the full length of anterior urethra for reconstruction of panurethral strictures with avoidance of a penile incision. In 2009, he reported and popularized a slight but important modification of his original technique, which involved a one-sided urethral dissection [75]. The preservation of the one-sided vascular supply to the urethra and its entire muscular and neurogenic support should represent a slight but significant step toward perfecting the surgical technique of urethral reconstruction using a minimally invasive approach. The preservation of the vascular blood supply


| (a) | (b) | (c) |

Figure 18.
Kulkarni's one-sided dorsal onlay graft for anterior urethroplasty for long urethral strictures. (a-c) The penile shaft has been inverted into the perineum where the entire reconstruction is performed. This technique can be used to repair the entire length of the anterior urethra (reproduced with permission from Sanjay Kulkarni, MD).

to one side of the urethra along with its muscular and neural support had a significant impact on functional outcomes. The whole operation is performed through the perineal approach only, making this a minimally invasive approach (**Figure 18**).

Staged reconstructions: staged urethroplasty is used for complicated strictures with significant scar tissue involved, failed hypospadias repair, multiple prior urethroplasty failures, long obliterative strictures, presence of diverticulum or fistulation, and strictures caused by lichen sclerosus, where complete removal of the native diseased urethra may be necessary. In all these circumstances, there is absence of enough healthy tissue to allow a successful one-stage reconstruction. Staged reconstructions are based on the marsupialization of the strictured urethra and involve a planned repair strategy characterized by more than one operation and inherent free tissue transfer. Classically, the term "two-stage urethroplasty" is a misnomer as a significant number of these patients end up requiring more than two operations to produce the final result, that is, a patent tubularized urethra [76]. Alternatives to staged urethroplasty are definitive perineal urethrostomy, combined double face grafting, or other less common individualized procedures.

Johanson's technique: in the first stage, the penis is placed on stretch and the distal end of the stricture is identified. A longitudinal penile skin incision is carried out over the strictured area. The stricturotomy is extended proximally until normal urethra is exposed. The lateral edges of the urethra are sewn with the skin edges (**Figure 19**). Because voiding in a standing position is not possible without dribbling, soiling of the scrotum, and a forward stream, patients may be offered a temporary perineal urethrostomy, if necessary, which is closed at the second stage of the reconstruction. At the second stage, the urethral plate is tubularized and a dartos flap is developed to cover the suture line to avoid fistulation.

Mesh graft urethroplasty: this procedure was first described by Schreiter and Noll [77]. In the first stage, a longitudinal incision is made over the strictured urethra. The urethra is marsupialized preserving the native urethral plate. The split thickness graft (or foreskin) is harvested in the standard fashion with an
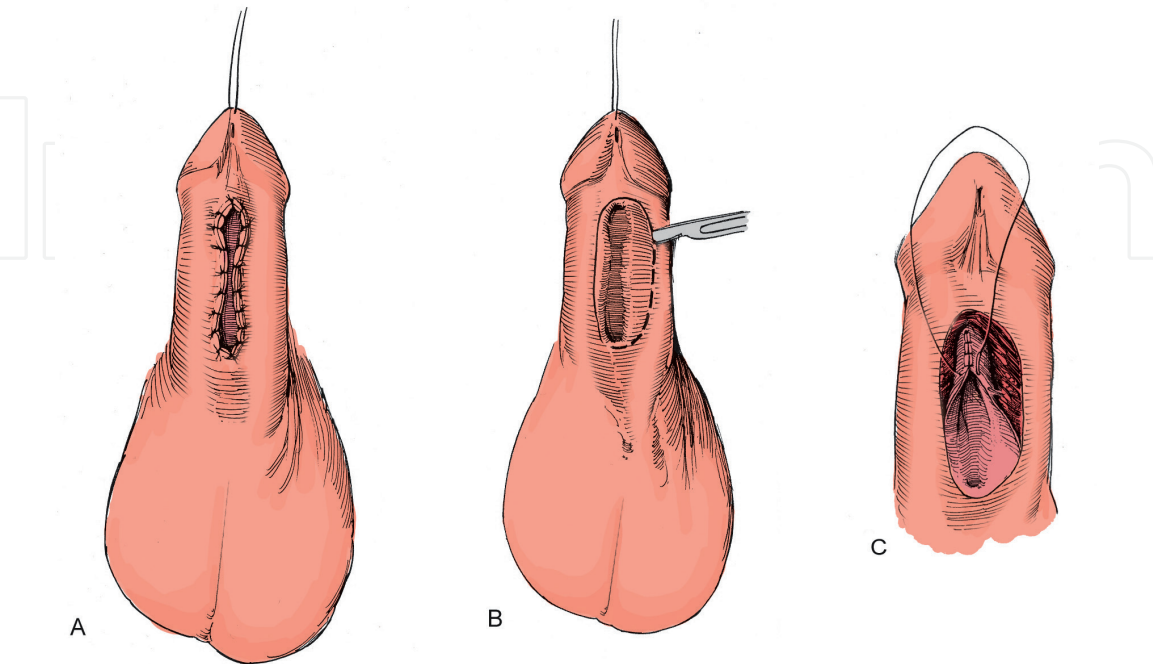
Figure 19.
Johanson's two-stage procedure. (A–C) The anastomosis of the skin edges and the longitudinal urethrotomy is performed at the first stage. The urethrotomy is fashioned as a neourethral tube at the second stage. Modification with use of oral mucosal graft has been described.
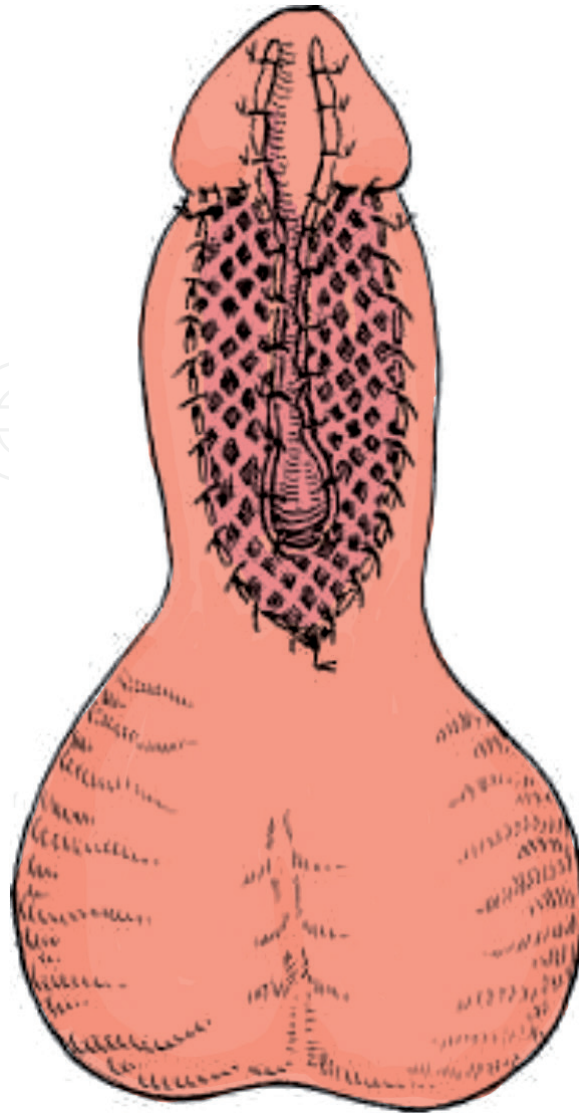
Figure 20.
Mesh graft urethroplasty as described by Schreiter. Meshed skin graft has been placed on the wound ground and quilted to the host bed (first stage). The prepared urethral plate is tubularized approximately 6 months later (second stage).

electrical dermatome and is meshed with a mechanical skin mesher using a 1:15 ratio sheet. The graft is placed on the wound ground lateral to the preserved urethral plate (**Figure 20**). The graft is fixed by running 5–0 monofilament sutures. The second stage (urethral tubularization) is performed in a standard fashion. In a study by Carr et al., success was achieved in 80% at a median follow-up of 38 months [78].

Staged oral mucosa graft urethroplasty: today, staged reconstructions using oral mucosal grafts has become a reliable and the most popular procedure to treat difficult anterior urethral strictures that are not amenable to single-stage graft or flap reconstructions. The indications are similar to the procedures described above. The surgical technique is generally similar (to variants) and based on the technique used for the Johanson and Schreiter's operations, that is, urethral marsupialization in the first stage followed by urethral tubularization 4–6 months later, the OMG being placed at the first stage. At times, it may be necessary to use additional grafts at the time of tubularization to optimize the urethral plate. This is the procedure of choice for strictures associated with LS. Success rates are very good when compared to earlier techniques with an acceptable number of surgical revisions. Multistage urethroplasty should replace "two-stage" urethroplasty as the accepted terminology as it is not uncommon for patients to require more than two procedures to complete

successful tubularization. This may lead to more realistic patient expectations as well. Although completion of the second stage may not always be necessary for functional improvement, cosmetic outcomes with restoration of a glanular meatus can be excellent and achieved in the majority of patients [79]. An algorithm of surgical reconstruction of strictures of the meatus, fossa navicularis, and penile urethral shaft is suggested (**Figure 21**).

Tissue engineering, stem cell, and future: the field of tissue engineering and scar modulation is an exciting area of research in reconstructive urology and is rapidly progressing. Much research has been devoted to the development of a tissue-engineered urethral graft. Currently used grafts, when long, can cause initial donor site morbidity or may be insufficient. Researchers have investigated cell-free and cell-seeded grafts as substitutes for human urethra. There are different approaches to developing these grafts with variable reported successes in studies conducted in animal and human models. Further research may improve the management of long and complex urethral strictures that usually require oral mucosa substitution of urethroplasty with tissue-engineered grafts. These grafts have become necessary because the use of oral mucosa may be limited by its availability. A combination of buccal (cheek), lingual (tongue), and labial (lip) mucosa may be utilized and necessary in some cases. Patients with reduced mouth opening or previous oral surgery may have less oral tissue for use. In addition, longer grafts carry a greater morbidity. The risk of donor site morbidity is increased in smokers, tobacco chewers, and those with poor oral hygiene, which will contraindicate the use of oral mucosa, and, therefore, necessitate a tissue-engineered graft [80].

To generate new tissues, biomedical engineering investigators have utilized three basic tools: cells, scaffold, and growth factor. The earliest use of human cells dates back to approximately 30 years ago [81]. Several different tissue-engineered grafts have been used for urethral reconstruction. There are two types of urethral grafts: (1) those that contain living autologous cells and (2) those that are cell free. The latter include grafts obtained from cadaveric or animal sources. This tissue undergoes treatment to become completely cell free. The resultant biological
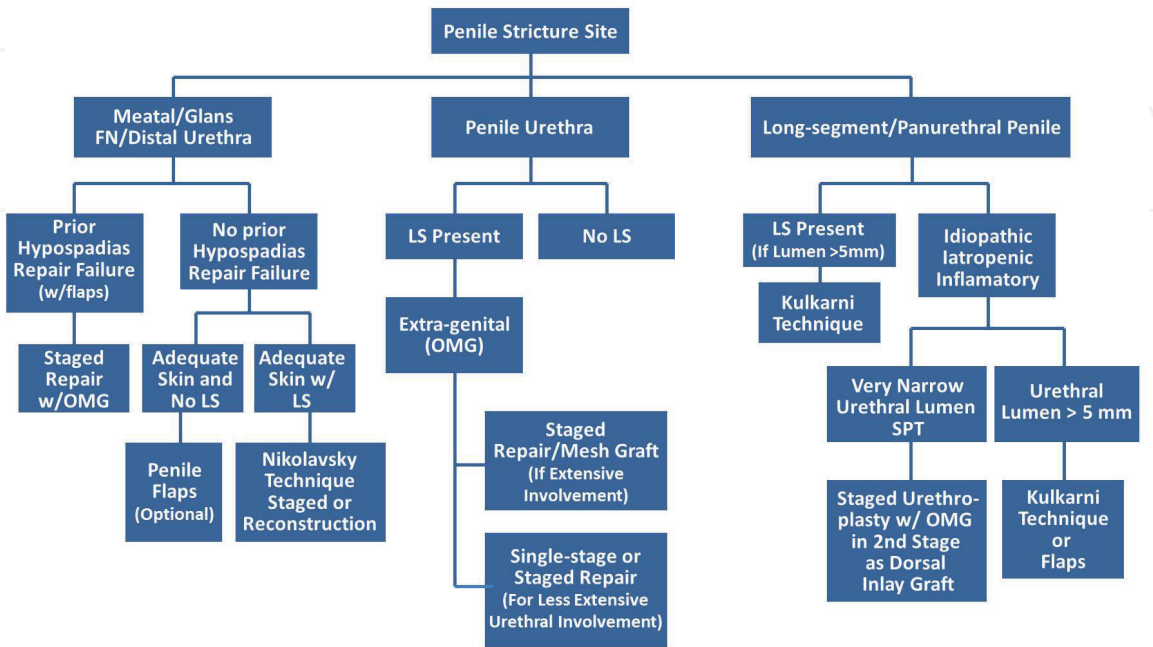
Figure 21.
Algorithm of surgical reconstruction of strictures of the meatus, fossa navicularis, and penile urethral shaft.
FN = fossa navicularis, LS = lichen sclerosus, TIP = tubularized incised plate, and OMG = oral mucosal graft.

matrix is then implanted. A good vascular bed is needed to allow take and infiltration of host cells. As a rule, these techniques would only be expected to be particularly successful for substituting short urethral defects. In contrast, cellularized grafts contain a matrix populated with autologous cells, which are obtained from a small biopsy from the patient. The cells are cultured, expanded, and seeded onto the matrix. The matrix containing cells is then implanted onto the host bed [82].

A critical element required for successful tissue engineering is the cell source. Cells can be isolated from autologous urine-derived stems cells, smooth muscle cells, adipogenic, chondrogenic, and neural lineages [83]. Because simple cell injection to a target site is rarely feasible, a scaffold, or a template, also called artificial extracellular matrix, is necessary. The major function of a scaffold is to assist proliferation, differentiation, and biosynthesis of cells [84, 85].

Scar modulation represents another potential development that may revolutionize urethral reconstruction. Antifibrotic injectables, acting as scar inhibitors, may be placed into the stricture after stricturotomy. Stents impregnated with tacrolimus or paclitaxel have been tried in animal and human models with apparently promising early results [86, 87].

Regenerative medicine (cell therapy and tissue engineering) has made solid progress over the last three decades. We cautiously hope that these technologies will finally enter the routine clinical environment and be applicable in the treatment of urethral strictures/stenosis.

Sexual impact of anterior urethroplasty: overall, anterior urethroplasty appears to have minimal or no impact on long-term sexual dysfunction. One study revealed a moderate effect on sexual function, especially transient chordee in 25% of patients [88]. In another study, the impact of urethroplasty was not worse than circumcision [89]. Another study found a minimal impact on ejaculatory function [90]. One further study reported erectile dysfunction (ED) in approximately 40% of patients, although recovery occurred in most by 6 months. In this study, bulbar urethroplasty affected erectile function more than penile urethroplasty, probably explained by the proximity of the bulbar urethra to the erectile nerves [89]. Even staged urethroplasty does not seem to influence sexual function in patients undergoing penile urethroplasty, although many may experience *de novo* penile curvature, reduced penile length, and/or reduced penile sensitivity [91]. In conclusion, a meta-analysis conducted by Blaschko et al. found that the risk of *de novo* ED after anterior urethroplasty was low at 1% with most of the cases of the *de novo* ED resolving within 6–12 months; however, the possibility of *de novo* posturethroplasty ED, even if transient from the psychological impact of surgery or during revascularization, should be discussed during preoperative evaluation [92].

8. Lower urinary tract symptoms (LUTS) and urethral strictures

The spectrum of lower urinary tract symptoms (LUTS) at initial presentation for urethral stricture disease (USD) is well described. Anterior urethral stricture disease most commonly presents as urinary obstruction and may occasionally present as acute urinary retention. However, there is little data addressing these symptoms in patients after urethroplasty. LUTS after urethroplasty for anterior USD and the relationship of these symptoms to USD recurrence has also been observed [93]. It was reported that men with a successful outcome after urethroplasty tend to remain asymptomatic, whereas those who recur have LUTS, typically with weak urinary flow but without dysuria and hematuria. The authors supported

the need for a USD-specific validated questionnaire to be used for follow-up after urethroplasty.

All men being evaluated for lower urinary tract symptoms (LUTS) should include urethral stricture in the differential diagnosis and include a combination of patient-reported symptom measures, uroflowmetry to assess severity of obstruction, and postvoid residual volume by ultrasound to determine degree of urinary retention. Patients with urethral stricture typically present a weak flow rate. However, evaluation of urethral stricture requires further specific testing to delineate the location, length of the stricture, and degree of narrowing such as urethroscopy and retrograde urethrogram with or without voiding cystourethrogram. LUTS are the usual clinical manifestation of urethral strictures, regardless of location, etiology, and severity. However, LUTS after urethral stricture repair are not uncommon. Urgency has been reported in 40% of men and urge incontinence in 12% of men after anterior urethroplasty. De novo urgency and urge incontinence is seen in 9 and 5% of men, respectively, after urethroplasty. Once a complication of urethroplasty (such as recurrent urethral stricture or diverticulum) has been excluded as a cause, evaluation of LUTS in such patients should focus on the differential diagnosis between bladder dysfunction (overactive bladder and underactive bladder) and other outlet obstructions (such as benign prostatic obstruction), dysfunctional voiding, or medical causes (such as nocturnal polyuria). Management of overactive bladder has different treatment options, which may include behavioral modification, physical therapy, anticholinergic, and/or beta-3 agonist medications. In more severe cases, intravesical onabotulinum toxin, sacral neuromodulation, or peripheral tibial nerve stimulation may be indicated. Definitive treatment for underactive bladder is limited in number and success. Although management of LUTS for patients after urethral stricture repair can usually proceed similarly as for patients without prior history of urethral reconstruction, special consideration and alterations in management need to be made when instrumenting the urethra, as the urethral lumen may be narrower in these patients.

Recently, an analysis of risk factors leading to postoperative urethral stricture and bladder neck contracture (BNC) following transurethral resection of prostate (TURP) has been performed [94]. The authors have found that lower resection speed, intraoperative urethral mucosal rupture, and postoperative continuous infection were associated with a higher risk of urethral stricture, whereas more severe storage symptoms and smaller prostate volumes were associated with a higher risk of BNC after TURP.

9. Future directions and goals

Penile urethroplasty has evolved significantly over the last eight decades, since the first attempts at reconstruction using preputial tubes or a staged approach using penile skin [95]. An improved understanding of the pathophysiology of LS and a high complication rate following skin-based reconstructions favored a shift to the use of oral mucosal grafts, particularly in LS strictures. To date, very little advances have been achieved with conservative/pharmacological therapeutic options to stabilize or modulate the scarring process of this recalcitrant cutaneous disease.

Currently, one of the critical limitations of penile urethroplasty is the common need for a staged reconstruction with all the inconveniences for the patient, and a 20–31% incidence of graft failure following the first stage, which leads to further

revision(s) prior to the final tubularization [95]. Insufficient oral mucosal grafts for panurethral stricture reconstruction, especially in redo cases, add serious problems.

Considerable research has been done in the areas of biomaterials, regenerative medicine, including scar modulation, and tissue engineering to overcome the limitations of current penile urethral stricture management. These experimental technologies appear exciting, revolutionary, and ripe with potential. The main goals of these research areas would be to produce scar inhibitors that might be placed into the stricture after urethrotomy, on the one hand, and to generate an ideal biomaterial in unlimited quantities, easily cultured in laboratory, readily available "off the shelf" and without the morbidity associated with graft harvesting, on the other hand. Unfortunately, we are not quite there yet.

10. Conclusion

The surgical treatment of penile urethral stricture is continually evolving. No one technique is appropriate for all situations, and the successful reconstructive urologist needs to be comfortable with a repertoire of different, versatile techniques in order to best treat each individual patient's problem. Since the early 1990s, OMG was introduced in urethral reconstructive surgery and has become the first choice of most urethral surgeons.

Although all are grouped as anterior urethral strictures, penile urethral strictures are different from bulbar urethral strictures. Flaps are still preferred to grafts in long, recurrent penile urethral strictures by some surgeons. Recently, one-stage dorsal OMG urethroplasty via perineal approach has been suggested for the management of most strictures of the penile shaft urethra with both good functional and remarkable cosmetic outcomes. However, in patients who have experienced failed hypospadias repair or in whom the penile skin and urethral plate are not suitable for urethroplasty, two-stage (usually multistage) urethroplasty is recommended. Management of some lengthy, complex strictures remains a great challenge even for experienced reconstructive surgeons. Staged urethroplasty, such as the Johanson's technique with or without the use of grafts, is still a good surgical option. Regenerative medicine continues to show promise, but further investigation is needed to reach clinical application in the future. All in all, these great improvements in penile urethral surgical technique should lead to optimization of the surgical treatment algorithm.

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