



## Anal sphincter reconstruction for fecal incontinence: Techniques, outcomes, and future directions

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### Abstract

Fecal incontinence, a debilitating condition that significantly impairs quality of life, affects 2%-21% of adults worldwide. For patients whose structural defects are unresponsive to conservative therapies, sphincter reconstruction remains the primary treatment approach. Although traditional surgical techniques effectively restore anatomy in the short term, their long-term efficacy is constrained by progressive muscle atrophy and fibrotic scarring. In complex cases, alternative interventions, including dynamic gracilis or gluteus maximus transposition and artificial sphincter implantation, offer therapeutic options yet are associated with increased surgical risks and high complication rates. Emerging therapies such as regenerative medicine and neuromodulatory approaches have potential, although further rigorous clinical validation is needed to establish standardized protocols. Optimizing fecal incontinence management necessitates precise patient stratification, multidisciplinary collaboration, and the development of individualized treatment algorithms. Advancements in this field depend on large-scale clinical trials and comprehensive long-term outcome assessments to improve therapeutic efficacy and patient-centered care.

**Key Words:** Fecal incontinence; Sphincter reconstruction; Overlapping sphincteroplasty; Sacral nerve stimulation; Regenerative medicine

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**Core Tip:** Anal sphincter reconstruction is essential for fecal incontinence with structural defects. Overlapping sphincteroplasty provides good short-term results for acute injuries, though long-term efficacy often declines. Dynamic muscle transposition or artificial sphincters offer options for complex cases, despite significant complication risks. Sacral nerve stimulation demonstrates excellent sustained efficacy for neuromuscular dysfunction. Combining sphincteroplasty with sacral nerve stimulation represents a promising strategy for mixed defects. Regenerative approaches show potential but require further validation. Optimizing outcomes hinges on precise patient selection, multidisciplinary collaboration, and robust clinical trials to establish long-term safety and efficacy of evolving techniques.

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## INTRODUCTION

Fecal incontinence (FI) is a debilitating disorder that significantly affects both physical function and psychological well-being, with a global prevalence of 2%-21% among adults[1]. The condition induces not only physical symptoms but also substantial psychosocial distress, as patients frequently experience shame and embarrassment related to stigma. These psychological consequences lead to marked deterioration in quality of life (QoL), manifesting as impaired daily activities, compromised interpersonal relationships, and worsened mental health status. Although conservative treatments offer symptomatic improvement for certain individuals, anal sphincter reconstruction remains the definitive intervention for patients with structural defects, directly targeting both anatomical disruption and functional deficits[2,3]. Conventional approaches such as overlapping sphincteroplasty achieve immediate anatomical restoration[4,5], however their long-term effectiveness is compromised by muscle atrophy and scar tissue formation[6]. Dynamic muscle transposition procedures and artificial sphincter implantation techniques[7,8] address complex defects but encounter limitations regarding durability and patient tolerance.[9,10]. Emerging technologies-such as regenerative medicine therapies (stem cells, bioengineered scaffolds)[11,12] and device-assisted strategies [magnetic sphincter augmentation, sacral nerve stimulation (SNS)][13,14], offer promising solutions by integrating biological repair with functional enhancement, potentially overcoming these limitations.

In this article, we conducted a comprehensive minireview on the epidemiology, pathophysiological mechanisms, diagnosis, and therapeutic advancements in FI, with a focus on the application and progress of anal sphincter reconstruction. We summarize the efficacy and limitations of traditional surgical approaches and consolidate research progress on emerging treatment options. Through this systematic and integrated strategy, we aim to provide more precise and effective solutions for FI management.

## DEFINITION AND EPIDEMIOLOGY OF FI

FI is clinically defined as the involuntary loss of bowel control, including uncontrolled passage of solid/Liquid stool or flatus[1,15]. Reported prevalence varies widely across studies, reflecting differences in case definitions, sampling, and cultural factors influencing disclosure[16]. Epidemiological investigations consistently identify higher incidence rates among women, primarily due to anal sphincter injuries and pelvic floor dysfunction resulting from obstetric trauma during vaginal delivery[17]. Gender-specific risk factors further include hormonal fluctuations during pregnancy and menopause[18]. Advancing age is an independent determinant, with the rising prevalence among older populations attributed to progressive neuromuscular degeneration and frequent comorbidities such as diabetes or neurological disorders[19,20]. Geographic variations in reported prevalence highlight the impact of cultural stigma associated with bowel dysfunction, disparities in healthcare accessibility, and inconsistencies in diagnostic methodologies[1]. Under-recognition remains common where stigma limits reporting and access to specialized care is constrained.

## AETIOLOGY AND PATHOPHYSIOLOGICAL MECHANISMS OF FI

### **Multifactorial causes of anal sphincter injury**

FI generally arises from the combined influence of multiple pathogenic elements as opposed to a single etiological factor. These factors jointly compromise the structural integrity and functional capacity of the anal sphincter complex. Among women, obstetric trauma represents the predominant etiological factor, with vaginal delivery posing a particular risk. Forceps-assisted deliveries, for example, double the risk of sphincter dysfunction compared with spontaneous vaginal birth due to excessive mechanical stress on the perineal muscles[17]. During childbirth, rapid perineal stretching can lead to third- or fourth-degree tears, with the latter involving full-thickness sphincter disruption. Although immediate repair is standard, suboptimal healing, often due to tissue ischemia, infection, or poor suturing, may result in residual defects

[21]. Long-term studies have revealed that many women with obstetric sphincter injuries develop FI later in life, even after initial repair[22,23]. The contributing factors include scarring, fibrosis, hormonal changes, and age-related muscle deterioration. Case studies emphasize that inadequate primary repair, especially after forceps delivery, is correlated with worse FI outcomes[17].

In addition to obstetric causes, surgical interventions in the pelvic region, particularly for colorectal, gynecologic, or urologic procedures, may inadvertently cause iatrogenic injury to the anal sphincter. In many cases, these injuries might not be recognized intraoperatively, leading to suboptimal repair and subsequent clinical deterioration[24]. For example, during low anterior resection (LAR) for rectal cancer, the narrow pelvic operating space, nerve traction, or stapler compression may directly damage the anal sphincter or its innervation. These iatrogenic injuries frequently evade intraoperative detection, subsequently manifesting as operative defecatory dysfunction characterized by impaired continence, urgency, and incontinence, a constellation of symptoms now recognized as LAR[25]. Clinical investigations have revealed that 30%-50% of patients subjected to LAR exhibit fecal FI, with endoscopic ultrasound assessments systematically detecting internal anal sphincter defects or thinning in affected individuals[26]. These imaging data provide objective documentation of subclinical sphincter injury occurring during surgical intervention and its direct association with subsequent functional deficits.

Local infections, ionizing radiation exposure, and age-associated degenerative alterations independently contribute to progressive sphincter damage. Pelvic infections localized to perineal tissues may trigger gradual inflammatory responses, leading to abscess development and subsequent myonecrosis, with eventual tissue loss or fibrotic scar formation[2]. Ionizing radiation not only reduces the quantity and quality of myocytes but also impairs the regenerative capacity of stem cells in irradiated tissues[24,27]. The natural decline in muscle mass and elasticity with aging (*i.e.*, sarcopenia) means that even minor sphincter injuries can have significant consequences in elderly patients[28]. Overall, surgical damage, local infection, radiation-induced injury, and degenerative changes serve as critical contributors to the pathophysiology of FI. Their impact is magnified by the fact that these factors often occur in tandem, leading to compounded impairments in both the anatomical and functional integrity of the anal sphincter.

### **Types of anal sphincter injury and assessment of injury severity**

The anatomical basis of continence involves precisely coordinated actions of several key structures: The internal anal sphincters (IAS) and external anal sphincters (EAS), the puborectalis muscle, and the intact pelvic floor musculature[29]. The IAS, which is composed of smooth muscle, generates 70%-85% of the resting anal tone, a critical mechanism for passive continence between bowel movements[30]. In contrast, the striated EAS mediates voluntary squeeze pressure, enabling conscious control during periods of elevated intra-abdominal pressure[31]. The puborectalis muscle forms a functional sling around the anorectal junction, maintaining the anorectal angle essential for fecal retention. These structures are dynamically supported by the pelvic floor musculature, which preserves their anatomical positioning and coordinated function[32].

Accurate diagnosis and quantification of anal sphincter injury are critical for devising an effective management plan for patients suffering from FI. Endoanal ultrasound (EAUS) has emerged as the gold standard for the detailed evaluation of anal sphincter integrity[21,33]. By using EAUS, clinicians are able to measure the thickness of sphincter muscles, identify disruptions in muscle fiber continuity, and document the extent of any defects caused by obstetric, surgical, or degenerative processes. EAUS has been instrumental in guiding surgical interventions by helping to map the areas in need of repair and providing a means to assess the completeness of the reconstruction intraoperatively when used in combination with real-time guidance techniques[34]. In addition, magnetic resonance imaging (MRI) offers complementary benefits because of its superior soft tissue contrast and multiplanar assessment capabilities. MRI can delineate complex pelvic floor anatomy and is particularly useful when EAUS results are inconclusive or when coexisting pelvic floor disorders are suspected. Anal manometry (ARM) is a quantitative technique that measures the resting and maximal squeeze pressures within the anal canal, thereby providing an objective assessment of both the involuntary and voluntary components of sphincter function[35]. ARM studies have established two critical pressure parameters that directly correlate with FI symptom severity: Resting pressure, which predominantly reflects IAS function; squeeze pressure, which serves as a marker of EAS performance. These pressure measurements show significant reductions in cases of sphincter dysfunction, with the degree of pressure decline corresponding to the extent of anatomical disruption observed in imaging studies[36].

Comprehensive clinical evaluation forms the cornerstone of diagnostic assessment for FI. Initial patient assessment requires detailed historical analysis to elucidate potential causative factors, encompassing previous obstetric trauma, surgical interventions, and episodes of infection or radiation exposure potentially affecting sphincter integrity. Digital rectal examination yields supplementary physical examination findings, permitting identification of sphincter defects, regions of tenderness, and aberrations in muscle tone. Integration of these clinical parameters with anorectal manometry and imaging studies establishes a multidimensional diagnostic framework that enables precise categorization of sphincter injury severity.

## **BACKGROUND AND SIGNIFICANCE OF ANAL SPHINCTER RECONSTRUCTION**

### **Concept and rationale of sphincter reconstruction**

Anal sphincter reconstruction surgery involves diverse surgical techniques aimed at restoring both the structural and functional integrity of the compromised anal sphincter complex, encompassing the internal and external sphincters with their associated neural innervation. By utilizing methods such as autologous tissue transfer, prosthetic device im-

plantation, or anatomical reconstruction, this intervention endeavors to reestablish active contractile function and passive continence mechanisms within the anal canal. The procedure primarily targets FI arising from multiple etiologies, including congenital anomalies, traumatic injuries, oncologic resections, and neurological deficits[2,3]. Surgical objectives focus on three core principles: Mechanical restoration of sphincter continuity through structural defect repair, such as addressing obstetric-related muscle tears or iatrogenic injuries; preservation of neurovascular supply to ensure muscle viability and functionality; and rehabilitation of neuromuscular coordination to regain reflex-mediated and voluntary control mechanisms essential for maintaining continence[37,38].

### **Limitations of conservative and neuromodulatory approaches**

While conservative management and neuromodulation interventions demonstrate significant utility in FI treatment, their capacity to resolve structural defects remains limited, with variable long-term efficacy across patient populations. Bulking agents, for example, yield transient therapeutic effects, necessitating repeated injections to sustain clinical benefit, but their enduring outcomes and safety profile remain under investigation[39]. Although biofeedback therapy has limited efficacy in patients with severe anal sphincter disruption and is capable of enhancing muscle coordination and sensory perception, this modality fails to address the underlying anatomical pathology[40]. SNS, notwithstanding its demonstrated capacity to ameliorate bowel control, entails substantial economic burden and demonstrates heterogeneous response patterns; select patients may manifest minimal clinical improvement, with enduring therapeutic efficacy remaining undetermined[41]. These therapeutic limitations underscore persistent gaps in FI management, thereby stimulating surgical innovation toward the development of more durable interventions.

### **Surgical indications and techniques for anal sphincter reconstruction**

**Patient selection and indications:** The selection of candidates for sphincter reconstruction surgery requires comprehensive consideration of both the duration of injury and functional assessment. For acute injuries (< 6 months), particularly those caused by obstetric or surgical trauma with no significant muscle atrophy or extensive scarring, early repair should be prioritized[24]. Patients with chronic injuries ( $\geq 6$  months) require a detailed evaluation of the muscle remnant volume and degree of scarring *via* EAUS or MRI[42]. Surgical indications remain if repairable muscle tissue is present (*e.g.*, defect extent  $\leq 1/2$  circumference, muscle thickness preserved  $\geq 50\%$ ) without severe neural degeneration (pudendal nerve conduction velocity  $> 30$  m/second).

Standardized scoring systems play a pivotal role in clinical assessment. The Wexner Incontinence Score (Cleveland Clinic Incontinence Score, CCIS), the most widely used evaluation tool, provides objective clinical decision-making support by quantifying the frequency of solid, liquid, and gas incontinence and its impact on lifestyle (0-20 points)[43]. The St. Mark score offers a comprehensive assessment across multiple dimensions, including frequency and type of incontinence episodes, as well as pad usage and lifestyle limitations. These scoring systems not only facilitate accurate preoperative assessment of disease severity but also guide the development of personalized treatment plans[21,44].

**Overlapping sphincteroplasty:** Overlapping sphincteroplasty is a surgical technique used to repair defects in the EAS, typically caused by obstetric trauma or injury, with the aim of restoring the anatomical integrity of the sphincter and improving continence function[4]. The procedure usually employs a transvaginal approach to address concurrent vaginal laxity or scarring. The specific steps include making an incision along the perineal scar line and dissecting subcutaneous tissue to expose the scarred EAS ends, carefully excising scar tissue and mobilizing the muscle ends circumferentially (while preserving neurovascular supply) to achieve tension-free overlap[34,42]; subsequently, the mobilized EAS ends are overlapped by 1-3 cm (adjusted on the basis of defect severity and muscle quality) and secured in layers *via* non-absorbable or slowly absorbable sutures to create robust repairs[5]; finally, the subcutaneous tissue and skin are closed, with perianal drainage placed if necessary. Over the past few decades, multiple researchers have conducted systematic studies on the short-term and long-term efficacy of overlapping sphincteroplasty (Table 1)[5,45-52]. Considering the variations in data due to advancements in surgical techniques, we focused only on studies from the last 10 years that involved overlapping sphincteroplasty. All included literature defined positive outcomes as improvement in incontinence, including symptomatic improvement and incontinence score improvement. Comparative analysis revealed that, without accounting for the influence of surgical proficiency, the improvement rate of incontinence gradually decreased as the follow-up period extended. For instance, Sørensen and Qvist[45] recently studied the short-term outcomes of 55 patients who underwent overlapping sphincteroplasty. Evaluations conducted six months post-surgery assessed stool frequency, incontinence frequency and type, and incontinence scores, showing that 71% of the patients experienced improvement. However, Barbosa *et al*[6] conducted a follow-up of up to 220 months on 370 patients who underwent the same procedure to observe its long-term efficacy, and the results indicated that only 46% of the patients maintained satisfactory outcomes. Additionally, Huag *et al*[51] found that when the postoperative follow-up period was extended from 5 months to 100 months and 220 months, the observed surgical efficacy rate decreased from 75% to 65% and 45%, respectively. In summary, existing studies demonstrate that while overlapping sphincteroplasty can significantly improve anal incontinence symptoms in the short term, its long-term efficacy shows a notable decline as the follow-up duration increases.

**Dynamic muscle transposition procedures:** When overlapping sphincteroplasty is unfeasible due to absence or severe damage, disruption, and nonfunctional anal sphincters, artificial anal sphincter (AAS) implantation or dynamic muscle transposition serves as the primary alternative to permanent stoma. Dynamic muscle transposition reconstructs sphincter function by transplanting muscles from other anatomical regions (gluteus maximus or gracilis), primarily gluteus maximus transposition[53,54] and graciloplasty[55,56]. The surgical approach for both procedures involves making an incision in the donor muscle area (*e.g.*, the upper gluteus maximus or medial thigh), dissecting a portion of the muscle

**Table 1 Results for overlapping sphincteroplasty**

Ref.	Number of patients	Mean age (years)	Mean follow-up period (years)	Positive outcome (%)
Sørensen and Qvist[45], 2025	55	45	0.5	71
Seyfried <i>et al</i> [5], 2018	148		1.0	73
Kayapınar <i>et al</i> [46], 2022	16	27.5	1.9	81
Berg <i>et al</i> [47], 2019	111	43	3.7	54
Carswell <i>et al</i> [48], 2023	107		4.8	69
Berkesoglu <i>et al</i> [49], 2021	50	44.6	5.2	64
Maldonado <i>et al</i> [50], 2019	29	41	7.0	53
Barbosa <i>et al</i> [6], 2019	370	33.7	18.3	46
Haug <i>et al</i> [51], 2021	20	36	0.4/8.5/18.3	75/65/45
Pla-Martí <i>et al</i> [52], 2020	35	55	2.5/9.2	71/40

while preserving its neurovascular supply, determining the amount of muscle harvested on the basis of the defect size, creating a subcutaneous tunnel from the donor site to the perianal region, transposing the muscle to encircle the anal canal, securing it to itself and surrounding tissues to form a new sphincter (with optional nerve anastomosis or electrode implantation for electrical stimulation in some cases), and finally closing the incisions and placing drains[9,10].

As alternative approaches when overlapping sphincteroplasty is contraindicated, these two techniques differ fundamentally: Gluteoplasty leverages the inherent physiological advantages of the gluteus maximus in terms of continence control (innervated by L5-S1) and robust muscle strength, enabling easier acquisition of voluntary contraction. Its high muscle volume also buffers against postoperative atrophy[57,58]. However, this technically demanding procedure is associated with significant donor-site morbidity (38% complication rate, including 64% donor-site impairment) due to bilateral harvesting requirements. The predominance (fatigue-prone) and procedural complexity of type II muscle fibres have limited its widespread adoption[59,60]. The innovation of dynamic graciloplasty lies in its electrical stimulation-mediated fibre-type conversion: Low-frequency current induces a phenotypic transformation from fatigue-prone type II fast-twitch fibres to fatigue-resistant type I slow-twitch fibres[61,62], overcoming the inherent inability of skeletal muscle to sustain contraction. In combination with its anatomical advantages, unilateral harvest feasibility, consistent tendon length, and easily identifiable obturator neurovascular bundle[63], it minimizes donor-site morbidity while permitting functional compensation by adjacent muscles, even restoring basic mobility. Clinical data from experienced centers demonstrate 80% success rates[64]. Nevertheless, dynamic graciloplasty still has 32% complication rates (including wound infections and device malfunctions)[64,65]. Its efficacy remains critically device dependent, as passive procedures without stimulation show < 50% success[66], revealing the inherent limitations of this technology.

### Emerging surgical and regenerative approaches

Emerging surgical and regenerative methods offer innovative directions for the treatment of FI. Studies indicate that cell-based therapies enhance the sphincter by transplanting autologous myocytes to fuse with or differentiate into new muscle fibres[11], injecting mesenchymal stem cells to promote muscle regeneration and secrete reparative growth factors[2,67], or utilizing nanofat enriched with stem cells/growth factors to improve tissue quality and stimulate vascular/nerve regeneration[68]. Device-assisted approaches target severe cases, employ implantable AAS systems (comprising an inflatable cuff, control pump, and pressure-regulating balloon) for mechanical continence control, or utilize biocompatible scaffolds to provide a regenerative framework loaded with bioactive factors. In a systematic review of the clinical application and developmental status of AAS, Wang *et al*[7] summarized that current clinical trial results indicate the implantation of an artificial sphincter induces morphological changes in peri-prosthetic tissues. The associated biomechanical imbalance may lead to loss of device efficacy and the occurrence of various complications. Although this approach can temporarily address FI in patients, no long-term efficacy data have been reported to date. Intraoperative guidance technologies, such as real-time ultrasound for precise defect localization and repair[34], combined with infrared navigation for instrument tracking increase surgical accuracy and reduce nerve injury risk. Adjunctive neuromodulation strategies, particularly SNS, independently improve sphincter contraction, pelvic floor coordination, and rectal sensation [13]. Furthermore, SNS can be integrated with surgical reconstruction as a postoperative adjunct to consolidate functional recovery[69,70]. In a systematic review and meta-analysis on the treatment of FI with SNS implantation, Huang and Koh [71] analysed data from 10 relevant studies. The results indicated that SNS implantation significantly improved patients' CCIS, with a median effective rate of 67%. However, they also noted that all the included studies were noncontrolled trials with small sample sizes. Additionally, the subjective bias inherent in the CCIS scoring system limits the evaluation of SNS efficacy[71].

### **Evaluation of anal sphincter reconstruction outcomes**

The evaluation of outcomes following anal sphincter reconstruction requires a combination of functional scoring systems, quality-of-life metrics, and objective physiological parameters to assess surgical efficacy comprehensively. Clinical studies have shown that overlapping sphincteroplasty can reduce the Wexner score from > 15 preoperatively to < 3 postoperatively, with a median reduction of 6 points in St. Mark's score, indicating initial functional improvement in 70%-90% of patients[47,72]. However, long-term follow-up (18 years) reveals that some patients may experience a rebound in scores to 8-12 points, indicating potential deterioration of surgical outcomes, possibly due to muscle atrophy or neural degeneration[6]. QoL assessments complement objective scoring through instruments such as the FI QoL Scale and generic scales (*e.g.*, the short-form 36). For example, in studies on SNSs, FI QoL Scale scores improved from 3.585 to 3.93, correlating with a decline in Wexner scores and reflecting psychosocial improvements[73]. Notably, even with favorable functional scores (Wexner  $\leq$  3), some patients still report dietary restrictions or social anxiety, highlighting discrepancies between subjective experiences and clinical metrics[74]. Thus, QoL evaluation is indispensable in assessing postoperative satisfaction. ARM and MRI also play crucial roles in evaluating the outcomes after sphincter reconstruction surgery. For example, dynamic graciloplasty can restore anal resting pressure to 44.6 mmHg and squeeze pressure to 103.6 mmHg, with contraction duration reaching 3.64 minutes and approaching physiological levels[10]. MRI assessment of postoperative sphincter morphological integrity serves as an effective predictor for fecal continence function in patients following surgery[34,75]. In summary, the evaluation of anal sphincter reconstruction outcomes requires multidimensional integration: Functional scores define incontinence severity, QoL scales capture subjective benefits, and manometry and imaging validate anatomical repair.

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## **COMPLICATION MANAGEMENT AND RISK MITIGATION**

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### ***Intraoperative technique optimization and risk prevention***

The success of anal sphincter reconstruction surgery relies not only on precise surgical techniques but also on comprehensive and systematic complication management and risk mitigation strategies. Meticulous operation and proactive prevention are key to surgical success, laying the foundation for improved outcomes and reduced complications. Studies have shown that employing a stepwise suturing technique for the internal and external sphincters, operating layer by layer along avascular planes, significantly reduces tissue damage and preserves anal sphincter function. Postoperatively, 61.8% of patients maintained intact internal sphincters, with marked improvement in continence (the average St. Mark score decreased by 6 points)[47]. The use of magnifying surgical loupes or microscopes and other precision instruments aids in accurately identifying muscle margins within scarred tissues, reducing the risk of incomplete apposition and neurovascular bundle injury. Anatomical reconstruction techniques, such as modified muscle transposition, significantly increase the resting pressure (27.6 mmHg to 41.7 mmHg) and squeeze pressure (57.9 mmHg to 93 mmHg,  $P < 0.001$ ) of the anal canal[76]. Moreover, overlapping sphincteroplasty combined with advancement flaps effectively addresses complex defects, achieving both anatomical and functional restoration[77]. Additionally, performing single-stage fistula tract excision combined with sphincter repair for proximal or complex fistulas yields a high primary healing rate (88.2%) and a low risk of severe incontinence (liquid incontinence rate of 2.3%)[78].

### ***Postoperative monitoring and early intervention***

The implementation of a structured postoperative monitoring protocol is crucial for the early detection and management of complications. This involves conducting daily clinical assessments to evaluate wound conditions such as erythema, exudate, and purulent discharge, alongside laboratory monitoring of vital signs, white blood cell counts, and other inflammatory markers. Such measures facilitate the prompt diagnosis and treatment of surgical site infections or partial wound dehiscence, thereby preventing the progression to deep abscess formation or complete rupture that could lead to sphincter dysfunction. Imaging surveillance, particularly transperineal or EAUS, enables early noninvasive evaluation of sphincter integrity. For example, residual external sphincter defects detected by immediate EAUS postobstetric injury repair (40% of cases, with 75% persisting at 12 weeks) were significantly correlated with higher rates of anal incontinence ( $P = 0.04$ ), serving as a critical early warning indicator[79]. Additionally, early functional assessments help identify abnormally low resting or squeeze pressures. Measurements such as resting pressure below 40 mmHg or squeeze pressure below 60 mmHg can distinguish between technical failure and neurogenic dysfunction, guiding timely intervention. Results from a retrospective cohort study demonstrate that the implementation of the aforementioned active surveillance strategy effectively mitigates suboptimal initial outcomes, culminating in satisfactory clinical endpoints for 92.9% of patients[72].

### ***Personalized and stepwise management***

Postoperative functional recovery relies on a personalized, stepwise, multimodal management strategy. During the early postoperative period (4-6 weeks), the therapeutic focus should be placed on the timely initiation of first-line rehabilitation interventions, primarily consisting of the following two components. First, structured pelvic floor muscle training serves as the foundational therapeutic approach, with its efficacy supported by grade B evidence from the International Continence Society[80]. This modality effectively enhances patients' pelvic floor muscle strength and endurance. Second, biofeedback therapy based on manometry or electromyography can serve as an important supplement. This treatment modality provides real-time audiovisual feedback to help patients optimize their muscle contraction patterns. Data from the CAPABLE clinical trial demonstrated that combined biofeedback therapy resulted in an average reduction of 2.3

points in Vaizey scores ( $P < 0.05$ )[81]. Therefore, this approach is particularly recommended for patients with persistent incontinence who have a poor response to conservative treatment, with an expected response rate of 60%-70% [14]. When first-line rehabilitation fails, secondary interventions should be considered. For patients with radiologically confirmed persistent structural defects and a poor response to conservative therapy, revisional sphincteroplasty may be performed. Additionally, SNS, percutaneous tibial nerve stimulation, and perianal bulking agent injections are effective treatment options for moderate-to-severe refractory FI postoperatively. Based on the European clinical practice guidelines for the diagnosis and treatment of FI[82], combined with conclusions from existing literature, we have summarized the clinical management pathway for FI to assist clinicians in optimizing treatment strategy selection (Figure 1). Regular multidisciplinary team assessments enable timely adjustment of treatment plans on the basis of patients' baseline manometry data, treatment preferences, and comorbidities, playing a critical role in postoperative sphincter function recovery.

## EMERGING TECHNOLOGIES AND FUTURE RESEARCH DIRECTIONS

### *Innovations in surgical techniques and device development*

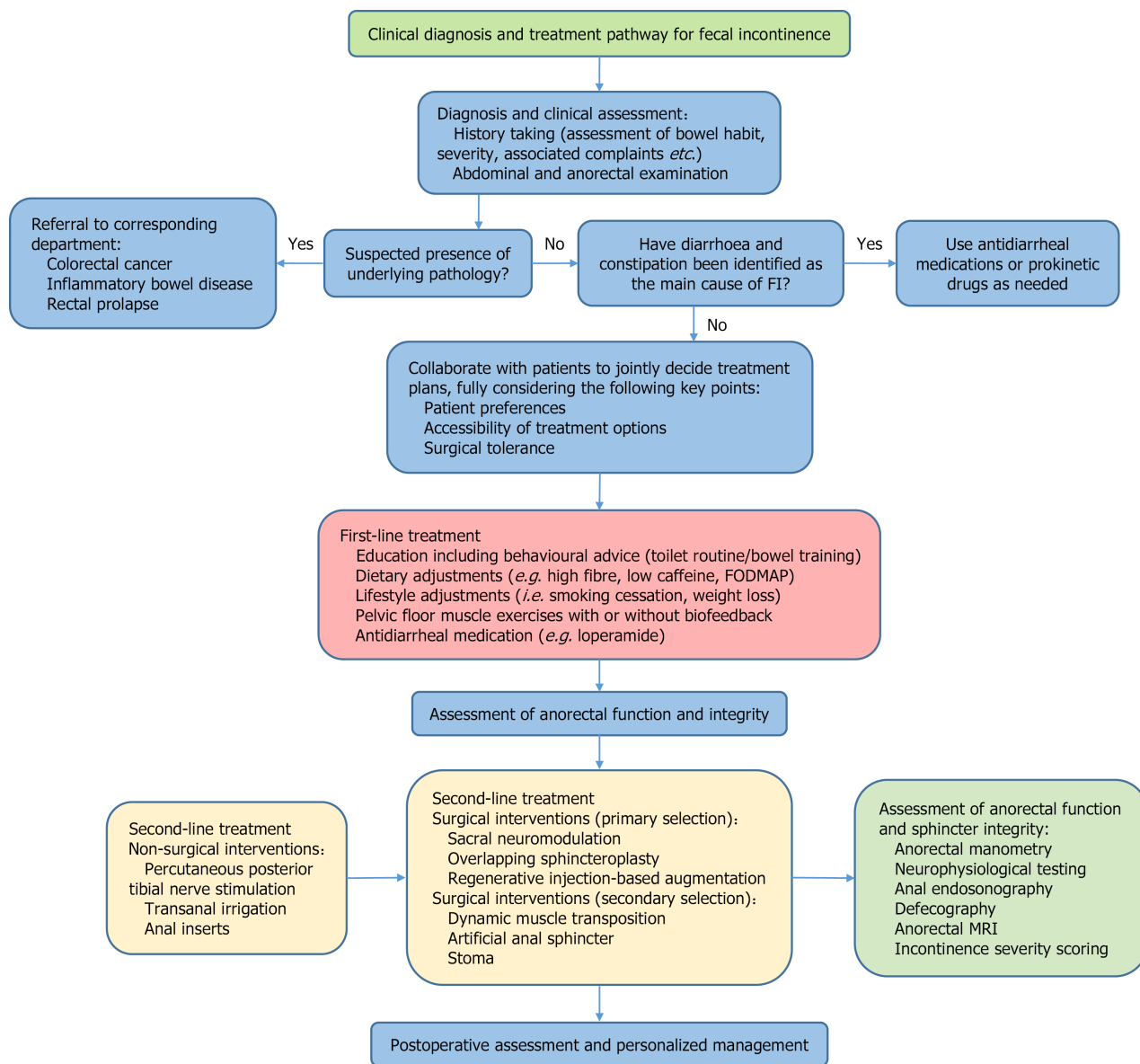
The field of sphincter reconstruction is exploring novel biomaterials to improve patient outcomes. These materials aim to provide structural support to damaged areas while promoting tissue regeneration[12]. 3D printing technology enables the creation of geometrically precise, porosity-controlled scaffolds tailored to specific anatomical defects, facilitating cell infiltration and tissue ingrowth[83]. Biodegradable synthetic polymers, particularly poly (lactic-co-glycolic acid), have gained widespread application in sphincter reconstruction because of their excellent biocompatibility and predictable degradation into nontoxic metabolites[84]. Similarly, natural extracellular matrix components, including collagen and hyaluronic acid, have been extensively investigated for their intrinsic bioactivity and ability to facilitate cellular adhesion and proliferation[85]. Current research efforts in scaffold bioengineering focus on optimizing three critical parameters, structural porosity, biomechanical characteristics, and host compatibility, all of which are essential for promoting effective tissue regeneration[86]. Preclinical studies utilizing *in vitro* models and animal experiments have provided compelling evidence that these engineered matrices can successfully support smooth muscle regeneration, stimulate neovascularization, and enhance the functional recovery of sphincter mechanisms. Nevertheless, several translational challenges persist, including the need to precisely match degradation kinetics with tissue remodeling rates, ensure long-term structural integrity, and minimize potential inflammatory responses. Addressing these limitations through continued material science innovation and rigorous clinical validation remains a priority for the field[12].

Modern AAS devices have undergone substantial technological advancements, with current-generation designs addressing multiple constraints inherent to conventional implants, namely, mechanical failure, infection susceptibility, and compromised patient comfort[8]. Shape-memory alloys (SMAs), particularly nitinol, have emerged as promising materials because of their unique thermomechanical properties. The superelastic characteristics of SMAs enable dynamic support that closely mimics natural sphincter function while offering superior mechanical consistency in AAS applications[87,88]. Compared with traditional devices, SMA-based implants demonstrate enhanced controllability, improved durability, and greater patient comfort. Emerging preclinical and clinical evidence supports their efficacy in restoring continence while maintaining favourable safety profiles. Nevertheless, several challenges require resolution, particularly regarding long-term device reliability, prevention of implant migration, and minimization of the risk of tissue erosion[7]. Recent computational studies utilizing finite element analysis have provided valuable insights into rectum-sphincter biomechanics. These investigations reveal that maintaining an anorectal angle below 90° with artificial devices significantly improves continence outcomes, offering critical guidance for future design optimization[89]. Such biomechanical analyses are informing the development of more anatomically compatible AAS systems with optimized stress distributions during physiological strain.

### *Advances in regenerative medicine*

Regenerative medicine offers novel approaches for treating FI by restoring the structure and function of the anal sphincter through integrated stem cell and nanofat therapies, as well as cytokine therapy and decellularized tissue regeneration methods. Stem cells, including mesenchymal stem cells and adipose-derived stem cells, can differentiate into smooth muscle cells and neurons while secreting growth factors that promote tissue repair[90]. Animal studies have demonstrated that these therapies enhance sphincter regeneration, angiogenesis, and neural recovery[90,91], whereas early clinical trials have reported improvements in patients' continence function and QoL with this therapy[11]. For example, nanofat injection following sphincteroplasty significantly increased resting pressure ( $P = 0.01$ ), thickened the external sphincter ( $P = 0.04$ ), and reduced Wexner scores ( $P < 0.05$ )[68]. However, challenges remain in standardizing cell sources, processing methods, and delivery techniques, as well as addressing potential tumorigenic risks and regulatory hurdles[92].

Cytokine therapy (*e.g.*, growth factors and chemokines) promotes tissue regeneration by regulating cell proliferation, differentiation, and migration, whereas decellularized approaches, such as extracellular matrix scaffolds and exosomes, provide a supportive microenvironment for repair without the risk of immune rejection or tumor formation. Studies have shown that cytokine therapy enhances smooth muscle regeneration and reinnervation in sphincter injury models, that extracellular matrix scaffolds offer structural frameworks for cell adhesion and tissue remodeling, and that exosomes facilitate regeneration by delivering therapeutic molecules[11,93].



**Figure 1 Clinical management pathway for fecal incontinence.** FODMAP: Fermentable oligosaccharides, disaccharides, monosaccharides, and polyols; FI: Fecal incontinence; MRI: Magnetic resonance imaging.

**Interdisciplinary and personalized treatment pathways**

The future of FI treatment lies in integrating surgical, regenerative, and neuromodulation strategies to address its complex pathophysiology and improve patient outcomes. For example, surgical sphincter repair combined with stem cell therapy may enhance muscle regeneration and neural function[93], whereas artificial sphincter implantation paired with SNS can improve sphincter control and rectal sensation[14]. Treatment selection should be individualized on the basis of incontinence severity, etiology, and overall health status. Further basic research and clinical case analyses are needed to elucidate synergistic mechanisms and therapeutic efficacy. Combined surgical, regenerative, and neuromodulatory approaches should be tailored to the patient’s sphincter injury type, neurological function, and quality-of-life needs.

Current FI research is often limited by small sample sizes, single-center studies, and short follow-up periods. The lack of standardized protocols and outcome measures makes it difficult to compare and draw definitive conclusions. Therefore, it is imperative to establish internationally standardized protocols and comprehensive assessment systems, coupled with multicenter randomized controlled trials, to rigorously evaluate the long-term safety profiles of emerging therapeutic interventions[93].

**CONCLUSION**

The surgical treatment of FI relies on effective reconstruction of the sphincter structure and functional deficits. Current therapeutic strategies exhibit diverse development, yet each has specific indications and limitations. Traditional techniques such as overlapping sphincteroplasty remain reliable first-line options for acute, well-defined sphincter

injuries (particularly obstetric related cases), offering definitive immediate anatomical restoration and significant early functional improvement. However, long-term follow-up reveals a gradual decline in efficacy, especially in cases of chronic injury or neuropathy, limiting its role as a universal long-term solution. For complex cases or patients refractory to standard reparative procedures, dynamic muscle transposition and artificial sphincter implantation, while providing substantial biomechanical support, are associated with considerable surgical invasiveness, complications (including tissue necrosis and device-related adverse events), and significant patient discomfort. These interventions present notable technical challenges, pose difficulties in complication management, and lack well-established long-term efficacy data. Consequently, such procedures have been documented predominantly within specialized tertiary care centers and are currently reserved for highly selected patients with recurrent defects or severe anatomical compromise[94].

SNS, as a transformative technology, improves both sphincter tone and rectal sensation *via* neuromodulation, demonstrating excellent sustained clinical response rates (75%-85% at 3-5 years) and favourable safety, making it a compelling option for patients with generalized neuromuscular dysfunction. Studies indicate that the sphincteroplasty combined with SNS, leveraging its unique neuromodulatory mechanism and relatively minimally invasive nature, represents the most promising core technology for addressing mixed-type deficits at present[71,95]. Regenerative medicine approaches hold biological promise for repair and reconstruction but remain exploratory. Current evidence is limited, and methodologies (cell sources, delivery, dosing) and efficacy assessments require standardization and rigorous validation.

The key to clinical breakthroughs hinges on three fundamental pillars: Precise patient stratification, multidisciplinary care integration, and rigorous evidence-based research. First, accurate classification of patients on the basis of etiology, defect characteristics, and neurological function is essential to guide tailored treatment strategies. Second, comprehensive collaboration across surgical, neuromodulation, gastroenterology, rehabilitation, and regenerative medicine specialties must be established to optimize care pathways. Critical research priorities include conducting large-scale randomized controlled trials for direct therapeutic comparisons; implementing long-term registry systems to assess real-world outcomes; advancing neuromodulation and device technologies through accelerated optimization; and executing well-designed translational studies to validate novel therapies such as regenerative medicine. Only by adopting such integrated, personalized, and precision-driven approaches-supported by robust clinical evidence-can we sustainably enhance long-term sphincter reconstruction outcomes and ultimately improve the QoL of FI patients.

## FOOTNOTES

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