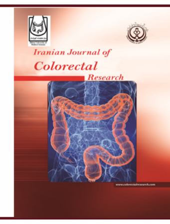
Review Article

Iran J Colorectal Res 2025;13(3):2-10.

Iranian Journal of Colorectal Research



Advances in Perineal Reconstruction After Abdominoperineal Resection: A Narrative Review of Techniques, Algorithms, and Future Directions

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Received: 2025-07-28
Revised: 2025-09-30
Accept: 2025-09-30

Abstract

Advances in rectal cancer treatment in the modern medical era have brought increased attention to wound complications, quality of life, and the recovery process. Consequently, perineal wound complications have become a significant concern following abdominoperineal resection (APR) for rectal and anal malignancies, especially in cases involving irradiation or anatomically complex surgical fields. This narrative review aims to review treatment options and various reconstructive strategies to optimize wound healing and functional outcomes. These options include primary closure, rotational and transposition flaps, musculocutaneous and perforator flaps, mesh prostheses, and emerging tissue-engineered scaffolds. Each method is critically evaluated with respect to indications, complication rates, and long-term outcomes, with comparative data guiding evidence-based selection.

To provide a comprehensive overview and improve the practical application of this review, we propose several algorithms designed to facilitate individualized surgical planning by incorporating patient-specific factors, defect characteristics, and oncologic context. These approaches are discussed within the framework of enhanced recovery protocols, highlighting the importance of multidisciplinary collaboration in achieving optimal outcomes.

Keywords: Colorectal Neoplasms; Proctectomy; Surgical Flaps; Wound Healing; Postoperative Complications

Please cite this paper as:
Alvandipour M, Mortazavi Milani A, Mohammad Javad Najafi MJ. Advances in Perineal Reconstruction After Abdominoperineal Resection: A Narrative Review of Techniques, Algorithms, and Future Directions. *Iran J Colorectal Res*. 2025;13(3):2-10. doi:

Introduction

The new medical era has introduced numerous advances across all domains of diagnosis, treatment, and post-treatment follow-up for various diseases, with some being more impactful than others, particularly in oncology. According to various literature sources, colorectal cancer is now a significant medical concern in developed countries and is becoming an increasingly important issue in developing nations. Recent advances in treatment have led to widespread and significant, complications, including perineal wound complications, following abdominoperineal resection (APR) for rectal and anal malignancies (1). Historically, primary direct closure has served as the standard method for repairing perineal defects; however, elevated rates of wound dehiscence, infection, and delayed healing, compounded by extensive pelvic dead space, irradiation, and patient comorbidities, have prompted the development of more sophisticated reconstructive techniques (2, 3). Flap-based reconstructions, mesh prosthetics, and recent innovations in tissue engineering and three-dimensional (3D) printed scaffolds are enabling personalized, functional, and durable solutions. Decision-making is a complex, multidisciplinary process that balances defect removal, aesthetic and functional restoration, minimal donor-site morbidity, and timely adjuvant therapies to achieve the best possible outcomes.

This narrative review synthesizes current and emerging surgical approaches for perineal reconstruction following APR. We critically evaluate the evidence supporting primary closure, rotational flaps, including Limberg and rhomboid designs; musculocutaneous and fasciocutaneous flaps such as the vertical rectus abdominis myocutaneous (VRAM), gracilis, gluteal, anterolateral thigh (ALT), and posterior thigh flaps; mesh prostheses; biological scaffolds; and novel tissue-engineered and 3D printed constructs. Indications, contraindications, complications, and outcomes are analyzed using decision algorithms. Multidisciplinary perioperative strategies are explored, and future research, including clinical trials and biomaterial innovations, is discussed to guide personalized, evidence-based reconstruction.

The Challenge of Perineal Wound Healing Following APR

APR, commonly performed for advanced or recurrent rectal and anal malignancies, results in a significant perineal defect involving the skin, soft tissue, and often a non-collapsible pelvic cavity. Factors contributing to impaired wound healing include prior or concurrent radiotherapy, patient malnutrition or hypoalbuminemia, diabetes mellitus, obesity, smoking, and the complex microbiological environment of the perineal region (2). Furthermore, surgical techniques such as extralevator APR (ELAPE) and multivisceral resection (pelvic exenteration) further enlarge the defect and dead space, thereby increasing morbidity and the risk of wound complications (4, 5).

Wound complications may include delayed healing (up to 60%), dehiscence, abscess formation, sinus or fistula development, chronic pain, and perineal hernia, with reported incidences ranging from 0.6% to 45% (2, 3, 6). These complications can delay postoperative recovery by hindering the timely administration of adjuvant therapy, increasing the healthcare burden, and reducing patients' quality of life (2, 7, 8).

Techniques for Perineal Reconstruction

Primary Direct Closure

Primary closure is the most practical technique used by surgeons, involving the approximation of perineal wound edges without supplemental tissue transfer or rotation. It is preferred for minor, non-irradiated defects with minimal dead space. However, this scenario is relatively uncommon in pelvic oncology due to the prevailing trends toward more extensive resections and intensified neoadjuvant therapy (2, 9, 10).

Although primary closure is commonly employed by numerous surgeons, it is associated with high rates of wound dehiscence, infection, delayed healing, and perineal hernia, particularly following chemoradiation (3, 7). Complication rates following primary closure can range from 30% to 60%, depending on patient and surgical factors. Several studies have reported median wound healing times typically between 40 and 60 days, with longer durations in cases of delayed healing (2).

Analysis of the literature demonstrates that radiotherapy and hypoalbuminemia are independent predictors of delayed healing and wound complications. Additionally, high-tension closure and inadequate obliteration of dead space are undeniable contributing factors (2, 7, 10, 11).

Geometrically Designed Flaps

The Limberg flap is a rhomboid transposition flap originally developed for pilonidal sinus surgery and has since been adapted for perineal reconstruction following APR. Its geometrically defined design facilitates tension-free closure and ensures dependable vascularity, making it suitable for moderate-sized defects, especially in non-irradiated areas. This technique is preferred due to its simplicity, reproducibility, and minimal donor site morbidity (12).

Clinical studies report favorable outcomes with low rates of wound dehiscence and infection when the Limberg flap is used in non-irradiated patients (6, 13). In irradiated fields, although the flap remains a viable option, careful preoperative planning is essential to ensure adequate perfusion and reduce the risk of wound breakdown. Compared to more substantial flaps such as the VRAM or gracilis, the Limberg flap provides a shorter operative duration and a reduced length of hospitalization. However, its volume capacity may be inadequate for extensive pelvic defects, leading some surgeons to prefer this technique primarily for perineal reconstruction following APR (13).

A recent randomized controlled trial by Alvandipour et al. (12) demonstrated significantly lower rates of wound complications, including infection and dehiscence, in patients reconstructed with the Limberg flap compared to those managed with primary closure. Additionally, the flap group experienced reduced postoperative pain, earlier mobilization, and shorter hospitalization, supporting its role in enhancing recovery and minimizing morbidity (12).

The Limberg flap is primarily suitable for cases where bulk reconstruction is unnecessary and the perineal defect is of moderate dimensions. It is particularly effective in patients who have not undergone irradiation or who have favorable wound healing capacity. A practical limitation of this flap is its limited reach to very anterior perineal defects; for defects located at the anterior commissure or those requiring extensive anterior advancement, alternative flaps with greater anterior reach should be considered. In cases involving extensive resections or irradiated areas, surgeons may consider alternative flap options to achieve better and more reliable outcomes (13).

Myocutaneous Flap Techniques

VRAM

The VRAM flap is a pedicled myocutaneous flap based on the deep inferior epigastric artery and vein. It includes the rectus muscle, with or without the anterior sheath, and an overlying skin paddle. The standard vertical design provides substantial bulk for obliterating dead space, a long vascular pedicle, and the flexibility to reconstruct both perineal skin and the pelvic cavity (14-17). The muscle is typically harvested from the right side, as the left side is often reserved for the colostomy.

VRAM is preferred for large-volume, irradiated, or contaminated defects, or when complete separation between the pelvic cavity and perineum is required (e.g., after total pelvic exenteration). It is also preferred in cases where the pelvic dead space is substantial and other regional flaps are unavailable or insufficient (14, 15).

Regarding the analysis of complication rates, recent meta-analyses and cohort studies indicate that VRAM closure reduces the incidence of perineal wound complications compared to primary closure, especially in high-risk populations. Reported major complication rates are approximately 14-18% for VRAM, compared to 23-40% for primary closure with or without omentoplasty (7, 14) (18). In irradiated cases, severe wound complications are also lower in the VRAM group, based on limited studies.

Donor site morbidity includes abdominal wall hernia, which occurs in 6-23% of large studies, potentially less frequently with modern, fascia-sparing harvest procedures, as well as occasional wound infections and dehiscence (14, 15, 17).

In cases of failure and flap loss, total flap necrosis is uncommon (<2-3%). Partial flap necrosis and recipient site dehiscence are infrequent; however, vigilance for potential complications is essential (14-16, 18). Table 1 presents a comparative summary of the primary closure technique versus VRAM flap reconstruction. It should be noted that patients selected for VRAM reconstruction are typically more complex, often presenting with larger defects, previous radiotherapy, contamination, or requiring multivisceral resections. Therefore, direct numerical comparisons with primary closure are subject to significant selection bias. The accompanying table is provided solely for descriptive context and should not be interpreted as evidence of the superiority or inferiority of either approach without risk-adjusted analyses.

The selection and technique of the flap must be adapted for patients with previous stomas, abdominal wall hernias, or multiple prior surgeries, as these conditions may preclude the use of the VRAM flap (11, 19).

Minimally invasive approaches to VRAM harvest, including laparoscopic- or robotic-assisted fascia-sparing techniques, have been developed to reduce donor-site morbidity and abdominal wall complications. Early reports suggest lower incidences of clinically significant abdominal bulges and improved cosmetic outcomes compared to open harvest, while maintaining the flap's volume and pedicle dependability. Preliminary data indicate hernia rates as low as 18-23%. The use of extended or oblique skin paddles may further reduce tension and donor-site complications in selected patients (18).

Gracilis Myocutaneous Flap

The gracilis muscle is harvested from the medial thigh, typically as a pedicled flap based on the medial femoral circumflex artery. It can be used as either a muscle-only or a myocutaneous flap.

Table 1: A descriptive comparison of outcomes between Primary Closure and VRAM Flap.

Outcome (2, 3, 16-18)	Primary Closure	VRAM Flap
Perineal wound comp.	38-40%	14-33%
Major comp. (dehiscence)	23-25%	14-18%
Flap loss	N/A	<2-3%
Donor site hernia	N/A	6-23%
Mean LOS (days)	12-16	15-18
Time to wound healing	40-60 days	40-54 days
Perineal hernia	5-10%	0-8%
Reoperation	3-5%	4-7%
Mortality*	2-4%	3-5%

*These cohorts are not directly comparable. VRAM is typically used in higher-risk patients (those with larger defects, prior radiation, contamination, or pelvic exenteration); therefore, the similar or longer length of stay and comparable crude mortality rates observed in the VRAM group likely reflect case complexity rather than operative inferiority.

Bilateral gracilis flaps are often employed for larger or circumferential perineal and vaginal defects, especially in irradiated tissue (19-21).

Ideal for moderate-sized contaminated or irradiated perineal defects, minor external genital defects, rectovaginal or rectourethral fistulas, and situations where VRAM is unavailable or undesirable (e.g., prior laparotomy or stoma). It is also preferred in cases requiring minimal donor morbidity or as part of a combined approach (e.g., with perineal exenteration) (19, 21, 22).

Donor site morbidity is minimal or rare, with occasional occurrences of thigh hematoma, seroma, or contour changes. Functionally, the gracilis muscle is expendable.

Recipient site complications in the myocutaneous variant exhibit a higher risk of tip necrosis (6-15%) due to variability in skin paddle perfusion. However, using a pure muscle flap with primary skin closure may reduce this risk (18, 20, 21).

Hernia protection suggests that unilateral or bilateral gracilis flaps may provide less bulk to fill significant pelvic dead space, potentially increasing the risk of hernia compared to VRAM flaps. However, in expert hands, this is not a major concern (18-20).

Comparative meta-analyses demonstrate similar recipient site complication rates between VRAM and gracilis, but indicate a higher risk of donor site hernia associated with VRAM. Consequently, the choice of procedure depends on patient-specific factors and the nature of the defect (18, 20).

Robotic and laparoscopic APR combined with bilateral gracilis muscle flaps are technically feasible, offering reduced operative trauma and donor site morbidity. Additionally, synchronous harvest is possible (22).

Gluteus Maximus Myocutaneous and Perforator Flaps

The gluteus maximus flap, traditionally a myocutaneous V-Y advancement based on the inferior or superior gluteal artery perforators, provides substantial, well-vascularized tissue essential for obliterating pelvic dead space and providing skin coverage, especially in defects involving the posterior or ischial regions of the perineum (10, 23-25). Bilateral approaches and perforator-based variants, such as SGAP and IGAP flaps, help minimize muscle sacrifice.

This type of flap is preferred for posterior, lateral, or sacral wounds, patients with prior abdominal surgeries, stomas, or contraindications to VRAM, and large, multicomponent defects, particularly in those who have undergone extensive irradiation.

The complication rates associated with the gluteus maximus flap are comparable to those of VRAM, with early wound complication rates ranging from approximately 14% to 41%, many of which are mild and self-limited. However, near-universal healing has been observed at the one-year follow-up reported (23).

Donor site morbidity is minor, with transient discomfort during sitting reported for four to six weeks. Sitting impairment is rare with modern techniques, especially when only segment of the muscle is harvested.

Turnover Flap and Buttock Rotation

The gluteal turnover flap, a perforator-based and minimally invasive alternative that often does not require a plastic surgeon, is currently being evaluated in randomized controlled trials for routine abdominal wall reconstruction (BIOPEX-2, NEAPE) (7, 26, 27). Its advantages include minimal donor-site morbidity, no additional scarring, and ease of use in laparoscopic procedures.

ALT Perforator Flap

The pedicled ALT flap, based on the descending branch of the lateral circumflex femoral artery, is increasingly used for large or complex defects, especially when the abdomen or buttock is unavailable due to prior surgery or scarring (11, 25, 28-31).

The supine harvest and the extensive skin paddle dimensions (exceeding 200 cm^2) make this technique especially advantageous for slender, younger patients or when the pelvic cavity is notably deep. Variants include myocutaneous, fasciocutaneous, chimeric, and split flaps.

Meta-analyses support similar complication rates and hospital stays compared to other flaps, with decreased donor site morbidity due to primary closure and minimal functional deficit (29). The ALT is also suitable for flap rotation into perineal and lower abdominal defects and can include the vastus lateralis muscle for added bulk (11, 25, 28).

Posterior Thigh Fasciocutaneous and Profunda Artery Perforator (PAP) Flaps

Posterior thigh fasciocutaneous and PAP flaps are characterized by their thin, pliable, and durable nature, providing coverage of skin and subcutaneous tissue without causing functional donor site morbidity. Their primary indications include smaller posterior or perineal defects, particularly when alternative options are limited or when a sensate, thin flap is preferred (32-34).

Cadaveric and clinical studies confirm the presence of numerous consistent perforators in the proximal posterior thigh. Clinical experience demonstrates that PAP flaps are easily harvested, can be tailored to the shape of the defect, and are primarily closed with concealed donor-site scars.

Case series report favorable healing rates, few complications, and no recurrent ulcers in the context of pressure wounds. Harvesting requires detailed preoperative planning, including Doppler ultrasound and computed tomography angiography (CTA), but the risk of significant complications is low (32). Meanwhile, thinner soft tissue limits functionality in deep pelvic dead spaces or larger, infected wounds. The flap may not adequately cover all perineal

Table 2: Reconstruction Techniques - Indications, Advantages, and Complication Rates

Technique	Indications	Advantages	Complication Rate/Issues
Primary closure	Small, unirradiated defects	Simple, rapid	High dehiscence (23-60%), hernia risk
VRAM flap	Large/irradiated/complex defects	Bulk, vascularity, dead space obliteration	Donor hernia (6-23%), rare flap loss
Gracilis flap	Moderate, contaminated/small defect	Low donor morbidity, easy harvest	Limited reach, skin tip necrosis
Gluteus maximus	Large, posterior/sacral, abdo contra	Durable, regional tissue, dead space fill	Sitting discomfort, otherwise minimal
ALT flap	Large, multiple tissue needs	Supine access, long pedicle, low donor risk	Bulky in obese, anatomical variation
PAP/Thigh flap	Small, posterior, sensate, non-bulk	Thin, minimal donor morbidity, aesthetics	Volume limits, variable perforators
Mesh	Hernia prevention, limited defects	Adds strength, cost-effective	Infection, rejection, and perineal hernia risk
Tissue Engineered	Experimental, personalized	Precise geometry, regenerative potential	Still experimental, clinical validation

topographies without microvascular anastomosis.

Local Perforator and Lotus Petal Flaps

In less complex or aesthetically challenging reconstructions, such as perineal or vulvar wounds and limited secondary defects, local fasciocutaneous perforator flaps, including the internal pudendal artery perforator (IPAP), lotus petal, and V-Y advancement flaps, are effective. These options are particularly advantageous for preserving female genitalia or providing coverage following the resection of specific perineal subunits.

A summarized comparison of various flap techniques is presented in Table 2.

Mesh and Prosthetic Reconstruction of the Perineum

Biological and Synthetic Meshes

Biological meshes (e.g., porcine or human acellular dermal matrices) and synthetic prosthetics (e.g., polypropylene, PGA/TMC) are increasingly used to reconstruct the pelvic floor and prevent perineal herniation after APR, particularly following ELAPE or pelvic exenteration (4-6, 35).

There remains an ongoing debate regarding the use of permanent synthetic mesh in irradiated fields. Many surgeons prefer biologic or biosynthetic meshes or flap-based reconstruction for previously irradiated or contaminated wounds, as these alternatives are believed to carry lower risks of chronic erosion, persistent infection, and long-term mesh-related morbidity.

Both methods significantly reduce perineal hernia rates compared to primary closure or flaps alone, herniation up to 26% post-ELAPE are reduced to approximately 8% with reinforcement. (6).

Wound and mesh infections, fistulas, and mesh erosions are recognized risks, particularly in irradiated or contaminated fields. Infection rates following mesh repair range from 4% to 22% for superficial infections and 0% to 8% for deep infections. Most mesh-related infections are manageable, with mesh removal rarely required (4, 35). Furthermore, chronic sinus formation and persistent draining tracts may develop around pelvic meshes, occasionally requiring extended wound care and, in severe cases, mesh explantation. When mesh removal is necessary, it involves significant morbidity, including additional surgeries, complex reconstructive procedures, and extended recovery periods. Consequently, these risks should be thoroughly discussed with patients when considering mesh placement in contaminated or irradiated fields.

Based on the literature, flap and mesh reconstructions have roughly equivalent short- and mid-term complication rates; however, combining mesh with tissue transfer (flap plus mesh) offers the lowest hernia recurrence risk, at 9% (6).

Recent studies support the early initiation of adjuvant chemotherapy in patients receiving biosynthetic mesh, demonstrating faster healing, shorter hospital stays, and fewer major wound complications compared to those undergoing primary closure (4, 5). Best practice involves selecting large meshes and overlapping them beyond the defect edges. Absorbable meshes are preferred when there is a risk of postoperative contamination or the possibility of future pelvic re-intervention.

Tissue Engineering and 3D Printed Scaffolds

Despite advancements in autologous and prosthetic tissue reconstruction, cases of recurrent perineal hernias, non-healing wounds, and donor-site morbidity persist. Tissue engineering and 3D printing techniques aim to reconstruct perineal or pelvic floor anatomy using patient-specific, biocompatible constructs designed to promote the regeneration of native tissue.

3D Bioprinting Techniques

3D bioprinted scaffolds can be precisely engineered to match the patient's defect geometry, enhancing dead space filling and mechanical support, while potentially integrating cells and biological factors to promote active healing (36-39).

Hydrogels, biodegradable polymers (e.g., PLGA, PCL), composite bioceramics (e.g., β-TCP, hydroxyapatite), and metallic implants (e.g., titanium) are all being investigated as scaffold substrates (38, 39).

Preclinical and early clinical data demonstrate the importance of porosity, along with mechanical and biological cues. Advanced design techniques enable precise control over pore geometry and the incorporation of signaling or growth molecules, thereby supporting vascularization and osteoinduction, processes critical for deep pelvic applications where traditional healing is insufficient (40).

Animal models and small human case series have demonstrated scaffold viability, host integration, and effective wound closure with structural stability; however, large-scale and long-term validation of safety and efficacy remains pending (36).

Challenges and future directions represent critical hurdles, including achieving vascularization, ensuring mechanical integrity, implementing scalable good manufacturing practice (GMP) processes, regulating degradation rates, and obtaining regulatory and ethical approvals for in vivo applications (39, 41). The ultimate goal is to supplement or even replace biological flaps in complex, recurrent, or high-risk cases where autologous tissue or mesh alone is insufficient.

Decision-Making Algorithms in Perineal Reconstruction

Current decision-making is complex and must take multiple factors into account:

- **Defect size:** Small, superficial defects can be closed directly, whereas larger, deeper, irradiated, or exenterative defects may require flap or mesh reconstruction.
- **Prior treatments:** Radiotherapy or previous surgeries often limit the use of local flaps and favor robust muscle-based transfers.
- **Patient factors:** Comorbidities, body habitus, stoma location, available donor sites, and patient goals are key parameters in the decision-making process.
- **Surgical approach:** Based on current surgeons' experience, laparoscopic and robotic surgeries may limit the use of certain abdominal flaps and instead favor options involving the thigh or gluteal region.
- **Multidisciplinary expertise:** Input from plastic surgery, colorectal surgery, urology, and gynecology is often essential for achieving optimal outcomes.

Algorithmic summary (adapted from recent multi-center studies and expert guidelines):

If the defect is small (typically less than 5 cm in greatest diameter with minimal dead space) and unirradiated, consider direct closure. Note that 'small' herein refers to a shallow defect lacking significant pelvic dead space. Defects characterized by measurable dead space, exposed bone, or prior radiation exposure should be managed with flap or mesh techniques, even if the surface diameter is less than 5 cm.

1. **Is the defect small (<5 cm), superficial, and unirradiated?**
   a. → Consider direct closure.
2. **Is there a deep, irradiated, or wide defect, or has pelvic exenteration been performed?**
   a. → Prefer muscle or myocutaneous flaps, such as VRAM, gracilis, gluteal, or ALT.
   b. If VRAM is contraindicated (due to prior stomas, scarring, or fascial defects): consider gracilis or bilateral gracilis flaps, or thigh/gluteal flaps.
   c. For circumferential, extended vaginal defects: bilateral gracilis flaps, tubed VRAM flap, or free jejunal flap.
3. **Is there a high risk of hernia?**
   a. → Consider mesh reinforcement, with or without a flap.
4. **Are you unable to use any local or regional flaps due to scarring or vascular issues?**
   a. → Consider a free flap or tissue-engineered/3D scaffold (experimental).
5. **Is the aesthetic or functional outcome, including mobility, a concern?**
   a. → Prefer fasciocutaneous or perforator (such as ALT or PAP) or local perforator flaps.
6. **Combine approaches** (mesh plus flap or NPWT) as indicated by the patient's needs and wound conditions.

Recently published algorithms present flowcharts based on these parameters, emphasizing individualized, multidisciplinary planning (10, 11, 42).

Outcomes and Risk Factors by Technique

Recent comparative studies reveal subtle differences in outcome profiles:

- Overall, flap reconstructions are more effective than primary closure in reducing the risk of perineal wound complications, particularly in complex or irradiated cases (12). Although infection, dehiscence, seroma, and hernia can still occur, but longer-term healing is superior to primary closure. VRAM flaps carry a risk of abdominal hernia or bulge, while gracilis and gluteal flaps are associated with minimal functional deficit, transient discomfort.
- Mesh repairs reduce the risk of herniation but may be associated with infections or fistula formation in irradiated or contaminated fields.
- Combined mesh and flap approaches appear to offer the lowest perineal hernia recurrence rates, although the data are still maturing (6).
- Tissue engineering and 3D printed scaffolds remain experimental but demonstrate promising potential for integration and tailored fit.

Key independent risk factors include anal cancer diagnosis, pelvic exenteration, ELAPE, prior radiotherapy, hypoalbuminemia, and complex defect geometry (2, 43).

Multidisciplinary Management Strategies

A multidisciplinary approach has become the standard, achieving the best outcomes in specialized centers staffed by skilled surgical, reconstructive, oncological, nursing, and allied health teams (8, 14). Enhanced recovery protocols (ERPs), nutritional optimization, early mobilization, wound-care bundles, and personalized perioperative plans help decrease complications and shorten hospital stays, even for elderly or frail patients (7, 8). Early, progressive mobilization is safe following flap-based perineal reconstruction and should be incorporated into routine care pathways (8).

Future Directions

Innovations on the Horizon

- **Minimally invasive flap harvests (robotic, laparoscopic):** Reducing morbidity, especially for VRAM and gracilis flaps, while achieving equivalent functional outcomes.
- **Next-generation scaffolds:** Patient-specific, 3D printed constructs incorporating biological factors and autologous cells to facilitate regenerative repair.
- **Perforator and local flaps:** Providing "like-for-like" reconstruction with reduced donor site morbidity, resulting in improved functional and aesthetic outcomes.
- **Refined decision algorithms:** Incorporating real-time intraoperative imaging (e.g., ICG angiography for perfusion assessment), artificial intelligence, and patient-reported outcome measures.
- **Multicenter, prospective, registry-based research:** Establishing robust evidence for rare events, optimal indications, and long-term quality-of-life outcomes.
- **Combined approaches:** Hybrid mesh/flap, NPWT/flap, and staged reconstructions tailored to increasingly complex wounds.

Conclusion

Perineal reconstruction following APR is an evolving field, progressing from simple primary closure to more durable, customized techniques involving muscle and myocutaneous flaps, mesh implants, and advanced tissue-engineered options. Evidence indicates that flap-based reconstructions result in improved healing and reduced complications, especially in patients with prior radiation therapy or complex clinical conditions. Mesh and biosynthetic scaffolds contribute to hernia prevention, especially when combined with autologous tissue. Recent advances in tissue engineering and 3D printing are creating new opportunities for personalized reconstruction, although further clinical validation is required.

A personalized, algorithm-based, risk-stratified decision-making process within specialized multidisciplinary teams is essential for achieving successful outcomes, supported by improvements in perioperative care. Continued research and technological advancements are expected to further enhance functional recovery and quality of life for patients undergoing these complex reconstructions.

Acknowledgments

We used AI-assisted language editing to improve grammar and clarity. The scientific content and interpretations are solely those of the author.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Ethical Approval

Ethical approval was not required for this study because it did not involve human participants, animal subjects, or identifiable data.

Authors' Contribution

All authors contributed equally to the literature search, writing, reviewing, and editing of this manuscript.

Conflict of interest: No conflict of interest.

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