12 Flaps and Grafts in Hypospadias Repair

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12.1 Introduction

Hypospadias is attributed to the failed fusion of the endodermal urethral folds, resulting in incomplete urethral tubularization. The incomplete tubularization of the urethra results in an ectopic urethral opening that can be found anywhere from the glans to the perineum. About 50% of hypospadias are distal (glans and coronal), 30% are middle (penile shaft), and 20% are proximal (scrotal and perineal). This arrest in development often also causes ventral chordee (penile curvature) and ventral foreskin deficiency, leading to a dorsal "hooded" prepuce. More severe presentations of hypospadias may be accompanied by peno-scrotal transposition, in which the scrotum is abnormally positioned superior and anterior to the penis.

Hypospadias repair should aim to achieve the following three main objectives: voiding in an upright position, an appropriate voiding stream, and normal penile appearance and function. There are hundreds of operative techniques with slight variations described in the hypospadiology literature with an ultimate goal of achieving normal penile function and cosmesis [1]. These modifications often focus on the method of reconstructing the urethra or correcting penile curvature. Urethral reconstruction for distal hypospadias may not need tissue replacement besides an interposition layer to cover the neo-urethra suture line, such as a dartos flap. Proximal hypospadias more commonly requires additional tissue during reconstruction to compensate for the congenital ventral tissue deficiencies [2]. In this chapter, we will describe the roles, types, and basic principles of flaps and grafts used for urethral substitution, augmentation, primary tissue for penile resurfacing, and interposition in hypospadias repair with current outcomes in literature using comparative studies.

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12.2 Patient Examination

Hypospadias should be diagnosed at birth with a thorough physical examination. Establishing a diagnosis during the neonatal period is essential, as performing a neonatal circumcision is contraindicated in these patients. This is because the prepuce is frequently used as a vascularized flap or free graft during the urethral reconstruction. After urologic consultation and shared decision-making with the patient's parents for repair, several factors should be taken into consideration

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prior to repair. A thorough genitourinary examination should be conducted to determine the meatal location, glans volume, penile length, degree of chordee, presence of peno-scrotal transposition, and depth and width of the urethral plate. These operative characteristics, in addition to a surgeon's preference and experience, play a role in the selection of a method of repair and use of pre-operative testosterone therapy for surgical optimization [3].

12.3 Flaps

12.3.1 History and Evolution

A flap is a transfer of tissue with an intrinsic vascular supply from one area of the body to another. Flaps have long been used in surgery for coverage of areas damaged by trauma, burns, radiation, chronic inflammation, and congenital anomalies. In fact, the earliest known description of flap use derives from ancient India [4]. The *Suśrutasaṃhitā*, dated back to almost 900 B.C., contains detailing of ancient Indian physicians using flaps for facial reconstruction. Similar principles of flap use have also been attempted by Aulus Cornelius Celsus (25 B.C.–50 A.D.) in ancient Rome and Oribasius of Alexandria (320–403 A.D.) in ancient Greece. Flap manipulation to replace skin defects has evolved throughout centuries into what is today modern plastic surgery.

One benefit of a flap transfer is that it carries its own blood supply, so it does not rely on the recipient bed for perfusion (Table 12.1). As such, it does not require microsurgical anastomosis with surrounding vessels for neovascularization. This allows for flaps to be used to reconstruct large areas of defect. In addition to the size of the defect, the surgeon must also account for the location, shape, depth, and surrounding skin laxity when planning for reconstruction. Another important consideration includes the local vascular supply that provides viable options for flap coverage, as well as ensuring that the flap is receiving sufficient perfusion. The current method of intraoperatively assessing flap perfusion in hypospadias is through the surgeon's clinical judgment of the tissue color and presence of bleeding. Though, a systematic review of intraoperative flap perfusion in microsurgery reports that fluorescence imaging and laser Doppler are suitable tools for assessment of flap perfusion [5]. These tools may be applicable in hypospadias repair in order to optimize flap survival.

Table 12.1 Broad comparison of characteristics between flaps and grafts in hypospadias repair

	Flaps	Grafts
Vascularity	Intrinsic vascular supply	Relies on recipient bed
Mobility	Limited mobility and rotation around pedicle	No mobile constraints for placement
Recipient site	Can survive on recipient site with questionable supply	Requires robust supply at recipient site for survival
Type of tissue	"Like" penile tissue	"Like," distant, or engineered tissue
Surgical sites	Single surgical site	One or more surgical sites

12.3.2 Flap Classification

Flaps can be classified through various methods such as the vascular supply of tissue, composition of tissue, and movement of tissue. When flaps are described by their vascular supply, they are either termed random or axial [7] (Fig. 12.1). Random flaps are not supplied by a named blood vessel. Rather, they are supplied by the interconnected dermal-subdermal plexuses. These systems of vascular supply are delicate and limited in the size of flap they can sustain. The distal end of a random flap is particularly prone to ischemia. This is due to its increased distance from a reliable blood supply and hyperadrenergic vasoconstrictive response to being incised and elevated [8]. Thus, prompt re-approximation of the flap to a vascularized source of nourishment is essential to optimize survival. Additionally, a 3:1 length-to-width ratio is used as a rule of thumb when harvesting a random flap to promote adequate circulation throughout the entire area. Axial flaps are developed based on angiosomes,

Fig. 12.1 An axial flap has a known blood vessel or vessels traversing its length, which supply the flap tissue directly and through their vascular networks. Random flaps do not contain an axial or named vessel. Instead, they are supplied by interconnected dermal-subdermal plexuses (Reprinted: Wisenbaugh ES, Gelman J. The Use of Flaps and Grafts in the Treatment of Urethral Stricture Disease. *Advances in Urology*. 2015 [6])

or territories of tissue that are vascularized by a specific vessel. The superficial and deep external pudendal arteries and their subdermal arterial plexuses are responsible for supplying the penile skin, prepuce, and subcutaneous tissue, which are all valuable resources in penile reconstruction.

Flaps can also be labeled by their method of transfer. Advancement flaps are transferred along the body parallel to their vascular pedicle. Rotation flaps are rotated around their vascular pedicle. The range of these flaps is limited as to not compromise the vascular supply from excessive rotational compression. Island flaps are used when the tissue bulk surrounding the vascular pedicle prevents adequate rotation. In island flaps, the cuff of tissue surrounding the vascular pedicle is removed to improve the rotational range. Attention must be placed to prevent torsion and kinks in the exposed vascular pedicle. Although these numerous variations encourage surgical innovation in flap use, an important principle is to prevent vascular compromise by minimizing excess flap rotation, pressure, and tension.

12.3.3 Flaps in Hypospadias

Flap use in hypospadias repair was first described by Bouisson in 1861, in which he used a scrotal flap to reconstruct the missing inferior segment of a urethra. Numerous methods of flap use have since been developed and implemented in hypospadias repair. Flaps are valuable in hypospadias repair due to ventral penile tissue deficiencies in severe presentations, which puts into question the reliability of the local perfusion and nutrition. When the decision is made to use flaps in hypospadias repair, local penile flaps are preferred as they can be well-mobilized, placed under minimal tension, and have a reliable blood supply. Local penile flaps are also preferred as they provide like tissue, which may provide superior aesthetic and functional results. Various techniques of flap use for urethral reconstruction in hypospadias repair have been described in the literature (Table 12.2). A brief summary of flap outcomes reported in the literature is outlined in Table 12.3. Techniques using penile skin, inner preputial skin, perimeatal tissue, and dartos tissue are implemented for urethral reconstruction. Tunica vaginalis and dartos flaps are used as intermediate healthy layers to cover the neourethra for fistula prevention (Fig. 12.2). Penile skin and scrotal flaps are effective options for skin resurfacing.

12.3.4 Onlay Island Flap

Onlay island flap (OIF) entails the use of a dorsal pedicled prepuce or penile skin flap on the ventral

Table 12.2 Brief description of flap technique characteristics, advantages, and disadvantages

Flap	Tissue type	Advantages	Disadvantages
Onlay island flap	Prepuce (inner or outer) or dorsal penile skin	Single-stage Urethral augmentation Use in distal, mid, and proximal repair	Highly variable complication rates reported
Dorsal preputial flap (Byars)	Inner prepuce	Urethral augmentation or substitution Use in severe cases	Two-stage Highly variable complication rates reported
Preputial tubularized island flap	Prepuce	Single-stage Urethral substitution	Severe fistula risk
Perimeatal flap (Mathieu)	Ventral penile skin	Single-stage Urethral augmentation	Poor cosmetic outcome Limited to mid-penile and distal repair

Table 12.3 Summary table of outcomes using different flap techniques reported in the literature

Authors	Meatal location	Technique (n) [# of planned stages]	Total complications	Urethrocutaneous Fistula	Meatal stenosis	Cosmetic complications
ElGanainy [10]	Coronal, subcoronal, distal	OIF (30) [1] Mathieu (30) [1]	0 (0%) 6 (20.0%) p = 0.036	0 (0%) 4 (13.3%)	–	OIF better cosmetically than Mathieu p < 0.001
Braga [13]	Peno-scrotal	OIF (40) [1] TIP (35) [1]	18 (45.0%) 21 (60.0%) p = NS	8 (20.0%) 15 (42.9%) p = 0.03	1 (2.5%) 1 (2.9%) p = NS	–
Long [15]	Proximal	Byars (81) [2]	40 (49.0%)	5 (6.2%)	5 (6.2%)	–
Stanasel [16]	Proximal	Byars (56) [2]	38 (67.9%)	32 (57.1%)	5 (8.9%)	–
McNamara [17]	Proximal	Byars (134) [2]	71 (53.0%)	39 (29.1%)	17 (12.7%)	–
Wiener [20]	Proximal	PTIF (74) [1] OIF (58) [1]	27 (36.5%) 18 (31.0%) p = 0.64	10 (13.5%) 10 (17.2%) p = 0.73	3 (4.1%) 2 (3.4%)	1 (1.4%) 3 (5.2%)
Ghali [21]	Distal, mid-penile, proximal	Mathieu (216) [1] PTIF (148) [1] OIF (42) [1]	33 (15.3%) 48 (32.4%) 3 (7.1%)	19 (8.8%) 22 (14.9%) 1 (2.4%)	1 (0.5%) 17 (11.5%) 0 (0%)	- 22 (14.9%) 3 (7.1%)
Wilkinson [28]	Distal	Mathieu (1496) [1] TIP (1872) [1]	–	79 (5.3%) 72 (3.8%) p = 0.03	7/1050 (0.7%) 57/1861 (3.1%) p < 0.001	–

aspect of the penis. This technique was popularized by Elder et al. in 1987 as a method for repairing mid-penile and distal hypospadias, as well as hypospadias that is too proximal to be repaired with the Mathieu technique [8]. This is performed by making a U-shaped incision along the urethral plate that extends proximal to the hypospadic meatus followed by a subcoronal circumferen-

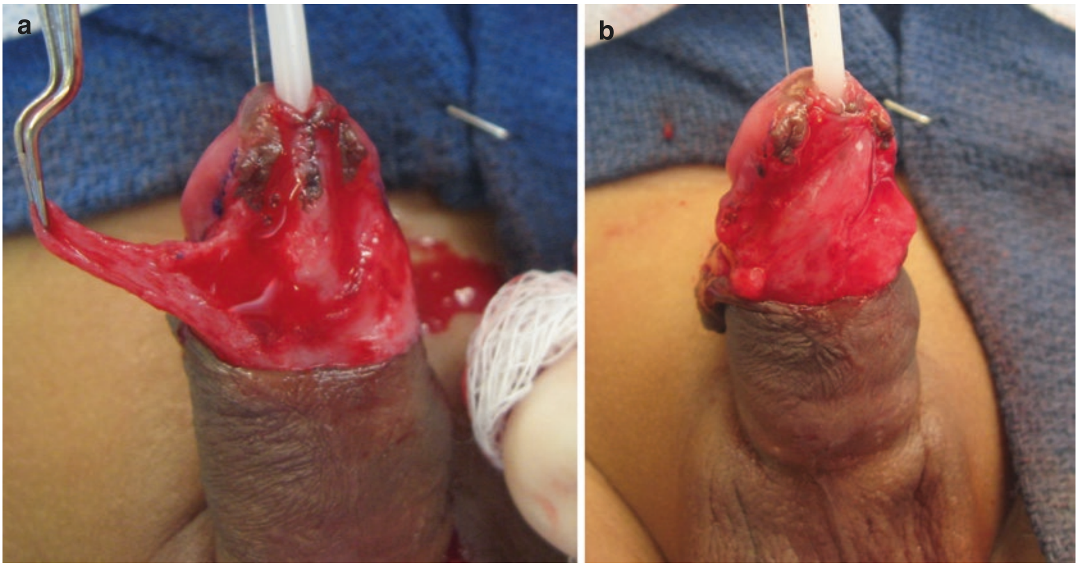

Fig. 12.2 Dartos flaps. (**a**) Lateral dartos flap harvested to cover the suture line at the neourethra in a distal hypospadias repair. (**b**) The suture line is covered. Glans flaps will then be re-approximated over the flap

tial incision. A pedicled skin flap is created on the dorsal penis using stay sutures to expose the junction between the inner and outer layers of the prepuce and then incising at this junction just beneath the inner preputial skin (Fig. 12.3) [9]. A longitudinal incision is made through the proximal dartos fascia to free the flap while preserving its vascular pedicle. The flap pedicle is dissected down to the penopubic junction to prevent tension during flap mobilization. The flap is then transposed over its pedicle onto the ventral aspect by placing the glans through the longitudinal incision via a buttonhole maneuver. The onlay island flap is then sutured to the bilateral edges of the urethral plate, covered with a second layer of vascularized inner preputial tissue, and then ventral skin and glans are re-approximated [10, 11]. OIF is an appropriate and reliable technique for urethral augmentation in hypospadias given its favorable post-operative outcomes and normal cosmetic appearance [12, 13].

12.3.5 Dorsal Preputial Flap

In many cases of severe hypospadias, the robustness of the ventral dartos tissue and urethra is insufficient for a successful single-stage hypospadias repair. A two-stage procedure may be more effective, as it allows an opportunity to use a graft or flap to provide sufficient vascularity and tissue prior to urethroplasty. The first stage entails orthoplasty, or straightening of the penis, followed by harvesting and placing a graft or flap. The second stage is comprised of urethroplasty, glansplasty, and a layered closure. Here we will discuss the use of dorsal preputial flaps during the first stage of repair.

The use of dorsal preputial flaps for hypospadias repair was popularized by Byars in 1951 [14]. During the first stage, a midline incision is made which extends to the hypospadic meatus (Fig. 12.4) [9]. A circumferential incision is then made proximal to the coronal sulcus. The penis is then degloved to its base to correct the chordee. Further orthoplasty techniques such as dorsal plication, ventral fairy cuts, or urethral mobilization may be necessary if chordee persists. Once the penile curvature correction is satisfactory, the glans is divided in the midline and dissected laterally in order to separate the ventral aspect off of the corpora cavernosa. The Byars technique is performed by extending the dorsal foreskin, which is then divided in the midline to allow for

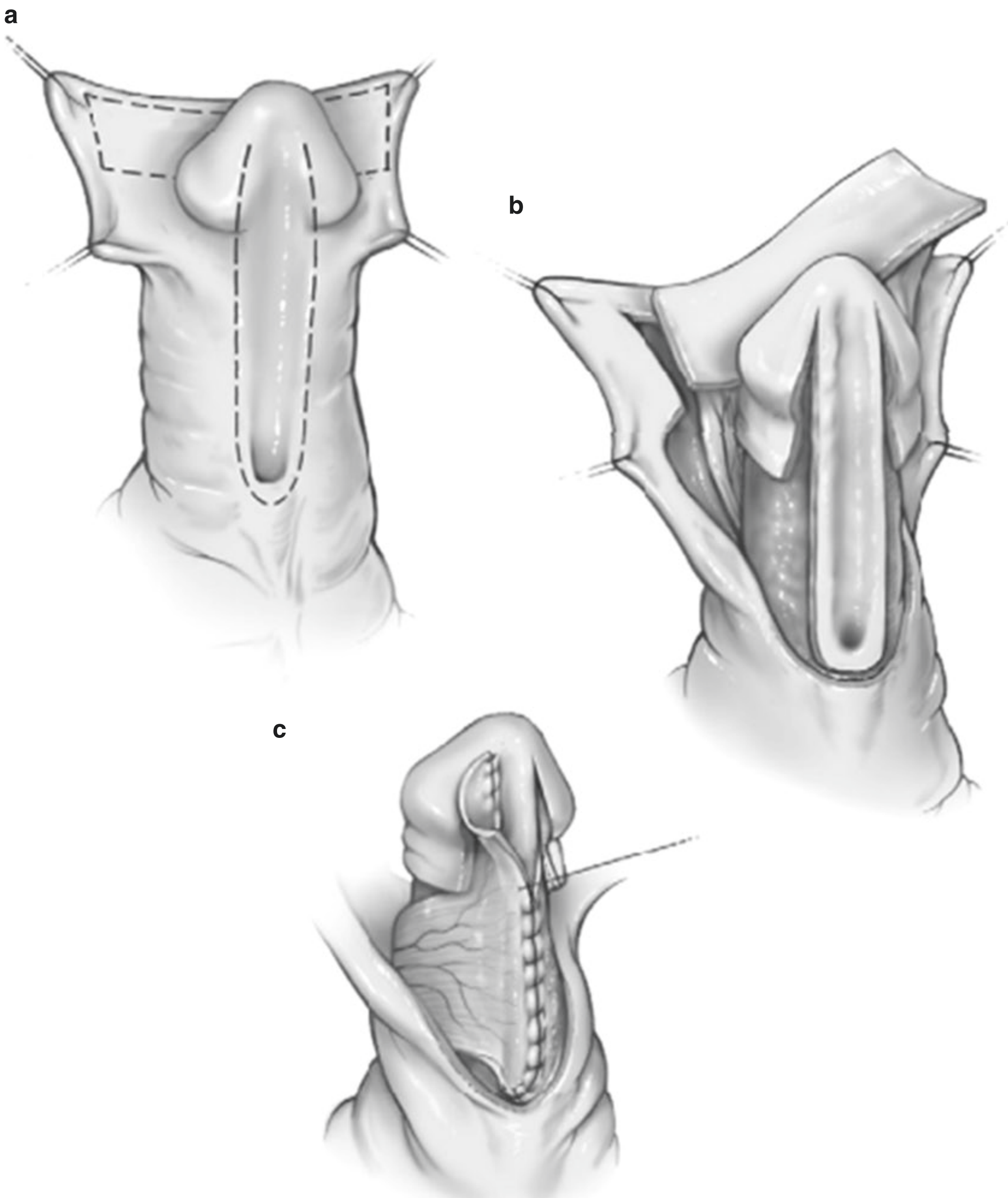

Fig. 12.3 Onlay island flap. (**a**) Incisional lines are outlined on the inner prepuce and the urethral plate. (**b**) The inner preputial flap is dissected along its vascular pedicle for mobilization. (**c**) The mobilized flap is transposed ventrally, either through a buttonhole maneuver or laterally. The flap is then sewn to the urethral plate for urethral augmentation (Reprinted with permissions from: Campbell-Walsh Urology tenth ed. Wein AJ, Kavoussi LR, Novick AC, Partin AW, Peters CA. Hypospadias. Fig. 130–12 p. 3515. Copyright Elsevier Health Sciences 2011)

ventral mobilization. The dorsal preputial flaps are rotated ventrally and sutured into the glanular cleft and distal urethral bed. The purpose is to establish a supple dartos bed for a safe and effective second-stage urethroplasty. The ventral skin is then closed at the midline. The second-stage urethroplasty should be performed after at least 6 months to allow for proper healing. Urethroplasty

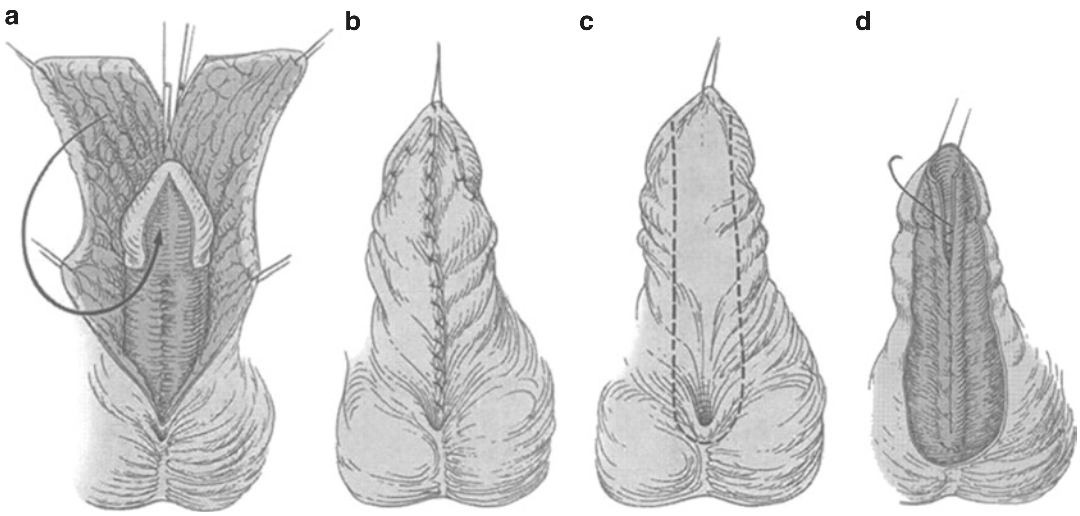

Fig. 12.4 Byars flaps. (**a**) Midline incision is made extending to the hypospadic meatus, followed by a circumferential incision proximal to the coronal sulcus. The penis is then degloved to its base to correct the chordee. Upon satisfactory chordee correction, the glans is divided in the midline. The dorsal foreskin is then extended and divided in the midline to allow for ventral mobilization. (**b**) The dorsal preputial Byars flaps are rotated ventrally and sutured into the glanular cleft and distal urethral bed. The ventral skin is closed at the midline. (**c**) Six months are allowed for proper healing after the first stage. In the second stage, U-shaped incision is made, which extends proximal to the meatus. (**d**) The strip is tubularized to create a neourethra (Reprinted with permissions from: Campbell-Walsh Urology tenth ed. Wein AJ, Kavoussi LR, Novick AC, Partin AW, Peters CA. Hypospadias. Fig. 130–17 p. 3520. Copyright Elsevier Health Sciences 2011)

may be performed using the surgeon's preferred technique. Thiersch-Duplay or TIP is currently the most widely-preferred method.

Urethrocutaneous fistula is often the most frequently reported complication. Other commonly reported complications include glans dehiscence, urethral stricture, urethral diverticulum, and meatal stenosis. When interpreting high complication rates for proximal hypospadias, it is important to remember that multi-stage procedures are used to repair the most complex and severe presentations and should not be compared to distal hypospadias outcomes [15–17]. Dorsal preputial flaps are viable options for embedding ventral penile vascularized tissue prior to urethroplasty.

Author's perspective—When used for proximal hypospadias, Byars skin flaps create a midline scar. This may complicate the second-stage tubularization and may impair the outcomes.

12.3.6 Preputial Tubularized Island Flap

Significant tissue deficiency in the urethral plate may require transection and replacement with a more robust substitute to create a neourethra. The preputial tubularized island flap (PTIF) was first described by Duckett in 1980 for a one-stage repair of severe hypospadias [18]. This technique involves a subcoronal circumferential incision, degloving the penis to its base, and orthoplasty. A dorsal transverse island flap is dissected from the inner prepuce that is equal or slightly longer in length to the distance between the hypospadic meatus and the glanular tip (Fig. 12.5) [9]. The flap is mobilized around its axial pedicle to allow for tension-free ventral transposition. The native urethra distal to healthy spongiosa is transected and removed. The flap is then tubularized over an appropriately-sized stent and anastomosed proximally to the spatulated native urethra. The neourethra is fixed at the new meatal opening through an artificially created glans channel. Another layer of dartos is used to cover the neourethra prior to re-approximating the ventral skin and glans [19]. The preputial tubularized island flap method has been noted to have higher complication rates than other techniques [20, 21] and should be reserved for severe and refractory presentations of hypospadias.

> *Author's perspective*—Tubularized flaps have high attrition rates, which may lead to common complications such as urethrocutaneous fistulas.

12.3.7 Perimeatal Flap

Perimeatal flaps involve the use of healthy ventral penile shaft skin as a flap for hypospadic urethral augmentation. The most popularized technique for perimeatal flaps was described by Mathieu in 1932 [22]. The Mathieu procedure entails using a U-shaped incision beginning at the glans and extending proximal to the hypospadic meatus to raise a flap on the ventral aspect of the penis. The length of the flap proximal to the meatus should be equal in length as the distance from the meatus to the glanular tip. Notably, the length of the flap should not be more than double the width, which limits the use of this technique to mid-penile or distal hypospadias. The flap is folded or flipped over distally to cover the hypospadic meatus (Fig. 12.6) [23]. The urethroplasty is completed by bilateral anastomosis of the onlay perimeatal flap to the urethral plate. The ventral skin and glans are re-approximated and closed over the flap. The Mathieu technique creates a round, horizontal meatus, which is cosmet-

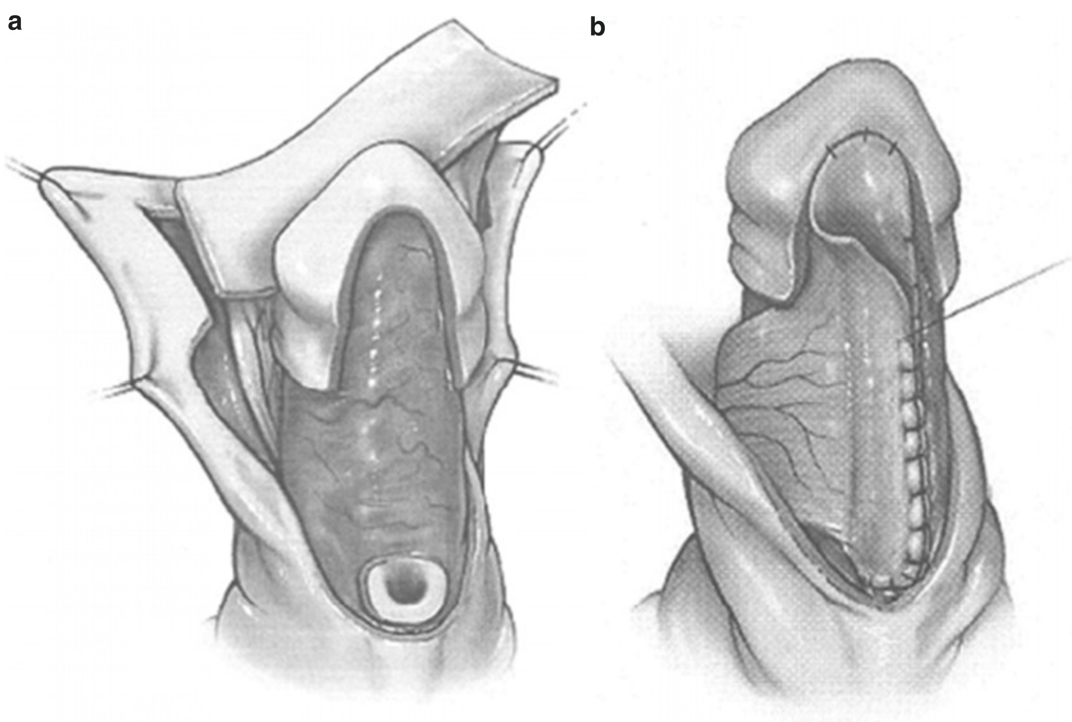

Fig. 12.5 Preputial tubularized island flap. (**a**) After adequate chordee correction, a dorsal transverse island flap is dissected from the inner prepuce. The flap should be equal or slightly longer to the distance between the hypospadic meatus and the glanular tip. The flap should be sufficiently mobilized to allow for tension-free ventral transposition. The native urethra distal to healthy spongiosa is removed. (**b**) The flap is tubularized over an appropriately sized stent and anastomosed proximally to the spatulated native urethra. The neourethra is fixed at the new meatal opening through an artificially created glans channel. A dartos flap should cover the neourethra prior to skin closure (Reprinted with permissions from: Campbell-Walsh Urology tenth ed. Wein AJ, Kavoussi LR, Novick AC, Partin AW, Peters CA. Hypospadias. Fig. 130–15 p. 3519. Copyright Elsevier Health Sciences 2011)

ically unfavorable compared to the normal vertical, slit-like meatus [24, 25]. Multiple technical modifications have been developed in order to create a vertical, slit-like meatus, such as hinging the urethral plate and a V-shaped incision on the flap apex [26, 27]. Fistulas are believed to be more common [28] after the Mathieu procedure due to the flap requiring two suture lines to approximate to the urethral plate. Though cosmetically unfavorable, Mathieu procedure can be an effective method of distal and mid-penile hypospadias repair using a perimeatal flap.

Author's perspective—Recession of the meatus and high fistula rates discourages the use of perimeatal flaps.

12.3.8 Intermediate Layer Flap

Urethrocutaneous fistula is one of the most commonly reported complications in the hypospadias literature [29]. The use of an additional waterproofing layer of vascularized tissue to cover the neourethra suture line has been shown to lower the fistula rate [30]. Dartos (DF) and tunica vaginalis (TVF) flaps are the most widely used sources of interposition layers due to their vascular reliability and accessibility. DF can be harvested from the dorsal or ventral penile skin, prepuce, or scrotum. TVF is harvested by opening the anterior and distal aspect of the scrotum with a transverse incision. When isolating the flap, two longitudinal incisions are made along the transverse incision while taking great care to preserve the spermatic cord and vascular supply from the cremasteric artery. The TVF is brought to the suture line through a subcutaneous tunnel [31]. The decision between these two tissue materials is left to surgeon preference. However, a recent meta-analysis compared 353 patients who received primary hypospadias repair using the TIP technique and either DF or TVF as intermediate layers [32]. Patients with TVF intermediate layers had better total post-operative complication, urethrocutaneous fistula, and wound-related complication rates than those with DF. Another systematic review supports using a TVF as the first-choice for urethral coverage [33]. Worse outcomes with a DF may be a result of damage to the blood supply of the neourethra and penile skin during flap dissection, which does not occur with a TVF. Ultimately, a vascularized intermediate layer flap should be used to

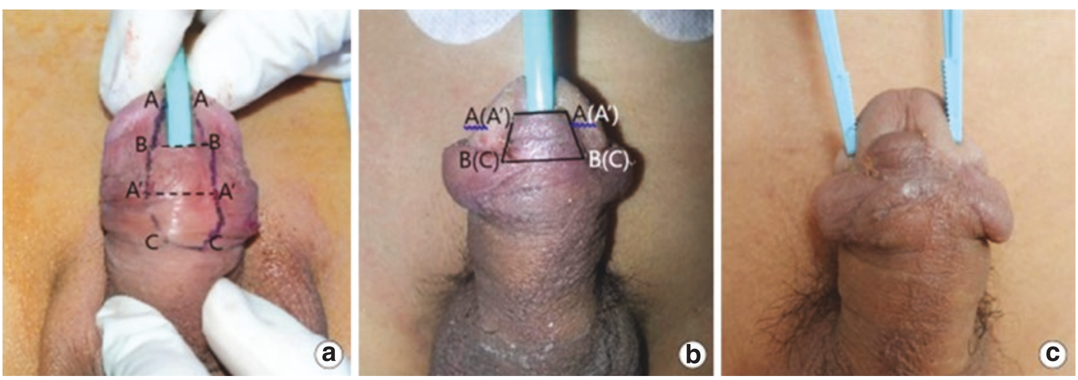

Fig. 12.6 Perimeatal flap. (**a**) The Mathieu procedure is started with a U-shaped incision from the glans that extends proximal to the hypospadic meatus to create a flap on the ventral aspect of the penis. The length of the flap proximal to the meatus should be equal in length to the distance from the meatus to the glanular tip. Chordee should be corrected as necessary after penile degloving. The flap is folded over distally to cover the urethral plate, followed by bilateral anastomosis of the onlay perimeatal flap to the urethral plate. The ventral skin and glans are re-approximated and closed over the flap. (**b**) Two weeks post-operation. (**c**) Three months post-operation (Reprinted with permissions from: Bae SH, Lee JN, Kim HT, Chung SK. Urethroplasty by Use of Turnover Flaps (Modified Mathieu Procedure) for Distal Hypospadias Repair in Adolescents: Comparison With the Tubularized Incised Plate Procedure. *Korean J Urol*. 2014;55(11):750–755)

limit post-operative complications, with recent studies supporting the use of TVF.

> *Author's perspective*—Interposition is the most important step in hypospadias surgery to prevent urethrocutaneous fistula. Most of the time, a dartos flap is available and adequate for interposition. There is rarely a need for a TVF.

12.3.9 Resurfacing of Skin

Ventral tissue deficiencies are characteristic of hypospadias and are typically more severe in proximal presentations. In most of these cases, Byars flaps or local penile skin flaps are sufficient for skin resurfacing [34]. A dorsal relaxing incision or Z-plasty may be necessary to allow for adequate tissue rearrangement. However, patients who have undergone multiple failed repairs often have more drastic tissue deficiencies. Not only is the recipient bed damaged due to the compromised vascularity and scarring of the skin and urethra [35], but the local tissue may also be affected and not usable for skin coverage. Scrotal flaps are fasciomyocutaneous flaps that can be rotated towards the penis for skin coverage. Scrotal flaps have an extensive arterial supply, making them a reliable option for skin resurfacing [36]. This is done by raising a flap from one hemiscrotum without crossing the midline and rotating it to cover the ventral penile skin defect [34]. A 2:1 length-to-width ratio is ideal for vascular preservation. Though cosmetic defects like dog-ears or hairy skin may occur, the favorable overall results demonstrate scrotal flaps are a dependable option where others are not available.

12.4 Grafts

12.4.1 History and Evolution

Free grafts are sheets of tissue that are detached from their vascular supply and placed in a new area of the body. Relative to skin flaps, graft use throughout history is not as extensive [37]. Early attempts for systematic trials of grafting on animals were noted by Thomas Birch throughout the seventeenth century, although these resulted in failure. In 1804, Giuseppe Baronio (1758—1814) published successful results from his skin grafting experiments on rams and other large animals. He noted using adhesive tape to fix the graft edges and gradual restoration of blood flow during healing. In 1874, Karl Thiersch (1822—1895) famously published his grafting findings. He described an adhesive material (fibrin) between the graft and recipient bed, revascularization of grafts, and improved success with thin grafts. He also described learning of an ancient Indian technique for graft preparation, in which the donor tissue was softly pounded to stimulate an inflammatory reaction prior to removal. This technique, termed "flagellation," was thought to improve graft survival. Thiersch's work throughout his life had a significant impact on the field of plastic surgery, as well as hypospadiology through his contribution to the Thiersch-Duplay technique.

Grafts are a valuable tool for reconstruction where local tissue availability is limited and flaps are not a viable option. Grafts are used in reconstruction due to their function as protective barriers for mechanical damage and fluid loss. Further, they provide the recipient site with improved tissue robustness after healing occurs.

12.4.2 Graft Characteristics

Skin and mucosa are the most frequently derived sources of tissue for engraftment. Skin grafts are classified as either full thickness or split thickness. Full-thickness skin grafts (FTSG) include all the layers of the epidermis and dermis. These are harvested by raising the dermis from the subcutaneous tissue using a scalpel and usually include hair follicles in that region. Split thickness skin grafts (STSG) include the epidermis and only a portion of the dermal layers. These are harvested using either a knife or a dermatome with an adjustable depth gauge. The key difference in physiologic characteristics between these two types of graft is the amount of dermis present [38]. Within the dermis are sweat glands, sebaceous glands, hair follicles, and increased amounts of elastin. These characteristics, along with increased overall thickness, lead to greater metabolic requirements and a higher risk for primary contraction in FTSG. Primary contraction is the immediate recoil after a graft is harvested and is correlated to the amount of elastin in the dermis layers. However, STSG are more likely to undergo secondary and overall contraction. Secondary contraction is caused by increased myofibroblast activity leading to graft contracture. FTSG have lower rates of secondary contraction due to the increased dermal layers, which shorten the life cycle of myofibroblasts and decrease their effect on graft survival [39]. Further, FTSG are advantageous in that they provide superior texture and aesthetic results at both donor and recipient sites compared to STSG [40]. However, STSG can be used to cover larger areas of defect and can be re-harvested from donor sites due to skin regeneration. Mucosal grafts differ from skin grafts in that they lack keratin, hair follicles, sweat glands, and sebaceous glands, which are sources of chronic inflammation when present in the urethra [41]. They may be obtained from the inner cheek, tongue, palate, bladder, and small intestine. The unique secretory epithelium of mucosal grafts makes them ideal options for urethral reconstruction. Of note, much of the knowledge and principles related to grafting in hypospadias is assumed from the skin grafting literature in plastic surgery. Future studies may focus on the specific physiologic processes of tissue materials and their recipient bed in hypospadias repair.

12.4.3 Graft Take

Since grafts are not attached to their own vascular supply, they rely on an adequate wound bed to survive. It is believed the graft must lie within 1–2 mm of the recipient vascular supply in order to successfully undergo the processes necessary for graft survival: plasmatic imbibition, vascular inosculation, and neovascularization [42] (Fig. 12.7) [43]. Plasmatic imbibition is the exchange of gas and nutrients from the wound bed to the graft during the first 48 h of tissue transfer. This occurs as the plasma diffuses from the recipient capillary bed into the graft vessels, thereby sustaining the graft and preventing immediate graft ischemia. Inosculation is described as the growth of a fine vascular network from the wound bed that interfaces with the dermis of the graft after 48–96 h of tissue transfer. These new capillary buds serve as the foundation for more dependable vascularization. Then, neovascularization occurs in which new blood vessels invade the graft and undergo a dual process of anastomoses with existing vascular channels and creation of new vasculature. Neovascularization establishes a permanent vascular supply to provide the nourishment necessary for healing. The need for adequate blood supply from the wound bed to the graft requires great care to achieve the equilibrium between hemostasis and perfusion. Due to this delicate process, grafts are typically only used in staged procedures in order to allow the graft to heal or “take” before continuing with reconstruction.

12.4.4 Grafts in Hypospadias

Grafts have been proven to be useful in hypospadias repair as there may be significant deficiencies in ventral tissue or scarring secondary to previous repair. The first description of graft use in hypospadias repair was in 1897 when Nové-Josserand tubularized a free skin graft for urethroplasty. There are various sources and techniques for grafting described in the current hypospadias literature, including autografts, allografts, and xenografts (Table 12.4). Autografts are derived from the same individual. Allografts are derived from the same species but a different individual. Xenografts are derived from completely different species. Preputial skin and buccal mucosa are the most commonly used graft material in urethroplasty. Bladder mucosa and posterior auricular skin have also been described for urethroplasty, however, it is used significantly less frequently due to their associated complica-

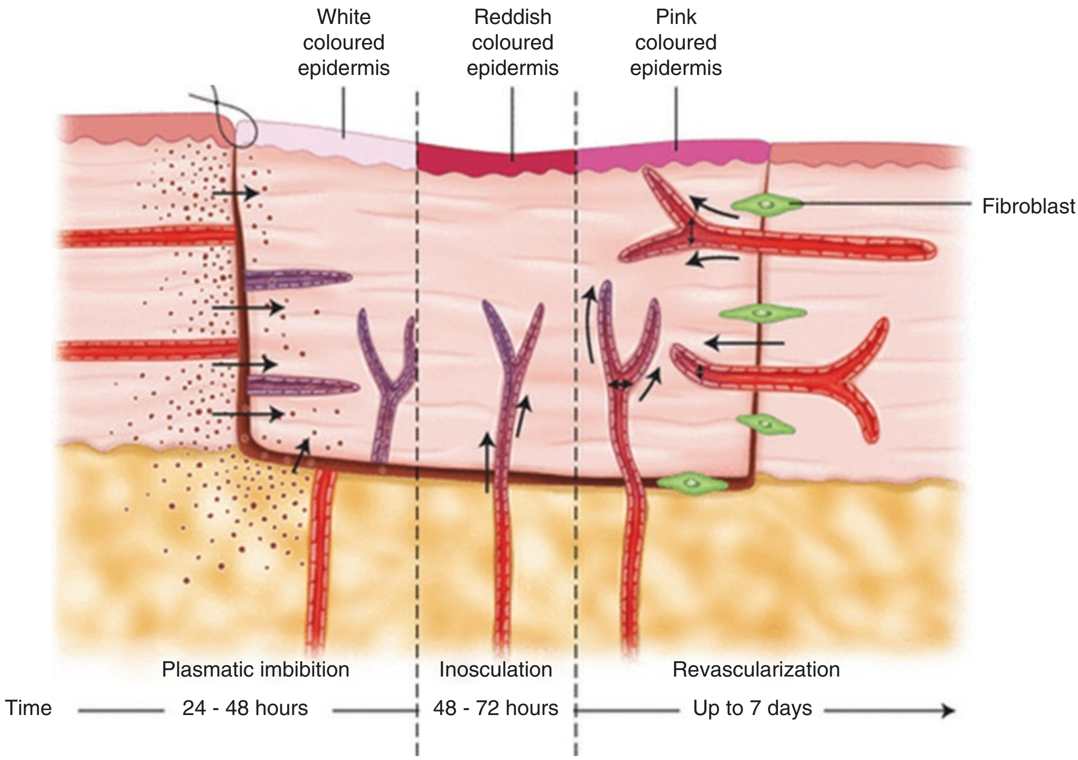

Fig. 12.7 Illustration demonstrating the 3 stages of graft healing. First, plasmatic imbibition occurs in which gas and nutrients diffuse between the recipient bed and the graft. Next, capillary buds begin to develop within the graft during inosculation. Finally, new blood vessels invade the graft and establish a permanent vascular network to revascularize the new graft tissue (Reprinted with permissions: Fortier JL, Castiglione CL, Guo L. Skin Grafting. In: Orgill DP, ed. *Interventional Treatment of Wounds: A Modern Approach for Better Outcomes*. Springer International Publishing; 2018:123–142)

tions. A brief summary of graft outcomes reported in the literature is outlined in Table 12.5. Lastly, several ventral lengthening techniques for chordee correction have been described with a variety of tissue material used including both flaps and grafts.

12.4.5 Preputial Skin Graft

Preputial skin is a commonly used source of flaps and autografts. Many surgeons prefer the use of preputial skin flaps over grafts due to the proximity of the flap to the urethra, which allows the flap to be rotated around its pedicle to preserve vascularity and optimize flap survival. However, an advantage of using preputial skin as a graft is that dissection becomes simpler since there is not a pedicle to be mobilized and preserved [44]. Further, there is relatively less bulkiness when using a graft compared to a flap, which may facilitate ventral skin closure. Though the preputial skin is typically hairless, it does have the potential to grow hair in the future [41]. The presence of hair follicles, as well as sebaceous and sweat glands, may cause neourethral complications due to chronic inflammation [41]. Preputial grafts are harvested from the inner prepuce and de-fatted prior to placement. Graft length should correspond to the length of urethral defect, beginning at the proximal aspect of the hypospadic urethral meatus to the glanular tip when the penis is fully stretched. Graft width depends on whether it will be used as an inlay or onlay. If it is to be used as

Table 12.4 Brief description of graft types and their respective advantages and disadvantages

Graft type	Advantages	Disadvantages
Preputial skin graft	Accessible Single surgical site Low complication rates	Sebaceous and sweat glands Possible luminal hair growth
Inner preputial skin graft	Hairless, accessible Single surgical site	Often not adequate for urethral replacement
Buccal mucosa graft	Hairless, accessible Histologically similar to urethra Highly vascularized Low complication rates	Two surgical sites Oral pain after graft harvest Contracture and facial deformities previously reported
Bladder mucosa graft	Histologically resembles urethra Accustomed to urine exposure	Invasive procedure Metaplasia upon air exposure Higher meatal complication rates
Post-auricular Wolfe graft	Accessible	Two surgical sites Fine hair in lumen Chronic inflammation in FTSG

an inlay for urethral augmentation in an atretic dorsal urethral plate, the width should be about 10 mm, or enough to lay within the incised urethral plate [45, 46]. This technique is effective in widening the urethral plate [47]. If the graft is used as an onlay in urethral augmentation, the width of the graft plus the dorsal urethral plate should be about 2 mm greater than the circumference of the proximal urethra [44]. The slightly greater width accounts for the suture line.

Preputial skin can also be used in multi-stage repairs when ventral tissue deficiencies or ventral chordee is not optimal for a single-stage repair. The Bracka technique is a widely accepted method for two-stage repair using the inner prepuce as a graft [48]. In this method, the urethral plate and glans are divided using a midline incision extending to the proximal meatus. The graft is quilted onto the ventral defect as a dorsal inlay graft (Fig. 12.8). The second stage is comprised of urethroplasty using the Thiersch-Duplay or TIP techniques. It is recommended to wait at least 6 months between stages to allow the new urethral plate to heal and become well-vascularized prior to tubularization.

Initial concerns regarding grafting in hypospadias questioned the ability for grafts to “take” and be functional, especially in severe cases where the recipient vascular bed may be insufficient. Meatal stenosis and neourethral strictures are complications that are thought to be related to ischemic donor tissue secondary to poor graft take, though these rates are reportedly low when using preputial grafts [49, 50]. This low rate of ischemia-related urethroplasty complications demonstrate the ability for preputial grafts to take, even in severe cases of hypospadias. In addition to implementation for primary repair, the Bracka technique using a preputial graft is highly regarded and more commonly performed for re-operation when the urethral plate is scarred and unlikely to re-epithelialize. A preputial skin graft is accessible, versatile, and adaptable, making it a favorable tool in hypospadias repair.

Author’s perspective—The two-stage urethroplasty using the free inner preputial skin graft has given consistent results across the board. When the graft is placed during the first stage, it is important to remove all scar tissue from the graft bed to optimize graft take. The graft quilting and dressing are critical for uptake.

12.4.6 Buccal Mucosa Graft

Buccal mucosa autografts are sheets of oral mucosa that are harvested from the inner cheek. Buccal mucosa grafts have the distinct advantage of having a rich submucosal vascular or pan laminar plexus that facilitates plasmatic imbibition and inosculation, thereby enhancing graft uptake and survival. Further, this mucosa is de-keratinized and its epithelial surface is accustomed to a moist environment, making it a suitable substitute in the urethra. A buccal mucosa graft is harvested by

Table 12.5 Summary table of outcomes using different graft material and techniques reported in the literature

Authors	Meatal location	Technique (n) [# of planned stages]	Total complications	Urethrocutaneous Fistula	Meatal stenosis	Cosmetic outcomes
Kolon [45]	All locations	Inlay, prepuce (32) [1]	2 (6.3%)	–	–	–
Cambareri [44]	Distal, mid-penile, proximal	Onlay, prepuce (62) [1]	22 (35.5%)	21 (33.9%)	3 (4.8%)	–
Ferro [49]	Proximal, scrotal, perineal	Bracka, prepuce (34) [2]	8 (23.5%)	2 (5.9%)	0 (0%)	0 (0%)
Markiewicz [52]	Not specified	Onlay, buccal (362) [1&2] Tube, buccal (55) [1&2]	71 (19.6%) 29 (49.1%) $p < 0.001$	–	–	–
Manasherova [41]	Peno-scrotal, scrotal, perineal	Bracka, prepuce (108) [2] Bracka, buccal (112) [2]	33 (30.6%) 23 (20.5%) $p = 0.092$	22 (20.4%) 15 (13.4%) $p = 0.21$	0 (0%) 0 (0%)	Buccal better cosmetically than prepuce
Lanciotti [53]	Peno-scrotal, scrotal, perineal	Bladder (50) [2]	23 (46.0%)	9 (18.0%)	4 (8.0%) *7 (14.0%)	8 (16.0%)
Nitkunan [56]	All locations	Bracka, PAWG (29^) [2]	2 (6.9%)	1 (3.4%)	0 (0%)	–
Pfistermüller [57]	All locations	Bracka, PAWG (66^)	6 (9.1%)	–	–	–

*Meatal prolapse complications; ^Secondary repairs

placing two stay sutures at the upper and lower cheek to optimize exposure (Fig. 12.9). An anesthetic is injected into the graft submucosal space. The required length of graft is measured and dissected sharply with great care to avoid injuring Stensen's duct. Bipolar electrocautery may be used for hemostasis. The harvest site may be left open or sutured closed, as both have similar outcomes for pain and complications [51]. The graft is then thinned, shaped, and immersed in an antibiotic solution prior to its use as a graft. In terms of use as a graft in single-stage procedures, buccal mucosa may be used as an onlay or inlay graft for urethral augmentation or as a tube graft for urethral substitution. A systematic review found greater success when used as an onlay graft compared to tube graft (80.4% vs 52.7%) [52].

Buccal mucosa grafts may also be used in two-stage repair via the Bracka technique. The Bracka technique, as described previously, originally intended for the use of a preputial graft to repair severe proximal hypospadias. However, buccal mucosa grafts have become increasingly favorable as an extragenital option due to the previously described characteristics [41]. Though the type of tissue differs compared to the rest of the techniques, the types of complications associated with buccal mucosa remain the same. These complications include urethrocutaneous fistula, meatal stenosis, and graft contracture. There is concern for surgical infection due to the oral microbiome that is introduced to the urethra. When appropriate, patients are started on prophylactic chlorhexi-

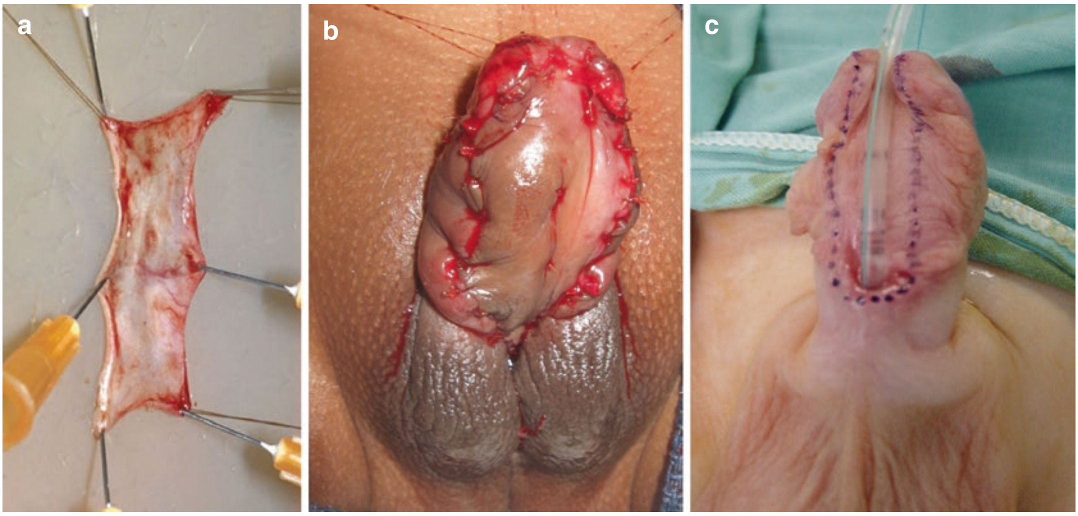

Fig. 12.8 Inner preputial graft. (**a**): Free graft derived from inner preputial skin. The graft has been thinned and prepared to cover the ventral penile defect in the first stage of a Bracka two-stage repair. (**b**) The graft has been quilted into place on the ventral penile shaft. The graft for this peno-scrotal hypospadias penis will be covered with a protected tie-over dressing and given 6 months to heal prior to the second stage. (**c**) Six-month follow-up of a different patient with proximal hypospadias after undergoing the first stage of a Bracka repair using inner preputial skin. The patient had excellent graft take and will undergo neourethral tubularization during the second stage

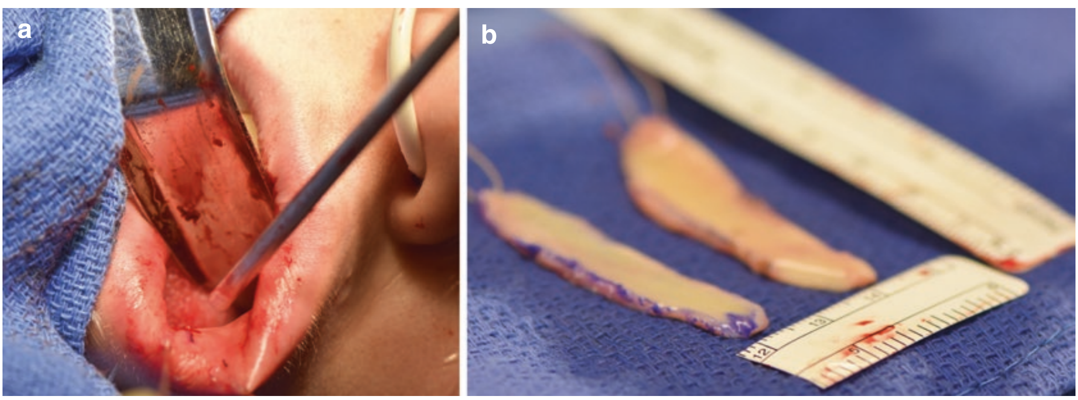

Fig. 12.9 Buccal mucosa graft. (**a**) The mouth is first disinfected with a mucosa-specific solution. Two traction sutures are in place at the border between the buccal mucosa and lip skin. A retractor is used to better expose the buccal mucosa. Metzenbaum scissors are used to lift the graft by dissecting in the plane between the mucosa and buccal fat, with great care to avoid injuring Stensen's duct. The donor site may be closed or left open. (**b**) The buccal mucosa will be de-fatted using curved scissors, shaped, and disinfected prior to being used as a graft

dine mouthwash 3 days prior to surgery, as well as broad-spectrum intravenous antibiotics the day before surgery to minimize this risk. Many surgeons favor buccal mucosa grafts due to the lower complication rates and histologic structure similarities between buccal mucosa and the native urethra [41]. Further, these grafts do not contain foreign structures such as sweat or sebaceous glands that lead to chronic inflammation and possible scar contraction of the graft [41]. Buccal mucosa is a favorable option for grafting in urethroplasty given its structural resemblance to native urethra, accessibility, and promising outcomes.

> *Author's perspective*—Buccal mucosa is the best tissue for urethroplasty if the inner prepuce or foreskin is unavailable. Precautions during harvesting should be taken, and avoid the lip if possible. Long-term contractures and facial deformities have been reported. Otherwise, this graft has excellent outcomes in all regards.

12.4.7 Bladder Mucosa Graft

In theory, bladder mucosa is well-suited for free autograft material in urethroplasty due to its functional resemblance to native urethra. Similar to buccal mucosa, bladder mucosa is de-keratinized and accustomed to moist environments. The bladder urothelium is continuously exposed to urine, making the graft a suitable substitute to the urethra. A bladder mucosa graft is obtained through a small Pfannenstiel incision. The bladder is filled via a bladder catheter and distended to facilitate identification of the anterior aspect. Once the anterior surface is identified, a deep incision is made through the detrusor muscle until enough mucosa is exposed to obtain a proper-sized graft [53]. The size of the graft depends upon the length of the defect as well as the repair technique of choice. Various methods have been described for bladder mucosa graft use such as an onlay patch for urethral augmentation or tubularization for urethral substitution.

Although the composition of bladder mucosa is comparable to that of native urethra, its use as a graft is limited for several reasons. Obtaining a bladder mucosa graft is much more invasive than harvesting a graft or flap from penile skin, preputial skin, and buccal mucosa. For that reason, bladder mucosa is rarely used for primary repair. Instead, it is typically only used in urethroplasty when nearby penile and preputial tissue has limited availability, such as in severe hypospadias or revision repairs. In these cases, it is more common practice to obtain a graft from the buccal mucosa due to the advantageous accessibility and histologic similarities. Another downfall for bladder mucosa as a urethral graft are the physiologic changes that occur when it comes in contact with air. Air exposure causes these grafts to undergo columnar metaplasia and develop mucinous glands leading to hyperplasia and edema [54]. As a result, bladder mucosa grafts are more likely to result in meatal complications, such as meatal prolapse or stenosis, due to the meatus enduring increased air exposure relative to the rest of the graft. Modifications have been made to avoid meatal and distal urethral complications secondary to air exposure [53]. Combined bladder mucosa and skin grafts, in which the distal urethra is a tubularized skin graft or flap, have been proven to be effective [55]. Overall, bladder mucosa grafts should not be considered the primary option in urethroplasty.

> *Authors perspective*—Bladder mucosa grafts are historical and not used in current practice due to the morbidities that are unique to bladder mucosa grafts and the availability of other widely accepted techniques.

12.4.8 Post-Auricular Wolfe Grafts

Post-auricular Wolfe grafts (PAWG) are another extragenital option for graft material in 2-stage repairs. PAWG is a readily-available, full-thickness skin graft. It is considered an option in hypospadias repair due to the absence of thick hair in the area, though fine hair of unknown clinical significance may be present [56]. The data for PAWG is limited, as many urologists prefer using preputial skin or buccal mucosa when managing urethral defects. The literature regarding grafting with PAWGs describes keloid formation at both the donor and recipient sites [56, 57]. These issues arise secondary to chronic inflammation when using full-thickness skin grafts in the urethra, as well as the creation of a separate surgical site during graft harvesting. As such, preputial skin and buccal mucosa are currently the preferred tissue material for urethral reconstruction.

> *Author's perspective*—PAWGs are very thick and difficult for tubularization. They may cause scarring at the donor site.

12.5 Ventral Lengthening

Severe chordee correction that is refractory to penis degloving can be repaired through multiple approaches, including ventral lengthening. Ventral lengthening is a highly considered technique in correcting severe chordee due to its ability to address the significant disproportion in length between the ventral and dorsal corporal bodies. The flap or graft used to cover the ventral defect in the tunica albuginea is what allows for ventral lengthening, as opposed to a dorsal plication which results in penile shortening. Ventral lengthening is associated with significantly lower rates of ventral curvature recurrence compared to dorsal plication (9.4% vs 27.9%) [58]. Various materials for ventral lengthening are described in the literature such as tunica vaginalis and dermis. Commercially available acellular matrix materials have also been studied, including small intestinal submucosa (SIS) and dermis.

Ventral lengthening is started by mobilizing the urethral plate off of the underlying corpora cavernosa [58]. A transverse incision is made through the tunica albuginea on the ventral aspect. It is essential to sufficiently extend this incision laterally to allow for complete release of chordee. The tunica albuginea is then lifted off the underlying tissue carefully through both proximal and distal dissection. A flap or graft of the surgeon's choice is then used to cover the ellipsoid defect. When harvesting a graft, the surgeon should ensure that it is 20–30% larger than the defect in order to avoid graft contracture and consequently recurrent curvature [59]. A tunica vaginalis flap or graft is often preferred when performing a ventral lengthening technique due to its easy accessibility. Dermal autografts are harvested from the inguinal crease, which allows for enough dermis to be removed as well as achieve cosmetic closure of the donor site [60]. The epidermis is removed from dermal grafts prior to detaching the graft from the underlying tissue. The flap or graft is anastomosed to the ellipsoid defect in the tunica albuginea, which then covers the corporal defect.

The viability of the donor tissue should be prioritized in corporoplasty, as poor attrition may result in tissue contracture and ventral curvature recurrence. Sufficient tissue vascularity is essential for optimizing tissue survival and preventing chordee recurrence, which highlights the issue of using flaps or grafts for ventral lengthening. One study compared tunica vaginalis flaps and grafts for ventral tunica albuginea defect coverage in rabbits [61]. There was no contracture in the flaps at 3 months, meanwhile 42% of the grafts had contracted by this point. Microscopic examination of three flaps all showed an intact blood supply and no evidence of tissue necrosis. In contrast, examination of three grafts all showed necrosis and granulation tissue at 2 weeks, which were replaced by collagenized fibrous tissue at 6 weeks. The reliable vascularity and lack of necrosis support the use of tunica vaginalis flaps in ventral lengthening. Further, reports have shown a 95% success rate when using tunica vaginalis flaps to correct penile curvature in hypospadias [59]. Dermal grafts may be considered when tunica vaginalis is unavailable, such as in patients with bilateral cryptorchidism or inguinal hernias [59]. However, experiences with dermal grafts have varied among hypospadias surgeons. Some hypospadiologists report excellent cosmetic and functional outcomes in 100% of patients with dermal grafts [60], while others report less than 60% success with a single dermal graft repair [62].

Xenografts and allografts are commercially available, pre-packaged graft materials that spare the need for additional donor site dissection and closure. Small intestinal submucosa xenografts are porcine-derived and composed of extracellular matrix bioscaffolds with type 1 collagen, which facilitates constructive remodeling of tissues [63, 64]. SIS grafts come pre-packaged as acellular, freeze-dried, and sterile. This graft type relies on inosculation and imbibition for vascular ingrowth and replacement of the graft by host tissue. There is limited literature published for outcomes after SIS graft use for chordee correction in hypospadias repair. The data thus far is unclear, as some authors report successful chordee correction with SIS corporal grafting [65], meanwhile others have found long-term complications of corporal scarring and dense fibrosis with SIS grafts [66]. Complications result due to graft rejection resulting in an inflammatory reaction and eventually fibrosis. An acellular dermal matrix allograft is also available for corporal grafting (Fig. 12.10) [67]. This human cadaveric-derived graft material has regenerative properties that have proven to function in other types of reconstructive surgeries [67]. Regeneration occurs through growth factors and vascular channels within the collagen scaffold that facilitate tissue infiltration, fibroblast proliferation, and neovascularization [68]. The data on ventral lengthening using acellular dermal matrices is limited, but one case series of 7 patients reports no recurrent ventral curvature after over a 1-year follow-up [67]. They report using grafts 20% larger than the defect to allow for contraction. Though there are various options for corporal grafting in ventral lengthening, there is not a clearly superior choice, leaving the decision for the surgeon's preference.

Authors perspective—The long-term outcomes are not yet known, especially venous leak and erectile function when these materials are used to cover the defect in corporotomies. Xenografts pose the challenge of infection.

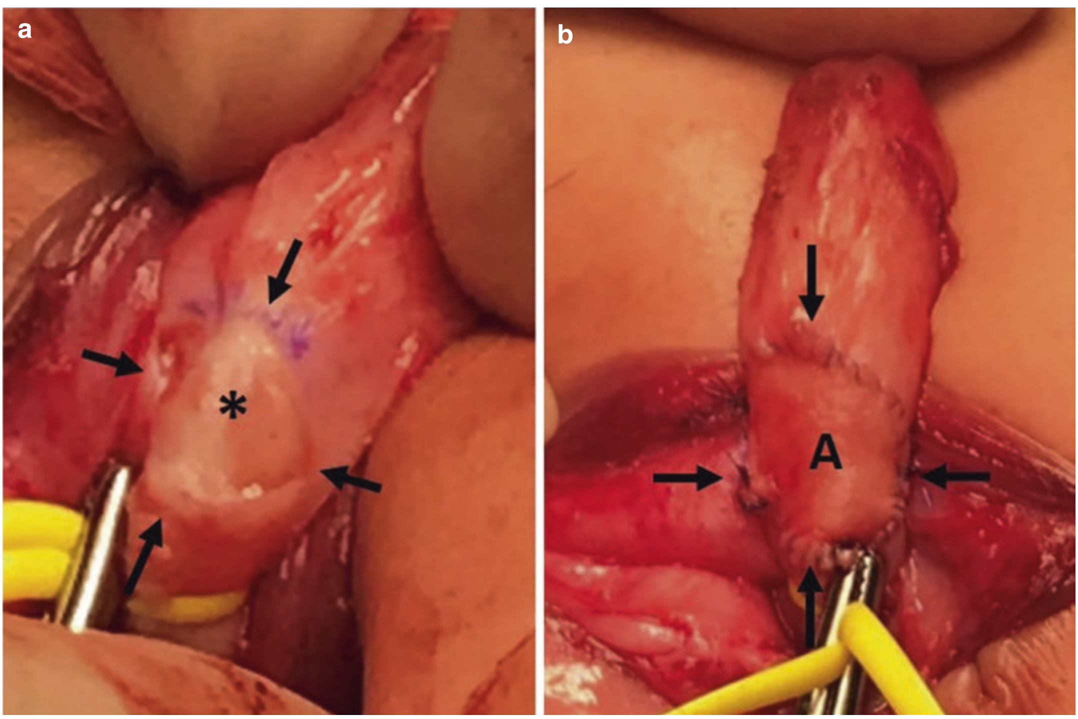

Fig. 12.10 Acellular dermal matrix graft. (**a**) The penis is completely degloved and an incision is made in the tunica albuginea, leaving a 180-degree ellipsoid defect outlined by the arrows. (**b**) An acellular dermal matrix graft is placed in the defect and sutured along its edges (Reprinted with permissions: Palmer LS, Palmer JS. The use of Alloderm® for correction of severe chordee in children: An initial experience. *Journal of Pediatric Urology*. Published online June 14, 2020)

12.6 Future Direction

Tissue engineering (TE) is a rapidly advancing field that aims to restore tissue and organ function. Scientists in TE draw principles from fields such as cell biology, material science, and biomedical engineering to develop natural and synthetic matrices to facilitate the regeneration of human tissue. In alignment with plastic surgery principles, the tissue material should possess similar biologic, physical, and mechanical properties to the native tissue. Though, there are a lack of tissue substitutes that perfectly resemble the native urethra and corpus spongiosum [69]. Other important qualities for optimizing scaffold success include adequate porosity, regenerative capacity, biodegradability, flexibility, and firmness [70]. One group reported using an amniotic membrane layer in proximal and revision hypospadias repairs, though results are not reported [71]. The amniotic membrane layer serves as collagen-based architecture and provides active growth factors, stem cells, and other biomolecules to stimulate healing and regeneration of tissue. Another group performed urethral defect repairs in 5 boys using tubularized 50:50 polyglycolic acid:poly (lactide-co-glycolide acid) mesh scaffolds seeded with autologous bladder smooth muscle and urothelial cells [72]. Though it was not hypospadias repair, there were no functional complications with the neourethras after a median 71-month follow-up. These favorable results are promising for tissue engineering for hypospadias repair.

Tissue engineering in hypospadias may evolve with the advancement of nanotechnology and 3-D bioprinting [69]. Nanotechnology allows engineers to regulate the microenvironment on a cellular level. The nanofibers composed of natural and synthetic polymers can sense cellular migration and control drug delivery, which work to directly influence local inflammation, angiogenesis, and healing [69]. Advances in 3-D bioprinting may enable for the creation of neourethras from scaffolds with precisely seeded cells [69]. The continued development of this innovative technology is promising for the future of hypospadias repair.

12.7 Conclusion

The use of flaps and grafts in modern hypospadias repair continues to be a valuable tool for pediatric urologists. Despite slight variation in the success rates and the availability of data for the techniques described, these methods are all seen as viable options in hypospadias repair. Ultimately, the pediatric urologist must weigh their options given the individual characteristics of the patient and their own technical experiences when deciding their method of reconstruction.

References

1. Stein R. Hypospadias. Eur Urol Suppl. 2012;11(2):33–45.
2. Wallis MC, Braga L, Khoury A. The role of flaps and grafts in modern hypospadiology. Indian J Urol. 2008;24(2):200–5.
3. Snodgrass WT, Villanueva C, Granberg C, Bush NC. Objective use of testosterone reveals androgen insensitivity in patients with proximal hypospadias. J Pediatr Urol. 2014;10(1):118–22.
4. Santoni-Rugiu P, Sykes PJ. Skin Flaps. In: Santoni-Rugiu P, Sykes PJ, editors. A history of plastic surgery. Berlin: Springer; 2007. p. 79–119.
5. Smit JM, Negenborn VL, Jansen SM, et al. Intraoperative evaluation of perfusion in free flap surgery: a systematic review and meta-analysis. Microsurgery. 2018;38(7):804–18.
6. Wisenbaugh ES, Gelman J. The use of flaps and grafts in the treatment of urethral stricture disease. Adv Urol. 2015;2015:8.
7. Ridenour BD, Larrabee WF. Skin flap design: physiology and biodynamics. In: Meyers A, editor. Biological basis of facial plastic surgery. New York: Thieme Medical; 1993.
8. Elder JS, Duckett JW, Snyder HM. Onlay island flap in the repair of mid and distal penile hypospadias without chordee. J Urol. 1987;138(2):376–9.
9. Snodgrass WT. Hypospadias. In: Wein AJ, Kavoussi LR, Novick AC, Partin AW, Peters CA, editors. Campbell-Walsh urology. 10th ed. Philadelphia, PA: Elsevier Health Sciences; 2011.
10. ElGanainy EO. A modified onlay island flap vs. Mathieu urethroplasty for distal hypospadias repair: a prospective randomised study. Arab J Urol. 2015;13(3):169–75.
11. Perović S, Vukadinović V. Onlay Island flap urethroplasty for severe hypospadias: a variant of the technique. J Urol. 1994;151(3):711–4.
12. Mohajerzadeh L, Mirshemirani A, Rouzrokh M, et al. Evaluation of Onlay Island flap technique in

shallow urethral plate Hypospadiasis. Iran J Pediatr. 2016;26(1):e660.
13. Braga Luis HP, Pippi Salle Joao L, Lorenzo AJ, et al. Comparative analysis of Tubularized incised plate versus Onlay Island flap urethroplasty for penoscrotal hypospadias. J Urol. 2007;178(4):1451–7.
14. Byars LT. Functional restoration of hypospadias deformities; with a report of 60 completed cases. Surg Gynecol Obstet. 1951;92(2):149–54.
15. Long CJ, Chu DI, Tenney RW, et al. Intermediate-term follow-up of proximal hypospadias repair reveals high complication rate. J Urol. 2017;197(3 Pt 2):852–8.
16. Stanasel I, Le H-K, Bilgutay A, et al. Complications following staged hypospadias repair using transposed preputial skin flaps. J Urol. 2015;194(2):512–6.
17. McNamara ER, Schaeffer AJ, Logvinenko T, et al. Management of proximal hypospadias with 2-stage repair: 20 year experience. J Urol. 2015;194(4):1080–5.
18. Duckett JW. Transverse preputial island flap technique for repair of severe hypospadias. Urol Clin North Am. 1980;7(2):423–30.
19. Sowande AO, Olajide AO, Salako AA, Olajide FO, Adejuyigbe O, Talabi AO. Experience with transverse preputial island flap for repair of hypospadias in Ile-Ife, Nigeria. Afr J Paediatr Surg. 2009;6(1):40.
20. Wiener JS, Sutherland RW, Roth DR, Gonzales ET. Comparison of onlay and tubularized island flaps of inner preputial skin for the repair of proximal hypospadias. J Urol. 1997;158(3 Pt 2):1172–4.
21. Ghali. Hypospadias repair by skin flaps: a comparison of onlay preputial island flaps with either Mathieu's meatal-based or Duckett's tubularized preputial flaps. BJU Int. 1999;83(9):1032–8.
22. Mathieu P. Traitement en un temps de l'hypospadias balanique et juxtabalanique. J Chir. 1932;39:481–4.
23. Bae SH, Lee JN, Kim HT, Chung SK. Urethroplasty by use of turnover flaps (modified Mathieu procedure) for distal hypospadias repair in adolescents: comparison with the Tubularized incised plate procedure. Korean J Urol. 2014;55(11):750–5.
24. Oswald J, Körner I, Riccabona M. Comparison of the perimeatal-based flap (Mathieu) and the tubularized incised-plate urethroplasty (Snodgrass) in primary distal hypospadias. BJU Int. 2000;85(6):725–7.
25. Ververidis M, Dickson AP, Gough DCS. An objective assessment of the results of hypospadias surgery. BJU Int. 2005;96(1):135–9.
26. Rich MA, Keating MA, Snyder HM, Duckett JW. Hinging the urethral plate in hypospadias meatoplasty. J Urol. 1989;142(6):1551–3.
27. Boddy S-A, Samuel M. A natural glanular meatus after 'Mathieu and a V incision sutured': MAVIS. BJU Int. 2000;86(3):394–7.
28. Wilkinson DJ, Farrelly P, Kenny SE. Outcomes in distal hypospadias: a systematic review of the Mathieu and tubularized incised plate repairs. J Pediatr Urol. 2012;8(3):307–12.
29. Hardwicke JT, Bechar JA, Hodson J, Osmani O, Park AJ. Fistula after single-stage primary hypospadias repair - a systematic review of the literature. J Plast Reconstr Aesthet Surg. 2015;68(12):1647–55.
30. Basavaraju M, Balaji DK. Choosing an ideal vascular cover for Snodgrass repair. Urol Ann. 2017;9(4):348–52.
31. Pescheloche P, Parmentier B, Hor T, et al. Tunica vaginalis flap for urethrocutaneous fistula repair after proximal and mid-shaft hypospadias surgery: a 12-year experience. J Pediatr Urol. 2018;14(5):421.e1–6.
32. Yang H, Xuan X, Hu D, et al. Comparison of effect between dartos fascia and tunica vaginalis fascia in TIP urethroplasty: a meta-analysis of comparative studies. BMC Urol. 2020;20(1):161.
33. Fahmy O, Khairul-Asri MG, Schwentner C, et al. Algorithm for optimal urethral coverage in hypospadias and fistula repair: a systematic review. Eur Urol. 2016;70(2):293–8.
34. Fam MM, Hanna MK. Resurfacing the penis of complex hypospadias repair ("hypospadias cripples"). J Urol. 2017;197(3, Part 2):859–64.
35. Amukele SA, Stock JA, Hanna MK. Management and outcome of complex hypospadias repairs. J Urol. 2005;174(4 Pt 2):1540–2. discussion 1542–1543
36. Mendez-Fernandez MA, Hollan C, Frank DH, Fisher JC. The scrotal Myocutaneous flap. Plast Reconstr Surg. 1986;78(5):676–8.
37. Santoni-Rugiu P, Sykes PJ. Skin Grafts. In: Santoni-Rugiu P, Sykes PJ, editors. A history of plastic surgery. Berlin: Springer; 2007. p. 121–39.
38. Thakar HJ, Dugi DD. Practical plastic surgery: techniques for the reconstructive urologist. In: Brandes SB, Morey AF, editors. Advanced male urethral and genital reconstructive surgery. Current clinical urology. New York: Springer; 2014. p. 69–82.
39. Rudolph R. Inhibition of myofibroblasts by skin grafts. Plast Reconstr Surg. 1979;63(4):473–80.
40. Iwuagwu FC, Wilson D, Bailie F. The use of skin grafts in postburn contracture release: a 10-year review. Plast Reconstr Surg. 1999;103(4):1198–204.
41. Manasherova D, Kozyrev G, Nikolaev V, et al. Bracka's method of proximal hypospadias repair: preputial skin or buccal mucosa? Urology. 2020;138:138–43.
42. Converse JM, Smahel J, Smahel J, Ballantyne DL, Harper AD. Inosculation of vessels of skin graft and host bed: a fortuitous encounter. Br J Plast Surg. 1975;28(4):274–82.
43. Fortier JL, Castiglione CL, Guo L. Skin Grafting. In: Orgill DP, editor. Interventional treatment of wounds: a modern approach for better outcomes. Cham: Springer International Publishing; 2018. p. 123–42.
44. Cambareri GM, Yap M, Kaplan GW. Hypospadias repair with onlay preputial graft: a 25-year experience with long-term follow-up. BJU Int. 2016;118(3):451–7.
45. Kolon TF, Gonzales ET. The dorsal inlay graft for hypospadias repair. J Urol. 2000;163(6):1941–3.
46. Asanuma H, Satoh H, Shishido S. Dorsal inlay graft urethroplasty for primary hypospadiac repair. Int J Urol. 2007;14(1):43–7.

47. Gundeti M, Queteishat A, Desai D, Cuckow P. Use of an inner preputial free graft to extend the indications of Snodgrass hypospadias repair (Snodgraft). J Pediatr Urol. 2005;1(6):395–6.
48. Bracka A. The role of two-stage repair in modern hypospadiology. Indian J Urol. 2008;24(2):210–8.
49. Ferro F, Zaccara A, Spagnoli A, Lucchetti MC, Capitanucci ML, Villa M. Skin graft for 2-stage treatment of severe hypospadias: back to the future? J Urol. 2002;168(4 Part 2):1730–3.
50. Castagnetti M, El-Ghoneimi A. Surgical management of primary severe hypospadias in children: systematic 20-year review. J Urol. 2010;184(4):1469–75.
51. Rourke K, McKinny S, St. Martin B. Effect of wound closure on buccal mucosal graft harvest site morbidity: results of a randomized prospective trial. Urology. 2012;79(2):443–7.
52. Markiewicz MR, Lukose MA, Margarone JE, Barbagli G, Miller KS, Chuang SK. The oral mucosa graft: a systematic review. J Urol. 2007;178(2):387–94.
53. Lanciotti M, Betti M, Elia A, et al. Proximal hypospadias repair with bladder mucosal graft: our 10 years experience. J Pediatr Urol. 2017;13(3):294.e1–6.
54. Ransley PG, Duffy PG, Oesch IL, Van Oyen P, Hoover D. The use of bladder mucosa and combined bladder mucosa/preputial skin grafts for urethral reconstruction. J Urol. 1987;138(4, Part 2):1096–8.
55. Fu Q, Deng C-L. Ten-year experience with composite bladder mucosa-skin grafts in hypospadias repair. Urology. 2006;67(6):1274–7.
56. Nitkunan T, Johal N, O'Malley K, Cuckow P. Secondary hypospadias repair in two stages. J Pediatr Urol. 2006;2(6):559–63.
57. Pfistermüller KLM, Manoharan S, Desai D, Cuckow PM. Two-stage hypospadias repair with a free graft for severe primary and revision hypospadias: a single surgeon's experience with long-term follow-up. J Pediatr Urol. 2017;13(1):35.e1–7.
58. Braga LHP, Lorenzo AJ, Bägli DJ, et al. Ventral penile lengthening versus dorsal plication for severe ventral curvature in children with proximal hypospadias. J Urol. 2008;180(4):1743–8. Published online October 2008
59. Braga LHP, Pippi Salle JL, Dave S, Bagli DJ, Lorenzo AJ, Khoury AE. Outcome analysis of severe chordee correction using tunica vaginalis as a flap in boys with proximal hypospadias. J Urol. 2007;178(4S):1693–7.
60. Pope JC, Kropp BP, McLaughlin KP, et al. Penile orthoplasty using dermal grafts in the outpatient setting. Urology. 1996;48(1):124–7.
61. Hafez AT, Smith CR, Mclorie GA, et al. Tunica vaginalis for correcting penile chordee in a rabbit model: is there a difference in flap versus graft? J Urol. 2001;166(4):1429–32.
62. Lindgren BW, Reda EF, Levitt SB, Brock WA, Franco I. Single and multiple dermal grafts for the management of severe penile curvature. J Urol. 1998;160(3 Part 2):1128–30.
63. Badylak SF. The extracellular matrix as a biologic scaffold material. Biomaterials. 2007;28(25):3587–93.
64. Elmore JM, Kirsch AJ, Scherz HC, Smith EA. Small intestinal submucosa for corporeal body grafting in severe hypospadias requiring division of the urethral plate. J Urol. 2007;178(4, Supplement):1698–701.
65. Weiser AC, Franco I, Herz DB, Silver RI, Reda EF. Single layered small intestinal submucosa in the repair of severe chordee and complicated hypospadias. J Urol. 2003;170(4, Part 2):1593–5.
66. Soergel TM, Cain MP, Kaefer M, et al. Complications of small intestinal submucosa for corporal body grafting for proximal hypospadias. J Urol. 2003;170(4, Part 2):1577–9.
67. Palmer LS, Palmer JS. The use of Alloderm® for correction of severe chordee in children: an initial experience. J Pediatr Urol. 2020;16(4):446.e1–5. Published online June 14, 2020
68. Chauviere MV, Schutter RJ, Steigelman MB, Clark BZ, Grayson JK, Sahar DE. Comparison of Allo Derm and AlloMax tissue incorporation in rats. Ann Plast Surg. 2014;73(3):282–5.
69. Chan YY, Bury MI, Yura EM, Hofer MD, Cheng EY, Sharma AK. The current state of tissue engineering in the management of hypospadias. Nat Rev Urol. 2020;17(3):162–75.
70. Zhang Y, Yoo JJ, Atala A. Chapter 46 - Tissue engineering: bladder and urethra. In: Lanza R, Langer R, Vacanti JP, Atala A, editors. Principles of tissue engineering (fifth edition). New York: Academic Press; 2020. p. 845–62.
71. Oottamasathien S, Hotaling JM, Craig JR, Myers JB, Brant WO. Amniotic therapeutic biomaterials in urology: current and future applications. Transl Androl Urol. 2017;6(5):943–50.
72. Raya-Rivera A, Esquiliano DR, Yoo JJ, Lopez-Bayghen E, Soker S, Atala A. Tissue-engineered autologous urethras for patients who need reconstruction: an observational study. Lancet. 2011;377(9772):1175–82.