

Salvage Urethroplasty With a Modified Tubularized Distal Penile/Preputial Skin Flap for Bulbar Urethral Necrosis After Failed Anastomotic Urethroplasty in Circumcised Patients: A Retrospective Multicenter Study

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Abstract

Introduction and Objective:

Bulbar urethral necrosis (BUN) is an uncommon but severe complication of anastomotic urethroplasty for pelvic fracture urethral injury (PFUI). This study describes a modified bilateral tubularized distal penile/preputial skin flap for reconstruction of segmental bulbar urethral loss in selected circumcised patients. The objective was to describe the technique and evaluate procedural success and functional urethral patency at standardized follow-up.

Materials and Methods:

This retrospective multicenter cohort study included a highly selected population of circumcised patients who developed BUN after anastomotic urethroplasty for PFUI at four tertiary reconstructive urology centers between 2015 and 2024. Although tubularized preputial/penile skin flap reconstruction has previously been described mainly in uncircumcised patients with an intact prepuce, the present study evaluated its adaptation to circumcised patients who retained sufficient residual distal penile/preputial skin adjacent to the circumcision line. Eligibility required this residual tissue to be sufficiently mobile, well vascularized, and long enough to construct the flap without excessive tension. The primary endpoint was procedural success at 2 years, defined as functional urethral patency ($Q_{max} > 15$ mL/s) without any therapeutic endoscopic or instrumental intervention for restenosis.

Results:

Across the four participating centers, 819 patients with PFUI underwent anastomotic urethroplasty during the study period. The initial repair failed in 128 patients, of whom 119 met the diagnostic criteria for BUN. Six patients were excluded because of insufficient residual distal penile/preputial skin, leaving 113 patients in the final cohort. Procedural success was achieved in 93/113 patients (82.3%) at 3 months and 84/105 (80.0%) at 2 years; eight patients were lost to 2-year follow-up. Thirty-seven high-risk patients underwent one planned prophylactic endoscopic dilation after catheter removal and before any documented restenosis.

Conclusion:

Modified bilateral tubularized distal penile/preputial skin flap urethroplasty appears to be a feasible single-stage reconstructive option for selected circumcised patients with BUN and adequate residual distal penile/preputial skin. Procedural success was observed in 82.3% of patients at 3 months and 80.0% of evaluable patients at 2 years. These findings should not be interpreted as evidence of superiority or established long-term durability. Standardized outcomes beyond 2 years, particularly at 5 and 10 years, remain necessary.

Keywords: salvage urethroplasty; distal penile/preputial skin flap; bulbar urethral necrosis; pelvic fracture urethral injury; urethral reconstruction

Introduction:

Turner-Warwick described spongionecrosis of the bulbar urethra in the setting of complex pelvic fracture urethral injury. Contemporary literature distinguishes bulbar urethral necrosis (BUN) from recurrent bulbar stricture or obliteration. BUN is characterized by segmental absence of the bulbar urethra, usually after previous PFUI repair, and is considered predominantly an ischemic reconstructive problem [1,23]. Severe recurrent fibrosis or a long recurrent stricture alone is insufficient to establish the diagnosis. This distinction is clinically important because true segmental urethral loss requires substitution with well-vascularized tissue rather than repeat excision and primary anastomosis. Reconstructive options include pedicled preputial or penile skin tube flaps, oral mucosal graft- or flap-based reconstruction, pedicled preputial flaps combined with dorsal buccal mucosal grafting, enterourethroplasty, microvascular free flaps, gracilis-supported buccal mucosal grafts, and anterolateral thigh flaps [5,6].

In the present study, two vascularized distal penile/preputial skin flaps were used to construct a neourethra in selected circumcised patients. Tubularized preputial and penile skin flap reconstruction has previously been described predominantly in uncircumcised patients, in whom an intact prepuce provides an obvious donor site. The novelty of the present technique lies in adapting this reconstructive principle to circumcised patients who retain sufficient residual distal penile/preputial skin adjacent to the circumcision line. The tissue used was therefore not an intact conventional preputial tube, but residual distal penile skin incorporating remaining preputial tissue. The primary aim was to describe this modified technique and evaluate procedural success and functional urethral patency. Erectile function, assessed with the International Index of Erectile Function (IIEF), was analyzed as a secondary exploratory outcome.

Materials and Methods:

Study design, ethics, and reporting:

This retrospective multicenter observational cohort study was approved or institutionally authorized at each participating center for retrospective use of de-identified clinical data. At the University of Oran 1 Ahmed Ben Bella, approval was granted by the Ethics and Clinical Research Approval Committee of the Faculty of Medicine (approval No. 134-4-2025). At Makkah Health Cluster (Mecca, Saudi Arabia), Mansoura University Urology and Nephrology Center (Dakahlia, Egypt), and Ahmed Maher Teaching Hospital (Cairo, Egypt), retrospective use of center-specific data was authorized by the relevant institutional research ethics authorities in accordance with local requirements. The study was conducted in accordance with the Declaration of Helsinki. Data were de-identified before multicenter aggregation. Reporting was revised in accordance with STROBE recommendations for observational studies, including explicit description of the study setting, eligibility criteria, participant flow, endpoint definitions, loss to follow-up, and complete-case handling of missing 2-year outcome data [26].

Patients:

Eligible patients with BUN after anastomotic urethroplasty for PFUI were identified from the clinical records of four tertiary referral centers with established expertise in reconstructive urology between January 2015 and December 2024. The participating units were affiliated with University of Oran 1 Ahmed Ben Bella (Oran, Algeria), King Faisal Hospital within Makkah Health Cluster (Mecca, Saudi Arabia), Mansoura University Urology and Nephrology Center (Dakahlia, Egypt), and Ahmed Maher Teaching Hospital (Cairo, Egypt). Each center included an experienced reconstructive urologist responsible for the procedure. At the Algerian center, patients referred from several national urology departments were centralized and managed by a single reconstructive team; the other three centers managed patients within their respective tertiary reconstructive units. The same operative technique, including flap design, pedicle preservation, retro-scrotal transfer, tubularization, and urethral

anastomosis, was used at all four centers. Postoperative surveillance was also standardized across centers, with the same scheduled outcome assessments at 3 months and 2 years and the same definitions of functional urethral patency, restenosis, and procedure failure. The source cohort comprised 819 patients with PFUI who underwent anastomotic urethroplasty: 489 patients from the Oran center (59.7%), 123 from Mansoura University Urology and Nephrology Center (15.0%), 90 from Ahmed Maher Teaching Hospital (11.0%), and 117 from King Faisal Hospital/Makkah Health Cluster (14.3%). The initial repair failed in 128 patients, of whom 119 met the diagnostic criteria for BUN. Circumcision status was determined from the preoperative genital examination and documented in the clinical record as part of donor-site assessment for flap planning. In circumcised patients, the amount, mobility, vascularity, and reach of residual distal penile/preputial skin adjacent to the circumcision line were specifically assessed preoperatively and confirmed intraoperatively. All 119 patients with BUN were circumcised. Previous circumcision did not automatically preclude use of the technique because some patients retained a sufficient amount of distal penile/preputial skin adjacent to the circumcision line. Eligibility required sufficient residual tissue to create a mobile, well-vascularized flap of adequate width and length without excessive donor-site tension. Six patients were excluded because the available distal penile/preputial skin was insufficient. The final cohort therefore comprised 113 circumcised patients with BUN and adequate residual tissue, all of whom underwent modified bilateral tubularized distal penile/preputial skin flap urethroplasty (Flowchart 1). Diagnostic definition and standardization of BUN:

BUN was defined according to a standardized radiographic criterion consistent with contemporary literature: segmental absence or discontinuity of the bulbar urethra on retrograde urethrography (RUG) and voiding cystourethrography (VCUG) after previous PFUI repair [23]. The diagnosis required demonstrable loss of a bulbar urethral segment between the opacified distal and proximal urethral ends. A long recurrent stricture, dense spongiofibrosis, or complete recurrent obliteration with preserved continuity of the bulbar urethra was not considered sufficient for a diagnosis of BUN. The same operational imaging criterion was applied at all four centers, and all 119 cases classified as BUN fulfilled this definition. Antegrade and retrograde urethroscopy were additionally used before reconstruction to delineate the proximal and distal urethral remnants and plan reconstruction. Standardized outcome assessment was performed at 3 months and 2 years. The primary endpoint was procedural success at 2 years. Functional urethral patency was defined as $Q_{max} > 15$ mL/s on uroflowmetry. Routine passage of a 14-Fr catheter was not performed in asymptomatic patients with $Q_{max} > 15$ mL/s. In patients with obstructive urinary symptoms, inability to pass a 14-Fr catheter was considered suspicious for restenosis and required confirmation by urethroscopy and/or urethrography demonstrating either an abrupt urethral cutoff or a filiform passage. Procedural success was defined as functional patency without any therapeutic endoscopic or instrumental intervention for restenosis after urethroplasty. Restenosis was defined as symptomatic recurrent narrowing that met the 14-Fr criterion and was confirmed endoscopically and/or radiographically. Procedure failure was defined as confirmed restenosis and/or the need for any therapeutic endoscopic or instrumental intervention after urethroplasty. One prespecified exception was permitted: a single prophylactic endoscopic dilation performed after catheter removal, before documented restenosis, in patients considered at high risk of recurrence because the reconstructed urethral defect length was ≥ 8 cm. This planned prophylactic dilation was considered an adjunct to the index reconstruction and was not classified as failure. Any subsequent dilation or other therapeutic endoscopic/instrumental intervention was classified as failure.

No formal sample-size calculation was performed because BUN is rare and the retrospective cohort included all eligible patients identified during the predefined study period.

Variable definitions:

Recorded variables included age, body mass index (BMI), PFUI complexity, pelvic fracture classification, stricture type and length, IIEF score, flap length, functional urethral patency, penile appearance, and patient-reported penile shortening or curvature. Postoperative complications recorded from the clinical files included glans hypoesthesia, urethrocuteaneous fistula, flap necrosis, wound infection, penile skin necrosis, urethral diverticulum, meatal stenosis, urinary incontinence, and bleeding. Penile curvature was recorded as a patient-reported present/absent postoperative complaint; no standardized objective curvature-angle measurement or validated curvature-specific patient-reported outcome instrument was used. Erectile function was assessed at three predefined time points: before salvage urethroplasty (baseline/pre-salvage), 3 months after surgery, and 2 years after surgery when follow-up IIEF data were available. The baseline IIEF assessment therefore reflected erectile function after the original pelvic fracture/PFUI and failed anastomotic urethroplasty but before the salvage procedure. For descriptive reporting, the study database categorized erectile dysfunction as severe (IIEF 6-10), moderate (11-16), or mild (17-25). Because these strata are study-defined and do not correspond to standard validated IIEF severity categories, erectile-function findings were treated descriptively rather than as a formal longitudinal treatment-effect analysis.

Categorical variables are presented as frequencies and percentages. Continuous variables are summarized using means, medians, ranges, or interquartile ranges, as appropriate. Univariate analysis of factors associated with functional urethral patency at 2 years was performed as a complete-case analysis including the 105 patients with documented 2-year outcomes; the eight patients lost to 2-year follow-up were excluded. Two-sided Fisher-Freeman-Halton exact tests were used for categorical variables with more than two levels (BMI class, pelvic fracture classification, and Goldman urethral injury classification), and Fisher's exact test was used for the 2 × 2 analysis of stricture type. Crude odds ratios (ORs) for functional patency and exact conditional 95% confidence intervals (CIs) were calculated using clinically appropriate reference categories. A two-sided P value <0.05 was considered statistically significant.

Surgical technique:

In patients who met the radiographic definition of BUN, the proximal and distal urethral remnants were further delineated before reconstruction. Semirigid urethroscopy was performed through both antegrade and retrograde approaches to evaluate the urethra and define the extent of segmental bulbar loss. Antegrade flexible cystoscopy was used to assess the bladder neck, posterior urethra, and verumontanum. A perineal incision was then made to expose the urethra. The bulbospongiosus muscle was divided in the midline, and the bulbar urethral remnants were circumferentially mobilized to expose the previous anastomotic region. Inferior partial pubectomy was performed when required to improve exposure after corporal separation (Fig. 2). Periurethral scar tissue around the proximal urethral end was carefully excised until healthy urethral tissue was identified. Nonviable or densely scarred tissue corresponding to the radiographic defect was excised as required, and the distal urethral end was ventrally spatulated to create a wide anastomotic margin.

A circumferential distal penile/preputial skin flap was then harvested. In this study, distal penile/preputial skin refers to mobile residual distal penile skin incorporating preputial tissue adjacent to the circumcision line. After placement of a traction suture on the glans, a circumferential flap approximately 25–30 mm wide was designed. The vascular basis of the flap was the superficial dorsal penile vascular pedicle carried within the subcutaneous dartos tissue. Dissection was maintained in the plane between the dartos and Buck fasciae in order to preserve this subcutaneous vascular pedicle. The circumferential flap was then divided ventrally and dorsally, creating right and left hemircumferential flaps. Each hemiflap retained its own subcutaneous superficial dorsal pedicle and therefore remained vascularized despite the circumferential skin incision (Figs. 3–5).

During transfer, the epithelial surface of the flap was oriented inward to line the neourethral lumen. The flap was brought to the perineum through a retro-scrotal tunnel passing behind the scrotum rather than by external rotation over the penile shaft. Care was taken to avoid pedicle torsion or compression and to align the tube with the proximal and distal urethral ends adjacent to the corpora without kinking. The residual penile skin bridge was preserved for shaft coverage whenever possible. Tension was minimized by complete mobilization of the urethral ends, a short direct tunnel, and conservative control of flap reach. In our operative planning, a flap length of approximately 8 cm was considered the preferred practical upper length to avoid traction on the pedicle; longer reach was accepted only if the transfer remained clearly tension-free. If additional skin coverage was required, local penile or perineal skin and, occasionally, a thin skin graft were used. Because only residual excess distal penile/preputial skin was harvested, flap construction did not necessarily produce a clinically significant donor-site skin deficit. Tissue adequacy was assessed preoperatively and confirmed intraoperatively on the basis of availability, mobility, vascularity, and the ability to construct the planned flap without excessive tension. Patients without sufficient residual tissue were not eligible for this technique. In selected cases, additional penile skin coverage required transfer of perineal skin or a thin skin graft.

Results:

Between January 2015 and December 2024, 819 patients with PFUI underwent anastomotic urethroplasty across the four participating tertiary reconstructive centers. The source cohort consisted of 489 patients treated at the Oran center (59.7%), 123 at Mansoura University Urology and Nephrology Center (15.0%), 90 at Ahmed Maher Teaching Hospital (11.0%), and 117 at King Faisal Hospital/Makkah Health Cluster (14.3%). The initial repair failed in 128 patients. Of these, 119 met the standardized radiographic definition of BUN, corresponding to 14.5% (119/819) of the anastomotic urethroplasty cohort. Six circumcised patients with BUN were excluded because they lacked sufficient distal penile/preputial skin for flap construction, leaving 113 patients in the final analysis, equivalent to 13.8% (113/819) of the original cohort (Flowchart 1). Mean age was 27.3 years. Among the 113 included patients, 87 (76.9%) had complex urethral injuries classified as Goldman type ≥ 3 , and 100 had American Association for the Surgery of Trauma grade 3-5 urethral injuries. The mean duration of available clinical follow-up was 53 months; however, standardized efficacy assessments were predefined at 3 months and 2 years, and follow-up beyond 2 years was not sufficiently uniform for formal efficacy analysis. Baseline and postoperative outcomes are summarized in Tables 1 and 2.

The mean flap length was 8.5 cm (range, 6.2-10.8 cm). Complete bulbar narrowing/obliteration was present in 99 patients (87.6%). Procedural success, according to the predefined criteria, was observed in 93/113 patients (82.3%) at 3 months and 84/105 (80.0%) at 2 years; eight patients were lost to 2-year follow-up. Immediate functional patency after catheter removal was observed in 95/113 patients (84.1%) and was considered an early technical outcome. A single planned prophylactic endoscopic dilation was performed after catheter removal in 37 patients considered at high risk of restenosis because the reconstructed urethral defect length was ≥ 8 cm. These dilations were performed before documented restenosis and were not classified as failures. Any subsequent therapeutic endoscopic or instrumental intervention for confirmed restenosis was classified as procedure failure. Before salvage urethroplasty, 99/113 patients (87.6%) were classified as having severe erectile dysfunction and 14/113 (12.4%) as having moderate erectile dysfunction according to the study-defined IIEF categories; none were classified as mild. At 3 months after salvage urethroplasty, severe, moderate, and mild erectile dysfunction were recorded in 67/113 (59.3%), 31/113 (27.5%), and 15/113 (13.3%) patients, respectively. At 2 years, IIEF data were available for 45 patients (39.8% of the original

cohort): 32/45 (71.1%) were classified as severe, 11/45 (24.4%) as moderate, and 2/45 (4.4%) as mild. Although the 2-year assessment represents a clinically meaningful late postoperative time point, missing IIEF data in 68 patients and the use of nonstandard severity categories preclude direct longitudinal comparison with the complete baseline cohort.

Postoperative complications are summarized systematically in Table 2. Wound infection occurred in 13 patients (11.5%), meatal stenosis in 7 (6.2%), and urethral diverticulum in 7 (6.2%).

Urethrocutaneous fistula was reported in 5 patients (4.4%), urinary incontinence in 3 (2.7%), flap necrosis in 2 (1.8%), postoperative bleeding in 2 (1.8%), and penile skin necrosis in 1 (0.9%). Glans hypoesthesia was reported in 34 patients (30.1%) at 3 months, 17 (15.0%) at 6 months, and 5 (4.4%) at 2 years. Penile shortening and curvature during erection were reported in 5 patients (4.4%) and 4 patients (3.5%), respectively.

Univariate analysis of factors associated with functional urethral patency at 2 years:

Among the 105 patients with documented 2-year outcomes, 84 had functional urethral patency and 21 did not. Goldman urethral injury classification was significantly associated with 2-year functional patency ($P = 0.002$). Compared with Goldman type 2 injury, type 4a injury was associated with substantially lower odds of functional patency (crude OR, 0.05; 95% CI, 0.003-0.43). BMI class showed a borderline overall association ($P = 0.050$), whereas pelvic fracture classification ($P = 0.146$) and stricture type ($P = 0.703$) were not significantly associated with 2-year functional patency. Complete univariate results, including crude ORs and 95% CIs, are presented in Table 3.

Discussion:

BUN is a distinct ischemic reconstructive condition and should not be used synonymously with severe recurrent bulbar stricture disease. Recent radiographic work defines BUN by segmental absence of the bulbar urethra after PFUI repair and emphasizes its predominantly vascular pathophysiology [23]. Accordingly, the present series included only patients with radiographically demonstrable segmental bulbar urethral loss or discontinuity; patients with recurrent narrowing, fibrosis, or obliteration but preserved bulbar urethral continuity were not classified as having BUN. The bulbar urethra receives both antegrade and retrograde vascular supply. The bulbospongiosus muscle surrounds the bulbar urethra, while arterial supply is derived from the bulbar arteries, perforating branches of the cavernosal arteries, and retrograde contributions from the distal penile vascular network [7,8]. The deep dorsal arteries lie lateral to the deep dorsal vein and may be injured during inferior pubectomy or crural separation if bone removal, periosteal elevation, or electrocautery compromises adjacent vascular structures. BUN may develop when retrograde perfusion is impaired. Complex posterior urethral reconstruction should therefore be undertaken by surgeons experienced in advanced perineal approaches. Additional factors that may compromise bulbar urethral viability include excessive distal urethral mobilization, concomitant hypospadias, and extensive spongiofibrosis after previous surgery [9,10].

Reported rates of BUN after PFUI repair vary according to referral patterns, trauma complexity, case volume, and surgeon experience. In a large tertiary-center experience, Kulkarni and colleagues treated more than 1,700 patients with PFUI between 1995 and 2021 and reported success rates of 79.1% for redo reconstruction and 85.4% for primary anastomotic urethroplasty; approximately 9% of patients ($n = 177$) developed BUN [11-13].

In the present study, efficacy was assessed at standardized postoperative time points using a predefined procedural-success framework. Success required $Q_{max} > 15$ mL/s together with freedom from therapeutic endoscopic or instrumental treatment for restenosis. Passage of a 14-Fr catheter was not performed routinely; it was reserved for symptomatic patients, and failure to pass the

catheter required endoscopic and/or urethrographic confirmation of recurrent narrowing. Procedural success was 82.3% at 3 months and 80.0% among patients evaluable at 2 years. Thirty-seven patients with a reconstructed urethral defect length ≥ 8 cm underwent one planned prophylactic endoscopic dilation after catheter removal and before restenosis developed. Because this maneuver was protocolized as postoperative prophylaxis rather than treatment of established recurrence, it was not classified as failure; any subsequent therapeutic dilation or other endoscopic/instrumental intervention was classified as failure. This endpoint definition should be considered when comparing the present results with series that use strictly intervention-free definitions of success.

Published outcomes of BUN reconstruction vary with case complexity, reconstructive technique, previous surgical history, follow-up duration, and the definition of success. Reported reconstructive strategies include pedicled preputial tube flaps, Q flaps, oral mucosal flaps, pedicled preputial onlay reconstruction combined with dorsal buccal mucosal grafting, scrotal drop-back procedures, and enterourethroplasty [14-16]. These heterogeneous series provide useful technical context but are not directly comparable with the present cohort because patient selection and outcome definitions differ. The present findings indicate that the modified bilateral flap can be performed as a single-stage reconstructive option in carefully selected patients, with functional urethral patency observed in 80.0% of evaluable patients at 2 years. However, the retrospective design, absence of a comparator group, and lack of standardized 5- and 10-year outcomes preclude conclusions regarding superiority or established long-term durability.

Joshi et al. [22] recently reported 41 patients who underwent pedicled flap reconstruction for BUN. Distal penile skin flaps were used in 24.4% of patients and had a 40% primary success rate, whereas overall primary and secondary success rates across all flap types were 66% and 78%, respectively. Direct comparison with the present cohort is not appropriate because of differences in patient selection, case complexity, previous surgical burden, flap design, follow-up duration, and outcome definitions. In the present study, one protocolized prophylactic dilation in high-risk patients was not classified as failure, whereas any therapeutic endoscopic or instrumental intervention for confirmed restenosis was considered failure. Accordingly, the numerical differences between studies should be interpreted descriptively and should not be taken as evidence that the bilateral technique is superior to other reconstructive approaches.

Conventional tubularized preputial flaps are most naturally applicable to uncircumcised patients with an intact prepuce and have already been described in that setting. The present series addresses a different and more restricted clinical situation: circumcised patients in whom sufficient residual distal penile/preputial skin remains available adjacent to the circumcision line. Circumcision status was therefore not merely a demographic characteristic but a technical selection variable, documented during preoperative genital examination and donor-site assessment. Previous circumcision did not automatically exclude the technique; however, patients without adequate residual tissue were not candidates and were excluded from this cohort. Accordingly, the present results should not be generalized to all circumcised patients. They also should not be directly extrapolated to uncircumcised patients, because donor-site anatomy, flap design, and tissue availability differ and because this study was specifically designed to evaluate the adaptation of the technique to circumcised patients with adequate residual tissue.

From a technical standpoint, the distinguishing feature of this modification is that the neourethral tube is created from two hemicircumferential distal penile/preputial skin flaps, each based on a superficial dorsal subcutaneous pedicle. The skin surface is directed inward, and the flap is delivered to the perineum through a retro-scrotal tunnel. This configuration aims to preserve vascularity, reduce pedicle traction, and permit midline alignment of the neourethra relative to the corpora and urethral ends.

Erectile dysfunction is a well-recognized consequence of PFUI and is usually multifactorial. Proposed mechanisms include cavernous nerve injury, disruption of branches of the internal pudendal or cavernosal arterial supply, direct corporal injury, venous dysfunction, and psychological effects of major pelvic trauma [24,25]. A systematic review and meta-analysis estimated that approximately 34% of men have erectile dysfunction after PFUI before definitive urethroplasty, whereas delayed urethroplasty was associated with only a modest additional incidence of de novo erectile dysfunction beyond that attributable to the initial injury [24]. These findings suggest that erectile dysfunction in this population is driven predominantly by the initial pelvic and urethral trauma rather than by urethroplasty alone. In the present cohort, baseline IIEF assessment was therefore performed after PFUI and failed primary anastomotic repair but before salvage reconstruction. The 2-year postoperative assessment is more informative than the 3-month assessment for late erectile-function status; however, it was available in only 45 patients. Accordingly, IIEF findings at baseline, 3 months, and 2 years are reported descriptively and should not be interpreted as evidence that the salvage procedure caused either recovery or deterioration in erectile function.

Vascular factors may nevertheless contribute to erectile function and urethral tissue viability after PFUI. Complete posterior urethral disruption and severe pelvic trauma may injure pudendal or cavernosal arterial branches, whereas transection and mobilization of the bulbar urethra during reconstruction can alter antegrade bulbar arterial inflow. Bulbar artery-sparing techniques have therefore been developed to preserve proximal arterial supply to the corpus spongiosum during anastomotic reconstruction [19]. Bulbar arterial flow can be assessed with Doppler ultrasonography, allowing preservation of one or both arteries when technically feasible. In the present retrospective cohort, however, the contribution of reduced antegrade bulbar flow to erectile dysfunction cannot be separated from the neurogenic and vascular effects of the original pelvic trauma. The data therefore do not establish bulbar urethral transection or loss of antegrade flow as the cause of the observed erectile dysfunction.

Penile curvature during erection was reported by 4 patients (3.5%). However, curvature was not assessed using standardized preoperative and postoperative angular measurements or a validated curvature-specific patient-reported instrument. Accordingly, this observation cannot be interpreted as objective evidence that the bilateral flap design prevents penile deviation. From a technical standpoint, dividing the circumferential flap into two hemicircumferential components and transferring them on opposite sides of the penis may distribute traction more symmetrically and therefore represents a potential biomechanical advantage of the technique [20-22]. This proposed advantage remains hypothetical and should be evaluated prospectively with standardized curvature measurements and validated patient-reported assessments.

Circumcision status or the amount of residual preputial skin should not be used to infer a culturally specific aesthetic ideal. Available evidence indicates that genital appearance is a subjective, patient-reported construct. In a geographically diverse sample, genital self-image did not differ significantly between circumcised and uncircumcised men; instead, greater satisfaction with one's own circumcision status was associated with a more positive genital self-image [27]. In a separate 2025 survey, most circumcised adult men reported no concern about penile appearance, including some men with objectively redundant foreskin [28]. Because no validated genital self-image or cosmetic-satisfaction instrument was administered in the present cohort, no formal conclusion regarding postoperative aesthetic satisfaction can be made. Glans hypoesthesia was the most frequent sensory complaint, affecting 30.1% of patients at 3 months, 15.0% at 6 months, and 4.4% at 2 years, and should be discussed during preoperative counseling.

Limitations

This study has several limitations. Its retrospective multicenter design may have introduced heterogeneity in referral patterns and documentation. However, all four institutions were tertiary referral centers in reconstructive urology, the same operative technique and postoperative surveillance protocol were used across centers, and each procedure was performed by an experienced reconstructive urologist. Individual surgeon case volume and reconstructive experience were not formally quantified or compared between centers. Although the same operational radiographic definition of BUN was applied across centers, imaging was obtained and interpreted as part of routine clinical care rather than through a prospective central adjudication protocol. Standardized efficacy assessments were available at 3 months and 2 years, but not at 5 or 10 years; therefore, very long-term durability cannot be established. The mean clinical follow-up of 53 months reflects the duration of available records and should not be interpreted as a standardized 53-month efficacy assessment. Eight patients were lost to 2-year follow-up and were excluded from the complete-case univariate analysis. The procedural-success definition also included a protocolized exception for one prophylactic endoscopic dilation after catheter removal in 37 high-risk patients with a reconstructed urethral defect length ≥ 8 cm. Although this intervention was performed before documented restenosis and was not considered treatment of failure, the endpoint is not identical to a strictly intervention-free definition and may limit comparison with other series. In addition, the 14-Fr catheter assessment was symptom-triggered rather than routinely performed in all patients. IIEF data at 2 years were available for only 45 of 113 patients, creating substantial potential for attrition bias. The historical IIEF severity categories were nonstandard, and objective neurovascular testing was not performed; erectile-function trajectories and causal mechanisms therefore cannot be established. No validated genital self-image or cosmetic-satisfaction instrument was used. Penile curvature was recorded only as a patient-reported present/absent finding; no objective preoperative/postoperative curvature-angle measurement or validated curvature-specific instrument was available, so any protective effect of the bilateral flap design against penile deviation remains unproven. An additional limitation is the highly selected donor-site anatomy of this cohort: all patients were circumcised and had sufficient residual distal penile/preputial skin to permit flap construction. Therefore, the findings cannot be generalized to circumcised patients without adequate residual penile skin and should not be directly extrapolated to uncircumcised patients, in whom flap anatomy and tissue availability differ. Finally, the univariate analysis was exploratory, several subgroups were small, and the absence of a comparator group precludes conclusions regarding superiority over other salvage reconstructive techniques.

Conclusion

BUN after PFUI repair is a complex ischemic reconstructive condition characterized by radiographically demonstrable segmental loss of the bulbar urethra rather than by recurrent stricture severity alone. In selected circumcised patients who retain adequate residual distal penile/preputial skin, modified bilateral tubularized distal penile/preputial skin flap urethroplasty appears to be a feasible single-stage reconstructive option. Procedural success was observed in 82.3% of patients at 3 months and 80.0% of evaluable patients at 2 years. These findings are specific to this selected retrospective cohort and do not establish superiority over alternative techniques or durable long-term success. Standardized 5- and 10-year outcome data and comparative studies are required before broader conclusions can be drawn.

Figures:

Fig. 1. Segmental absence of the bulbar urethra on voiding cystourethrography (VCUG), consistent with BUN

Fig. 2. Inferior partial pubectomy

Fig. 3. Two parallel incisions in the distal penile/preputial skin

Figs. 4 and 5. Ventral and dorsal division of the circumferential distal penile/preputial skin flap

Fig. 6. Tubularization of the distal penile/preputial skin flap

Fig. 7. Anastomosis of the tubularized flap to the proximal and distal urethral ends

Fig. 8. Schematic representation of the modified bilateral distal penile/preputial skin flap: (A) circumferential design based on the superficial dorsal vascular pedicles; (B) division into right and left hemicircumferential flaps, each retaining its own pedicle; (C) retro-scrotal tunneling to the perineum; (D) tubularization with the epithelial surface oriented inward; (E) final position of the neourethra adjacent to the corpora; and (F) operative principles used to avoid tension.

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Variable	Patients, n (%)
Total cohort	113 (100)
Mean age, years	27.3 (range, 16–57)
BMI class	
≤18.5 kg/m ²	21 (18.6)
18.5–25 kg/m ²	80 (70.8)
≥25 kg/m ²	12 (10.6)
Pelvic fracture classification	
Tile A, stable	5 (4.4)
Tile B, vertically stable	13 (11.5)
Tile B, rotationally unstable	55 (48.7)
Tile C, unstable	40 (35.4)
AAST urethral injury classification	
Grade 1, contusion	0 (0)
Grade 2, stretch injury	13 (11.5)
Grade 3, partial disruption	48 (42.5)
Grade 4, complete disruption with gap <2 cm	16 (14.2)
Grade 5, complete disruption with gap ≥2 cm	36 (31.9)
Goldman urethral injury classification	
Type 1, elongation/stretching	0 (0)
Type 2, urethral disruption	26 (23.0)
Type 3, membranous urethral disruption	61 (54.0)
Type 4, bladder neck injury	10 (8.8)
Type 4a, bladder base injury	11 (9.7)
Type 5, anterior urethral trauma	5 (4.4)
Preoperative IIEF category (before salvage urethroplasty)	
Severe erectile dysfunction, 6–10	99 (87.6)
Moderate erectile dysfunction, 11–16	14 (12.4)
Mild erectile dysfunction, 17–25	0 (0)

Table 1: Baseline characteristics and preoperative outcomes

Variable	Patients, n (%)
Total cohort	113 (100)
Type of bulbar lesion	
Partial narrowing	14 (12.4)
Complete obliteration	99 (87.6)
Mean flap length, cm	8.5 (range, 6.2–10.8)
Postoperative IIEF at 3 months	
Severe erectile dysfunction	67 (59.3)
Moderate erectile dysfunction	31 (27.5)
Mild erectile dysfunction	15 (13.3)
Postoperative IIEF at 2 years (available-case data, n=45)	
Severe erectile dysfunction	32/45 (71.1)
Moderate erectile dysfunction	11/45 (24.4)
Mild erectile dysfunction	2/45 (4.4)
Early functional urethral patency after catheter removal	95/113 (84.1)
Functional urethral patency at 3 months	93/113 (82.3)
Functional urethral patency at 2 years	84/105 (80.0)
Postoperative complications and patient-reported outcomes	

Glans hypoesthesia at 3 months	34 (30.1)
Glans hypoesthesia at 6 months	17 (15.0)
Glans hypoesthesia at 2 years	5 (4.4)
Penile shortening	5 (4.4)
Penile curvature during erection	4 (3.5)
Urethral diverticula	7 (6.2)
Urethrocutaneous fistula	5 (4.4)
Flap necrosis	2 (1.8)
Wound infection	13 (11.5)
Penile skin necrosis	1 (0.9)
Meatal stenosis	7 (6.2)
Urinary incontinence	3 (2.7)
Postoperative bleeding	2 (1.8)

Note: Postoperative complication percentages are calculated using the full study cohort (n=113), unless another denominator is explicitly stated. IIEF data at 2 years were available for 45 of 113 patients.

Table 2: Operative and postoperative outcomes

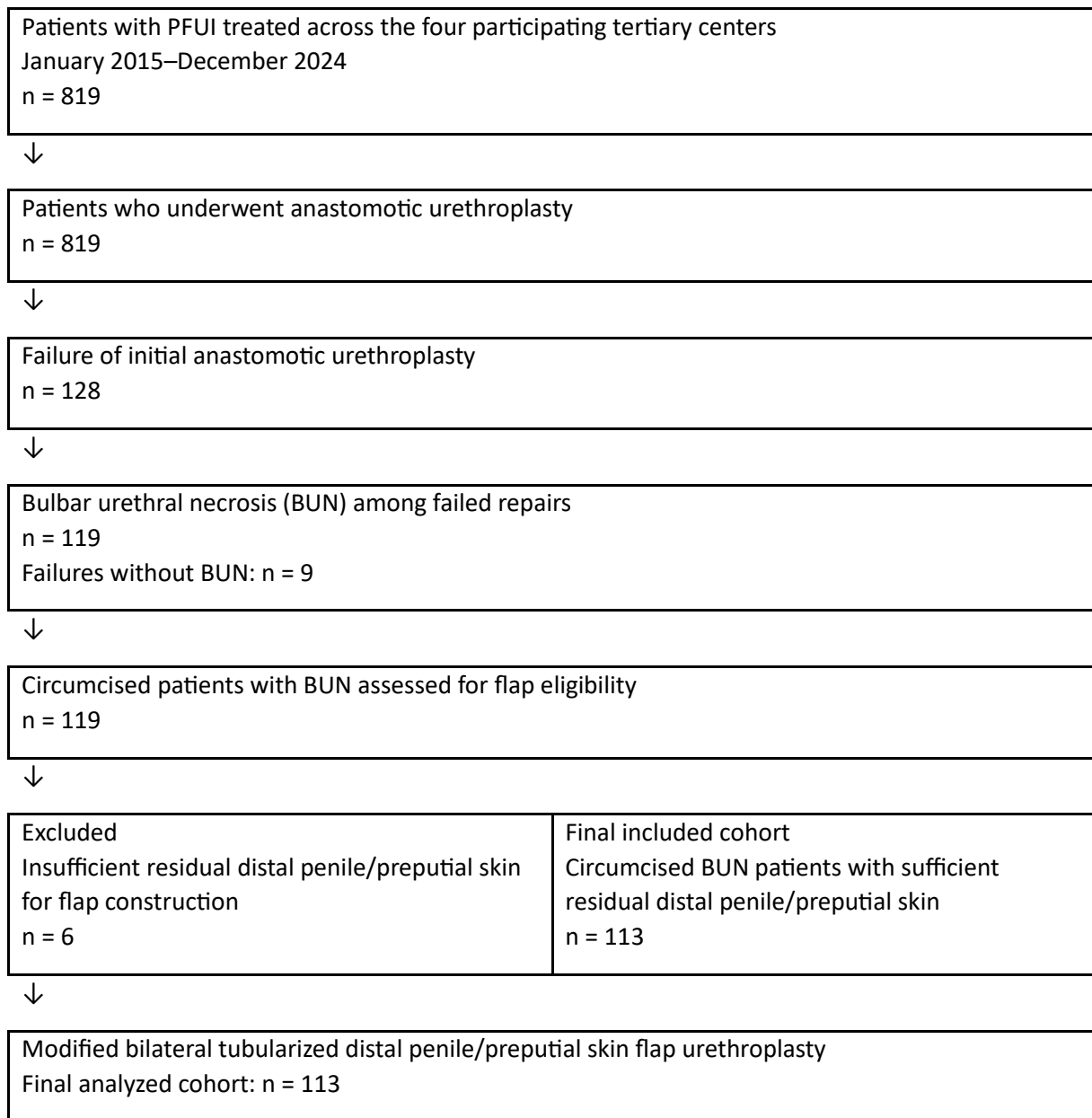
Variable / category	Evaluabl e	Functional urethral	Loss of urethral	Crude OR (95% CI)	P value
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	at 2 years, n	patency, n (%)	patency, n (%)		
BMI class					
≤18.5 kg/m ²	17	12 (70.6)	5 (29.4)	0.41 (0.11–1.78)	0.050
18.5–25 kg/m ²	76	65 (85.5)	11 (14.5)	Reference	
≥25 kg/m ²	12	7 (58.3)	5 (41.7)	0.24 (0.05–1.15)	
Pelvic fracture classification					
Tile A (stable)	5	5 (100)	0 (0)	∞ (0.26–∞)	0.146
Tile B (vertically stable)	13	13 (100)	0 (0)	∞ (0.82–∞)	
Tile B (rotationally unstable)	52	40 (76.9)	12 (23.1)	1.15 (0.37–3.47)	
Tile C (unstable)	35	26 (74.3)	9 (25.7)	Reference	
Goldman urethral injury classification	0	NA	NA	NA	0.002
Type 1, elongation/stretching					
Type 2, urethral disruption	26	23 (88.5)	3 (11.5)	Reference	
Type 3, membranous urethral disruption	57	49 (86.0)	8 (14.0)	0.80 (0.13–3.75)	
Type 4, bladder neck injury	9	7 (77.8)	2 (22.2)	0.47 (0.04–6.66)	
Type 4a, bladder base injury	8	2 (25.0)	6 (75.0)	0.05 (0.003– 0.43)	
Type 5, anterior urethral trauma	5	3 (60.0)	2 (40.0)	0.21 (0.02–3.47)	
Type of stricture					0.703
Partial narrowing	12	9 (75.0)	3 (25.0)	0.72 (0.16–4.56)	
Complete narrowing	93	75 (80.6)	18 (19.4)	Reference	

Table 3: Univariate analysis of factors associated with functional urethral patency at 2 years

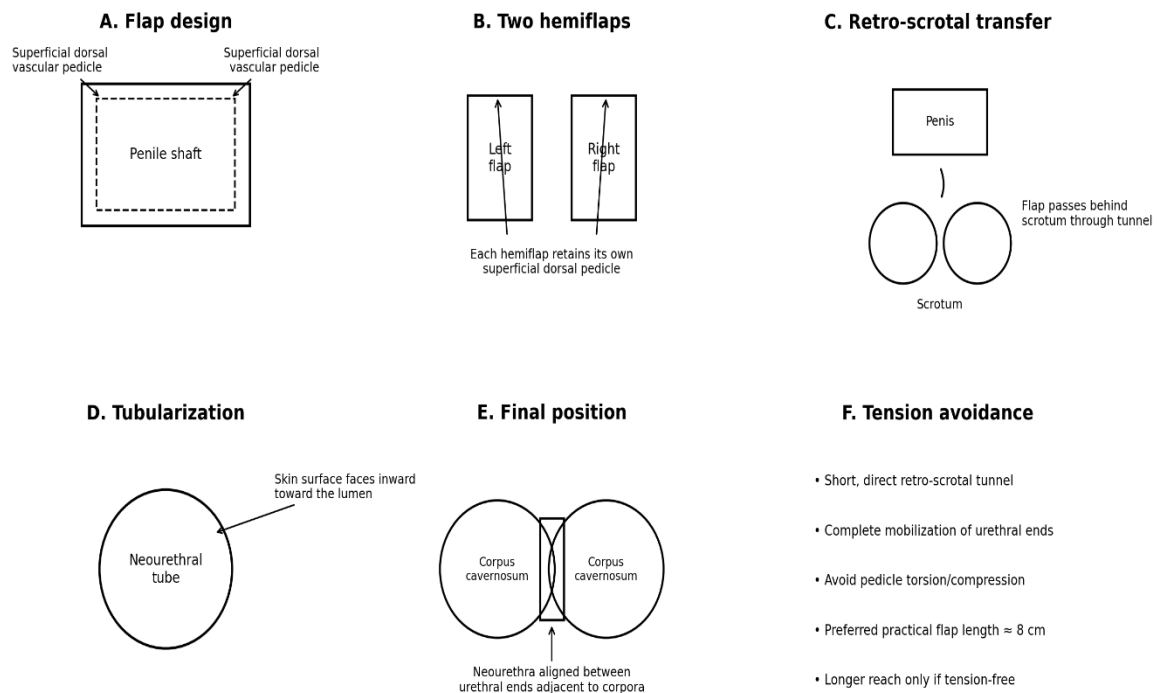
Note: Complete-case analysis included 105 patients with known 2-year outcomes (84 with functional urethral patency and 21 without); eight patients were lost to follow-up. Lost-to-follow-up distribution: BMI, 4/4/0; Tile classification, 0/0/3/5; Goldman classification, 0/0/4/1/3/0; partial/complete narrowing, 2/6. ORs represent the odds of functional urethral patency. Global P values were calculated using two-sided Fisher-Freeman-Halton exact tests for BMI, pelvic fracture classification, and Goldman classification, and Fisher's exact test for stricture type. ORs and 95% CIs are exact conditional estimates; infinite ORs reflect zero loss-of-patency events in the corresponding category.

Flowchart 1. Study selection and inclusion process



Abbreviations: BUN, bulbar urethral necrosis; PFUI, pelvic fracture urethral injury.

Figure 8. Operative schematic of the modified bilateral distal penile/preputial skin flap



Schematic showing the key technical steps and anatomical relationships: circumferential distal penile/preputial skin design based on the superficial dorsal vascular pedicles; ventral and dorsal division into two hemicircumferential flaps; retro-scrotal tunneling; tubularization with the skin surface facing the lumen; final positioning adjacent to the corpora; and operative measures used to minimize pedicle traction.

Figures



Fig 1 : Absence of the bulbar urethra (MCU)



Fig2 : inferior partial pubectomy

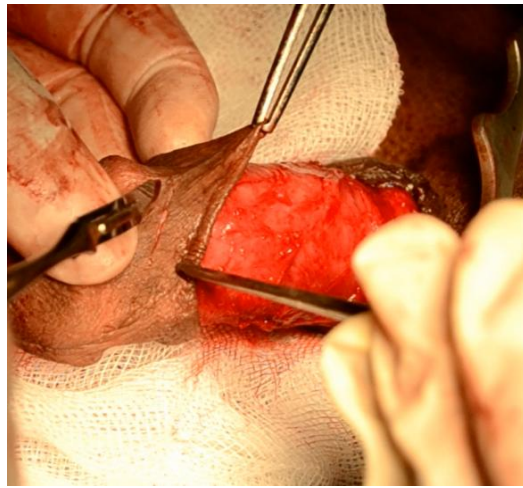


Fig3: Two parallel penile skin incisions

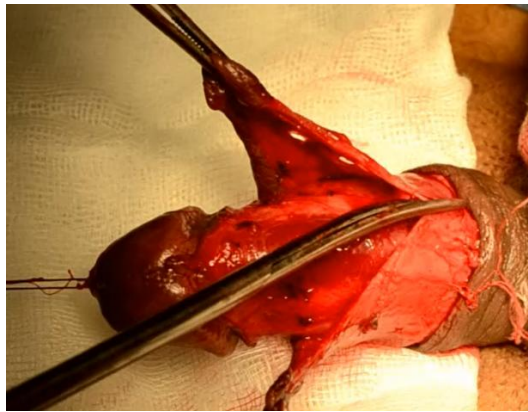
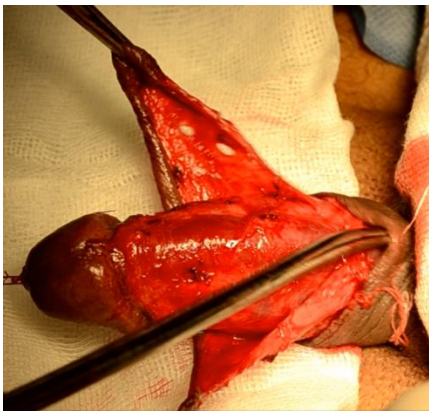


Fig4,5: The penile circular skin flap was separated on the ventral and dorsal side

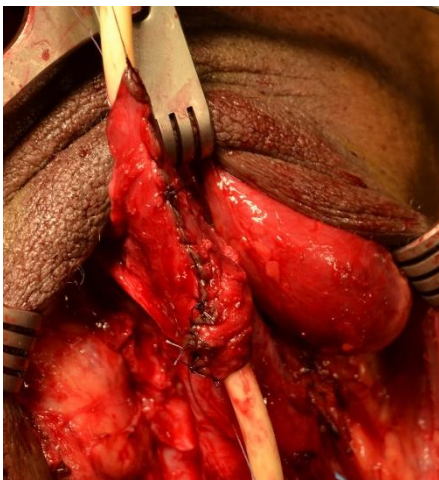


Fig6: Skin flap was shaped into a tube

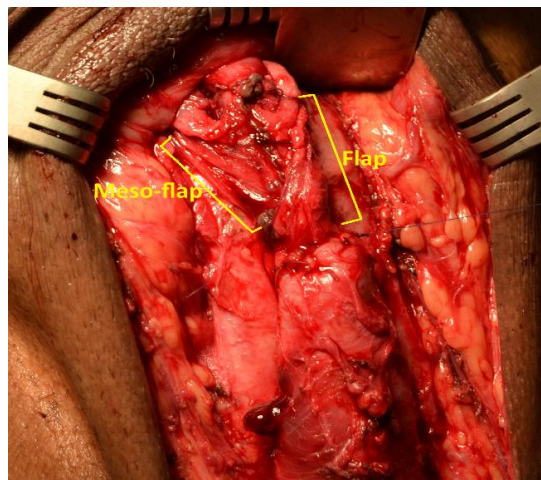


Fig7: Suturing the flap with proximal and distal urethra

