

REVIEW ARTICLE

Transanal total mesorectal excision for rectal cancer: Technical evolution, oncological safety, and a critical appraisal of current evidence

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Abstract

Transanal total mesorectal excision (TaTME) is an innovative, minimally invasive technique derived from the concept of natural orifice transluminal endoscopic surgery. Since its introduction in 2010, TaTME has been primarily used for mid- and low-rectal cancers, particularly in patients with anatomically challenging pelvises. Evidence from international registries, single-center cohorts, and systematic reviews indicates that, when performed in high-volume centers by surgeons who have completed structured training, TaTME can achieve high rates of circumferential resection margin negativity and satisfactory TME specimen quality. In well-selected and appropriately matched patients, intermediate oncological outcomes, including local recurrence and survival, were comparable to those of conventional laparoscopic TME. However, TaTME remains associated with ongoing concerns, including a steep learning curve, a relatively high incidence of low anterior resection syndrome, and persistent debate regarding oncological safety, particularly following reports of atypical local recurrence patterns from national registries. Focusing on oncological safety, this review provides a critical evaluation of evidence across three interrelated domains: pathological quality, long-term oncological outcomes, and postoperative functional outcomes and quality of life. Importantly, available data suggest that early oncological concerns may have been partly attributable to premature adoption, inadequate training structures, and insufficient quality assurance during the initial implementation phase, rather than to inherent oncological limitations of TaTME. Accordingly, TaTME should be implemented only within a rigorously regulated framework incorporating structured training, multidisciplinary decision-making, and continuous quality monitoring, while carefully balancing oncological radicality with functional preservation and long-term quality of life.

Keywords: Rectal cancer; Transanal total mesorectal excision; Oncological safety; Low anterior resection syndrome; Minimally invasive surgery; Evidence-based medicine; Precision surgery

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1. Introduction

Colorectal cancer remains a major global health burden.¹ Surgical management of mid- and low-rectal cancer, which is relatively common in China, is particularly challenging due to the confined pelvic anatomy. While total mesorectal excision (TME) is the oncological cornerstone, achieving precise dissection in the deep pelvis is difficult.

With the continuous development of minimally invasive surgical concepts and techniques, laparoscopic and robotic-assisted TME have been widely adopted in the treatment of rectal cancer worldwide.² Several large randomized controlled trials have systematically evaluated the oncological safety of minimally invasive TME. The COLOR II trial³ demonstrated that laparoscopic TME achieved local recurrence rates and long-term survival outcomes comparable to those of open surgery, while the ACOSOG Z6051 trial⁴, based on pathological endpoints, further supported the oncological adequacy of laparoscopic TME in terms of circumferential resection margin (CRM) involvement and TME specimen integrity. However, in patients with a “difficult pelvis”—characterized by anatomically unfavorable factors such as male sex, obesity, or a narrow pelvis—the transabdominal approach can be challenged by inadequate visualization and limited instrument maneuverability in the deep pelvis.⁵

To address these constraints, transanal TME (TaTME) was developed, applying natural orifice transluminal endoscopic surgery (NOTES) principles to rectal cancer.⁶ Prior to its clinical application, the feasibility of this concept was critically validated by Sylla *et al.*⁷ through a series of systematic animal experiments. Using a live porcine model, they demonstrated that the transanal approach enabled reverse dissection along the mesorectal plane, facilitated control of the inferior mesenteric vessels, and enabled safe intracorporeal anastomosis, thereby providing anatomical and technical proof of feasibility and preliminary safety for rectal cancer surgery. Building on these findings, Sylla *et al.*⁷ reported the first successful clinical application of laparoscopic-assisted TaTME in rectal cancer patients in 2010, marking the formal transition of this concept from experimental exploration to clinical practice. Its “bottom-up” approach provides a direct, coaxial view of the distal pelvis, which may facilitate more precise distal margin control and mesorectal dissection, especially in ultra-low tumors or difficult pelvises.⁸

However, similar to many emerging surgical techniques, the development of TaTME has not been without controversy. In 2019, a national study based on data from the Norwegian Cancer Registry reported a significantly higher local recurrence rate after TaTME compared with conventional surgery (9.5% vs. 3.4%), leading Norwegian

health authorities to suspend its routine clinical use.⁹ This report attracted widespread international attention within the colorectal surgical community and triggered extensive debate regarding the oncological safety of TaTME, prompting a global re-evaluation of its potential benefits and risks across different clinical settings.^{10–12}

Beyond oncological outcomes, the long-term impact of TaTME on postoperative function and quality of life has also emerged as a major concern. A relatively high incidence of low anterior resection syndrome (LARS), the challenge of achieving outcome homogeneity in the presence of a steep learning curve, and the difficulty in defining optimal patient selection criteria currently represent key issues in both academic discussion and clinical decision-making.¹³ Meanwhile, several fundamental scientific questions remain to be elucidated, including whether continuous intraoperative carbon dioxide insufflation has been hypothesized to be associated with unintended tumor cell dissemination, and the potential biological mechanisms underlying the observed atypical local recurrence patterns characterized by multifocal and anterior-dominant distribution.¹⁴ These issues extend beyond the technical aspects of TaTME and focus on fundamental principles of oncological surgery.¹⁵

Unlike prior systematic reviews that primarily compare outcome metrics, this article adopts a critical narrative review format with a systems-level analytical perspective. We structure our appraisal not only around the hierarchy of evidence (pathological to survival outcomes) but also around the interactive axes of technique execution, learning curve dynamics, and systemic governance (e.g., training, quality control, case selection). This framework allows us to synthesize heterogeneous evidence and explain controversies (e.g., atypical recurrences) by examining their potential roots in the dissemination process rather than attributing them solely to the inherent properties of the technique. The subsequent sections are organized to reflect this analytical journey: from technical evolution and outcome appraisal to mechanistic hypothesis exploration and systemic recommendations for safe implementation.

2. Methodological framework

This article is a critical narrative review, chosen to enable a systems-level analysis of TaTME evidence beyond quantitative synthesis. The aim was to synthesize and critically evaluate evidence across technical, oncological, and functional domains, with explicit focus on dissecting the roots of safety controversies and outcome heterogeneity.

2.1. Search strategy and study selection

A systematic literature search was conducted across

PubMed, Embase, the Cochrane Library, and Web of Science (January 2010–June 2025). Key search terms included “transanal total mesorectal excision,” “TaTME,” “rectal cancer,” “oncological outcomes,” “local recurrence,” and “LARS.” Two reviewers independently screened the studies. Inclusion criteria encompassed clinical studies, registries, and systematic reviews on TaTME for rectal adenocarcinoma, while exclusion criteria comprised case reports and non-English articles.

2.2. Synthesis and appraisal

A thematic, rather than quantitative, synthesis was conducted. Evidence was organized into predefined domains (e.g., technical evolution, safety outcomes, functional sequelae) and critically appraised with an emphasis on study design and potential confounders (e.g., learning curve, patient selection). Higher-level evidence (e.g., prospective cohorts, randomized controlled trials) was prioritized in the conclusions.

2.3. Structural rationale

The review progressed from evidence appraisal to mechanistic exploration and finally to systemic recommendations, mirroring the evolution of the TaTME discourse and facilitating a holistic understanding of its clinical integration.

Importantly, the clinical relevance of TaTME was also interpreted within regional practice contexts. In China, where mid- and low-rectal cancers represent a relatively high proportion of cases, TaTME has been incorporated into a progressively structured national training and research framework. Since the first international structured TaTME training workshops held in 2018, high-volume centers have established standardized curricula integrating proctored initial cases, simulation training, and stepwise clinical mentorship, in alignment with core international consensus principles.^{16–18} Multicenter evaluations, including data from the TaLaR trial, suggest that TaTME, when implemented under regulatory oversight, achieves oncological outcomes comparable to laparoscopic TME.¹⁸ Ongoing domestic multicenter collaboration and device innovation continue to support safer dissemination.¹⁸ These developments mirror global efforts emphasizing modular credentialing systems and quality governance^{8,19}, while emerging directions—including robotic platforms, artificial intelligence (AI)-assisted decision tools, and objective skill assessment—are expected to further refine TaTME practice worldwide.²⁰

3. Critical appraisal of technical evolution and oncological implications

The evolution of TaTME has followed a trajectory from conceptual validation through rapid dissemination to a phase of reflection driven by real-world outcomes.²¹

3.1. Conceptual emergence and feasibility validation (2007–2012): Translating the natural orifice transluminal endoscopic surgery concept into rectal cancer surgery

During its conceptual phase, TaTME research focused on anatomical feasibility. Building on NOTES principles, Sylla *et al.*²² first demonstrated in a porcine model that a transanal approach could achieve mesorectal dissection and anastomosis. Subsequently, a limited number of early clinical cases further supported the technical feasibility of completing TME through a transanal approach combined with laparoscopic assistance in carefully selected patients.⁷ [Figure 1](#) provides a simplified conceptual illustration of the transanal’s “bottom-up” approach underlying TaTME.

It should be emphasized that these early explorations provided the necessary groundwork for subsequent standardization of surgical workflows and the initiation of larger-scale clinical investigations, marking the transition of TaTME from conceptual exploration toward systematic clinical evaluation.²³

3.2. Rapid dissemination and preliminary outcome assessment (2013–2018): The rise of registry studies and accumulation of optimistic data

Transanal TME entered a phase of rapid global dissemination during this period. The international TaTME registry, established in 2014, reported its initial results in 2017; among 720 patients, 96% of specimens were “complete/near-complete” with a 4.0% CRM positivity rate.²⁴ Concurrent single-center studies reported comparable short-term pathological outcomes to laparoscopic TME.^{25,26} Large retrospective analyses conducted by Chinese investigators similarly demonstrated high CRM negative rates—up to 97.3%—when TaTME was performed in experienced centers.¹⁸ At this stage, TaTME was widely regarded as a potential solution to the anatomical challenges of a “difficult pelvis,” owing to its ability to provide a coaxial, direct-view operative field in a confined pelvic space and to partially mitigate instrument collision and visual blind spots. Consequently, the technique attracted substantial international attention. In parallel, multiple international and national expert consensus and procedural guidelines were published to

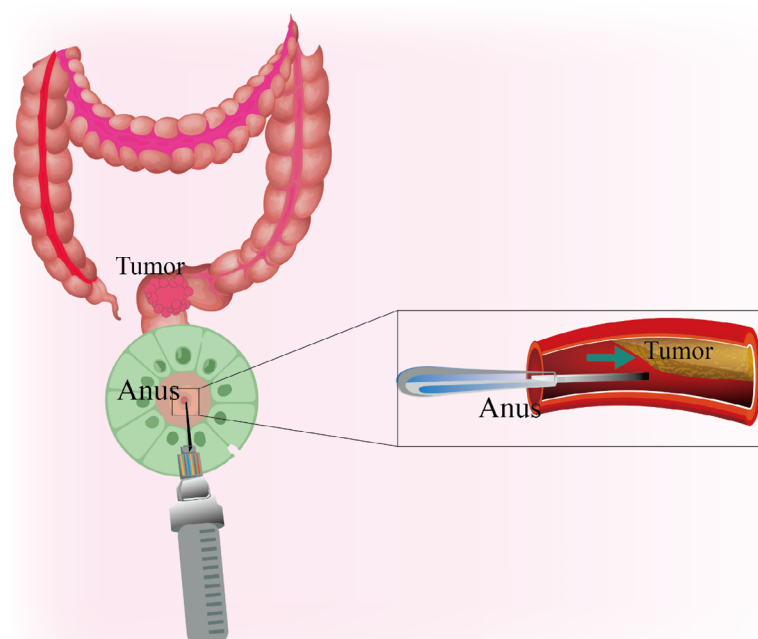


Figure 1. A simplified schematic illustrating the conceptual “bottom-up” transanal approach in transanal total mesorectal excision. Image created by the authors using Adobe Illustrator.

promote standardization of surgical workflows.²⁷ However, this early optimism was tempered by significant selection bias and center effects.²⁸

3.3. Emergence of controversy and deep reflection (2019–2025): Safety concerns, evidence reappraisal, and strengthened quality control

In 2019, a study based on data from the Norwegian National Cancer Registry significantly altered academic discourse surrounding TaTME. This report demonstrated a significantly higher local recurrence rate following TaTME compared with conventional transabdominal approaches (9.5% vs. 3.4%), with recurrences frequently characterized by multifocal distribution and early occurrence, often within 12 months after surgery.⁹ Subsequently, studies from the Netherlands, Denmark, and Sweden reported similar observations, describing distinctive “atypical” local recurrence patterns after TaTME, including multifocal pelvic recurrences and predominant involvement of the anterior anastomotic region or pelvic sidewalls.^{29,30} These findings positioned oncological safety as a central concern within the international colorectal surgical community and prompted a shift in research focus from early technical dissemination toward evidence-based reassessment and rational reflection.

First, the hypothesis of technique-related tumor cell dissemination suggests that continuous carbon dioxide

insufflation used to maintain the transanal operative workspace may, depending on pressure levels and airflow dynamics, facilitate unintended dispersion, suspension, or implantation of tumor cells dislodged during traction or tissue transection within the pelvic cavity.^{14,31,32}

Second, the learning curve effect and technical execution bias hypothesis emphasize that during the early phases of technique adoption—before full maturation and standardization—surgeons may inaccurately identify key pelvic anatomical planes, particularly the plane between the anterior rectal wall and Denonvilliers’ fascia adjacent to the seminal vesicles, prostate, or posterior vaginal wall. Inappropriate plane selection, excessive traction, or inadvertent mesorectal tearing may thereby increase the risk of residual tumor cells or iatrogenic implantation.³³

Third, in extremely narrow or anatomically asymmetric pelvises, mechanical efforts to maintain this trajectory may inadvertently lead surgeons to dissect closer to the rectal wall or mesorectal tissue in certain regions—particularly posterior to the prostate or along the pelvic sidewalls—thereby deviating from the optimal mesorectal plane and increasing the risk of microscopic residual disease.²⁸

Fourth, the local immune microenvironment alteration hypothesis proposes that the transanal operative route, continuous carbon dioxide pneumopelvis, and potentially more extensive pelvic tissue manipulation

may induce inflammatory responses and cytokine release profiles distinct from those observed in conventional transabdominal surgery.

This phase marked a paradigm shift from technical dissemination to safety-focused reflection. Importantly, subsequent analyses indicated that after heightened awareness and improved patient selection post-2019, recurrence rates showed a declining trend.³⁴ To structure the heterogeneous recurrence patterns reported after TaTME, the proposed underlying mechanisms can be conceptually categorized into several non-mutually exclusive hypotheses, as summarized in Table 1. These mechanisms may interact under specific clinical and

system-level conditions, particularly during early dissemination of the technique.

4. Evidence-based evaluation of oncological outcomes: From short-term pathological indicators to long-term survival data

Oncological outcomes of TaTME should be assessed using a multilayered evidence framework that integrates short-term pathological indicators (e.g., CRM, TME quality) and long-term metrics (e.g., recurrence, survival). Interpreting evidence requires accounting for confounders such as study design, patient selection, center experience, and

Table 1. Overview of hypothesized mechanisms underlying atypical local recurrence associated with transanal total mesorectal excision

Hypothesis category	Core mechanistic rationale	Potential tumorigenic/recurrence pathway	Key evidence and limitations
Technique-related tumor cell dissemination hypothesis	Carbon dioxide insufflation may promote dispersal and implantation of exfoliated tumor cells via airflow ^{14,31,32}	Airflow-driven cellular dissemination → unintended pelvic implantation → multifocal or atypical local recurrence	<i>In vitro</i> experiments and animal models support the theoretical plausibility of airflow-mediated cell spread; however, direct clinical evidence in humans, as well as definitive pressure thresholds and airflow patterns, remain lacking
Learning curve effect and technical deviation hypothesis	During the early phase of technique adoption, insufficient recognition of critical anatomical planes (e.g., between Denonvilliers' fascia and the prostate or posterior vaginal wall), inappropriate plane selection, or excessive traction may occur	Iatrogenic mesorectal disruption or residual tumor cell retention → local implantation or recurrence ³³	Multiple retrospective studies suggest the early learning phase represents a high-risk period; however, a clear quantitative definition of an "adequate learning curve" remains elusive
Potential limitations of the "cylindrical" resection concept	In pursuit of an ideal cylindrical total mesorectal excision specimen, surgeons may be forced to deviate from the "holy plane" of the mesorectum in patients with a narrow or anatomically asymmetric pelvis	Dissection closer to the tumor-bearing bowel wall or mesorectum → microscopic residual disease → local recurrence ²⁸	Anatomically and theoretically plausible, but direct pathological–radiological–recurrence site correlations are currently insufficient
Case selection bias and the "indication creep" hypothesis	During dissemination of the technique, transanal total mesorectal excision may be inappropriately applied to complex cases originally unsuitable for this approach (e.g., cT4b tumors, bulky lesions, extensive anterior wall invasion, or prior pelvic irradiation)	Cases with intrinsically high baseline recurrence risk → adverse outcomes erroneously attributed to the surgical approach ³⁵	Supported by retrospective analyses; however, complete adjustment for selection bias and confounding factors is challenging
Alteration of the local immune microenvironment hypothesis	The transanal approach, sustained carbon dioxide pneumoperitoneum, and more extensive pelvic tissue manipulation may induce local inflammatory and cytokine responses distinct from those seen in conventional transabdominal surgery ³⁶	Suppression of local immune surveillance (e.g., natural killer cells, macrophages) → enhanced survival, implantation, and angiogenesis of residual tumor cells	An emerging research direction primarily supported by basic and translational studies; direct clinical evidence remains limited

Notes: These mechanisms are not mutually exclusive and may interact synergistically; direct causal relationships have not yet been conclusively established.

learning curve phase to draw balanced conclusions from heterogeneous data.

4.1. Circumferential resection margin and surgical quality: Short-term advantages and limitations as a definitive endpoint

A large body of retrospective studies, prospective registry data, and meta-analyses consistently demonstrate that, when performed in high-volume centers by experienced teams, TaTME is generally associated with high rates of CRM negativity, most commonly reported at 94–97.3%.^{24,37,38} This finding is widely attributed to the “bottom-up” surgical approach inherent to TaTME, which provides a direct, coaxial, and magnified operative view in the narrowest and most technically demanding distal pelvic region. Such visualization facilitates more accurate delineation of the distal resection margin under direct vision and enables early entry into, and maintenance of, the correct mesorectal dissection plane, particularly when managing anteriorly located mid- and low-rectal tumors, thereby partially compensating for the visual limitations of the transabdominal approach.³⁹

A multicenter propensity score-matched study published in 2018 further substantiated these observations. Focusing on magnetic resonance imaging (MRI)-defined ultra-low rectal cancer (tumor lower edge < 5 cm from the anal verge), the study demonstrated a significantly lower CRM positivity rate in the TaTME group compared with the laparoscopic TME group (4.9% vs. 12.2%, $p = 0.432$), suggesting a potential advantage of this technique in ultra-low sphincter-preserving surgery.⁴⁰

Nevertheless, it is crucial to recognize that CRM negativity is a necessary but not sufficient condition for achieving favorable long-term oncological control. The Norwegian study provides an important cautionary example: despite negative CRM findings on routine pathological assessment, a higher local recurrence rate was still observed in the TaTME cohort.⁹ This phenomenon suggests the possible contribution of microscopic residual disease not detectable by conventional pathological methods (such as gross examination or routine sectioning), intraoperative micro-dissemination of tumor cells (as discussed in earlier hypotheses), or tumor-intrinsic aggressive biological behavior acting in concert.⁴¹

Beyond CRM status, the integrity of the TME specimen—typically categorized as “complete,” “near-complete,” or “incomplete”—also constitutes a critical indicator of surgical quality. Data from the international TaTME registry report a combined rate of “complete/near-complete” TME specimens as high as 96%.²⁴ However, subsequent studies have indicated that in non-selected

centers or during the early learning curve phase, rates of incomplete TME specimens and intraoperative rectal perforation may be substantially higher. Therefore, oncological safety cannot be definitively inferred from favorable CRM negativity alone and must instead be evaluated in conjunction with long-term follow-up data and multidimensional outcome measures.

4.2. Local recurrence and survival: Emerging long-term data and heightened attention to recurrence patterns

In recent years, an increasing number of studies with follow-up durations of three years or longer have been published, providing deeper insight into the oncological outcomes of TaTME. However, the reported results remain heterogeneous. A large international multicenter prospective cohort study published in 2021—representing a subsequent analysis of the international TaTME registry ($n = 2803$)—reported a two-year local recurrence rate of 4.8% following TaTME, with no significant difference compared with historical data from laparoscopic TME. Multivariable analysis further identified male sex and higher pathological T stage (pT3–4) as independent risk factors for local recurrence after TaTME.⁴² As summarized in Table 2, reported CRM positivity and local recurrence rates after TaTME vary substantially across studies, reflecting differences in study design, patient selection, institutional experience, and follow-up duration. In contrast, a Dutch multicenter retrospective study published in 2021 reported a higher five-year cumulative local recurrence rate of 12.5% and detailed descriptions of multifocal and anterior-dominant recurrence patterns.⁴³

In addition, a 2023 systematic review and meta-analysis that included 14 comparative studies found no statistically significant difference in three-year local recurrence rates between TaTME and laparoscopic TME.⁴⁴ However, the authors highlighted substantial heterogeneity among the included studies and noted the lack of long-term follow-up data beyond five years. The heterogeneity illustrated in Table 2 underscores that isolated findings—whether favorable or unfavorable—should not be interpreted in isolation when assessing the oncological safety of TaTME. Overall, these divergent findings may be attributable to multiple factors, including differences in patient population composition, timing of surgical implementation (with many cases performed during the global early learning curve), patient selection criteria, adjuvant treatment strategies, and intensity of follow-up.

With respect to long-term survival outcomes, available mid-term follow-up data suggest that TaTME may achieve overall prognostic results comparable to those

of conventional transabdominal surgery.^{45,46} A long-term single-center follow-up study by Marks *et al.*²⁵ reported a five-year overall survival rate of up to 90% following TaTME. Nonetheless, these analyses consistently highlight the paucity of high-quality randomized controlled trials directly comparing TaTME with alternative surgical approaches. Collectively, the variability in outcomes summarized in Table 2 highlights the current limitations of registry-based and retrospective evidence and reinforces the need to await long-term oncological results from ongoing randomized controlled trials. The current evidence base is largely derived from observational studies and therefore has limited evidentiary strength.^{47,48} At present, the colorectal surgical community continues to closely monitor several large, ongoing, or recently completed multicenter randomized control trials, including the COLOR III, GRECCAR 11, and TaLaR trials, whose long-term (five-year) oncological outcomes are expected to provide the highest level of evidence for defining the safety profile and appropriate indications of TaTME.^{49,50}

4.3. Learning curve: A key confounder underlying oncological safety and outcome heterogeneity

The learning curve is widely regarded as one of the most critical confounding factors contributing to the substantial heterogeneity in oncological outcomes of TaTME across centers and time periods. Systematic reviews and meta-analyses indicate that surgeons typically need to complete approximately 35–50 TaTME procedures before key oncological indicators—such as CRM positivity, intraoperative rectal perforation rates, and overall perioperative complication rates—reach a relatively stable plateau.⁵¹ Multiple studies further demonstrate that during the early learning curve phase, usually defined as the first 20–30 cases, TaTME is associated with significantly higher risks of CRM positivity, intraoperative rectal perforation, and overall complications compared with the mature phase of practice.⁵²

A 2024 study employing machine learning-based analysis of surgical video data provided a more granular characterization of the TaTME learning process.⁵³ This analysis identified anterior rectal wall dissection and the identification and preservation of pelvic autonomic nerves as the most technically challenging steps and the most frequent sources of technical deviation during the learning phase, thereby offering objective evidence to inform targeted simulation training and skill reinforcement strategies.

Notably, propensity score-matched studies have shown that when TaTME cases performed during the mature learning curve phase are compared with matched

laparoscopic TME cases, differences in oncological outcomes are often no longer statistically significant.¹³ These findings suggest that adverse outcomes observed during the early learning curve are more likely attributable to immature technical execution, insufficient anatomical familiarity, and suboptimal patient selection, rather than to inherent and insurmountable flaws in the fundamental principles of TaTME itself.⁵⁴ Accordingly, the safe dissemination of TaTME should not occur in the absence of systematic planning, but should be firmly grounded in structured, stepwise, and supervised training and credentialing programs. Initial implementation is best concentrated in high-volume regional centers with adequate caseloads, multidisciplinary support, and standardized mentorship capacity.¹¹ At present, professional organizations such as the International Society of University Colorectal Surgeons and the European Society of Coloproctology continue to promote the development of globally harmonized training standards and quality assurance frameworks to mitigate learning curve-related risks and facilitate the standardized application of this technique.

5. Functional outcomes and quality of life: The success of sphincter preservation and the hidden trade-offs

For patients with mid–low rectal cancer, sphincter preservation is a key goal, and TaTME's “bottom-up” approach can facilitate ultra-low anastomoses, expanding its feasibility.⁵⁵ However, anatomical success does not guarantee functional success. LARS is the most significant functional complication, central to evaluating outcomes after TaTME.⁵⁶

5.1. Low anterior resection syndrome: High incidence and its complex multifactorial mechanisms

Low anterior resection syndrome refers to a constellation of symptoms centered on defecatory dysfunction after rectal resection, typically including increased stool frequency, urgency, fecal incontinence, difficulty with evacuation, and a sensation of incomplete emptying, all of which may substantially impair daily quality of life.⁵⁷ Multiple meta-analyses and prospective cohort studies consistently report a high incidence of moderate-to-severe LARS after TaTME, commonly ranging from 50% to 73.8%.^{13,58} A comparative study further suggests that, compared with conventional laparoscopic TME, the incidence of LARS after TaTME may be slightly higher during the early postoperative period, particularly within the first six months.⁵⁹ Overall, LARS is considered a result of complex interactions among patient-related factors, tumor characteristics, multimodal treatment strategies (especially neoadjuvant

Table 2. Circumferential resection margin status and local recurrence outcomes of transanal total mesorectal excision in representative studies

Study	Country/region	Study design	Sample size (<i>n</i>)	Positive circumferential resection margin rate	Local recurrence rate (time point)	Remarks
Penna et al. ²⁴	International	Prospective registry study	720	4.0%	Not reported	Data from the early implementation phase, primarily reflecting technical feasibility
Van et al. ⁴³	The Netherlands	Retrospective multicenter study	624	Not reported	12.5% (first 10 cases)	Reported atypical local recurrence patterns, triggering safety concerns
Roodbeen et al. ⁴⁰	International	Prospective cohort study	2803	5.1%	4.8% (two-year)	Largest prospective cohort to date, providing intermediate-term oncological outcomes

Notes: The included studies span different countries, study designs, and stages of technical development. Outcome heterogeneity should be interpreted in the context of case selection, institutional experience, and follow-up duration. The positive circumferential resection margin rate refers to the ultra-low rectal cancer subgroup.

chemoradiotherapy), and technical aspects of surgery. The TaTME approach may exert specific influences on functional outcomes through the following mechanisms.

5.1.1. Pelvic autonomic nerve injury

The reverse dissection pathway of TaTME brings the surgeon into contact with pelvic neural structures from a perspective and sequence different from that of the transabdominal approach. Although, in theory, the “bottom-up” view may facilitate earlier identification and protection of the hypogastric nerves (sympathetic components) proximally, handling the terminal branches of the pelvic plexus becomes more complex in and around the anal canal. Fine parasympathetic nerve fibers innervating the internal and external anal sphincters, rectum, and urogenital organs may be injured by traction, thermal spread, or direct transection, leading to altered neorectal sensation and impaired regulation of anal sphincter tone.⁶⁰

5.1.2. Factors related to ultra-low anastomosis

Transanal total mesorectal excision is often applied to achieve extremely low anastomoses, even at the level of the dentate line (e.g., coloanal anastomosis, <3 cm from the anal verge). Previous studies have clearly established that anastomotic height from the anal verge is among the strongest predictors of LARS. The lower the anastomosis,

the smaller the capacity and the poorer the compliance of the colonic segment serving as the “neorectum,” with a concomitant reduction in the ability to modulate defecatory reflexes, resulting in combined impairment of storage function and continence.⁶¹

5.1.3. Additive impact of neoadjuvant chemoradiotherapy

Most patients with locally advanced mid- and low-rectal cancer receive neoadjuvant chemoradiotherapy before surgery. Radiation-related pelvic fibrosis, neural plexus injury, and microvascular changes may act synergistically with surgical trauma, thereby aggravating postoperative dysfunction. This adverse effect is particularly evident in patients undergoing ultra-low anastomosis.^{62,63}

5.1.4. Mechanical effects on the anal sphincter complex

Transanal manipulation typically requires insertion of a single-port platform with a diameter of approximately 3–4 cm and prolonged maintenance, resulting in sustained mechanical dilation and traction on the anal sphincter complex (particularly the internal sphincter). This may induce transient or permanent structural and functional changes, thereby affecting resting pressure and voluntary contraction capacity.⁶⁴ A prospective anorectal manometry

study published in 2021 reported that the decline in maximum squeeze pressure at three months after TaTME was significantly greater than that observed after laparoscopic TME, providing objective functional support for this mechanism.⁶⁵

5.1.5. Alterations in colonic motility and transit

Coloanal or low colorectal anastomosis following rectal resection alters anatomical continuity and may affect segmental peristalsis and colonic transit. Together with the limited neorectal capacity, this may promote stool fragmentation and frequent defecatory urges, thereby exacerbating defecatory dysfunction.⁶⁶

5.2. Integrated assessment of quality of life

Symptoms of LARS can significantly impair quality of life. The most severe impact typically occurs 6–12 months postoperatively, with 20–30% of patients suffering long-term severe LARS.^{67,68} Studies using the European Organisation for Research and Treatment of Cancer questionnaires indicate that TaTME patients may experience worse early-to-midterm role, social, and emotional function, alongside more pronounced bowel symptoms, compared to those undergoing laparoscopic TME.⁶⁹ This underscores the need for a thorough preoperative counseling on functional prognosis.

5.3. Multidimensional exploration of functional preservation and rehabilitation strategies

To improve functional outcomes after TaTME and mitigate the impact of LARS on quality of life, current research and clinical practice have proposed a series of comprehensive, multi-level interventions spanning preoperative assessment, intraoperative technique, and postoperative rehabilitation management.

5.3.1. Preoperative precision assessment and decision-making

Preoperatively, multidisciplinary discussion should weigh the functional cost of sphincter preservation, especially in patients with poor baseline function.⁷⁰

5.3.2. Intraoperative technical refinement and nerve-protective strategies

During surgical implementation, meticulous dissection and nerve preservation principles should be emphasized. Precise separation, under direct vision, of the avascular plane between the posterior layer of Denonvilliers' fascia and the seminal vesicles or posterior vaginal wall may reduce the risk of injury to the neurovascular bundles running posterolaterally to the prostate or vagina.⁷¹ Robotic-assisted TaTME, owing to its three-dimensional

visualization, fine instrument control, and tremor filtration, may offer potential advantages in identifying and protecting neural structures; however, its functional benefits require further validation in high-quality studies.^{72,73}

Regarding anastomotic reconstruction, for patients undergoing ultra-low anastomosis, a colonic J-pouch or side-to-end colooplasty may be considered to increase neorectal capacity and slow intestinal transit. Multiple randomized controlled trials have shown that, compared with straight coloanal anastomosis, pouch reconstruction is associated with a lower incidence and severity of LARS and improved functional satisfaction.⁷⁴ In addition, emerging technologies such as intraoperative nerve monitoring and augmented/mixed reality navigation may, in the future, provide supportive tools for real-time nerve localization and protection, although these approaches remain exploratory at present.⁷⁵

5.3.3. Perioperative rehabilitation and functional training

Perioperative rehabilitation is crucial. Preoperative pelvic floor training ("prehabilitation") may aid postoperative recovery, and early postoperative structured rehabilitation (e.g., biofeedback) can improve continence.⁷⁶ In parallel, individualized dietary counseling (e.g., increasing soluble fiber intake and avoiding gas-producing foods) and appropriate pharmacological interventions (e.g., antidiarrheals or bulking agents) may facilitate long-term symptom management.

5.3.4. Application of functional prognosis prediction models

In recent years, multifactorial functional outcome prediction models have gradually been introduced into clinical practice. By integrating baseline patient characteristics (such as age, sex, and anorectal manometry parameters), tumor-related factors (location and stage), and treatment variables (neoadjuvant chemoradiotherapy, surgical approach, and whether a pouch was constructed), such models—including the Pre-Operative Low Anterior Resection Syndrome Score and LARS prediction nomograms—enable quantitative estimation of an individual patient's risk of developing moderate-to-severe LARS after surgery.^{4,62}

6. Multidimensional analysis and rebalancing of core controversies

6.1. Controversies in oncological safety: Inherent technical flaws or challenges in execution and system-level dissemination?

Following the Norwegian report,⁹ accumulating evidence

has shifted the debate on TaTME safety toward rational reappraisal. Current data suggest that early reports of higher recurrence rates likely stem from systemic dissemination issues—such as non-standardized technique, underestimation of the learning curve, inadequate quality control, and inappropriate patient selection—rather than from inherent flaws in the TaTME concept itself.^{54,77} Taken together, the coexistence of multiple plausible mechanisms (Table 1) indicates that oncological safety concerns surrounding TaTME are unlikely to stem from a single technical factor, but rather from interacting procedural, learning curve, and system-level influences. This interpretation can be examined across several key dimensions.

6.1.1. Underestimation of the learning curve and premature independent implementation

During the early phase of TaTME dissemination, some centers began performing clinical TaTME independently after completing only a limited number of observational visits or animal training sessions, and in some cases without sufficient experience in laparoscopic TME. Under such circumstances, patients were effectively exposed to the high-risk segment of the learning curve. The lack of mandatory, stepwise, and supervised training entry mechanisms has been regarded as one of the major systemic contributors to the increased frequency of early adverse outcomes.⁵²

6.1.2. Inappropriate case selection and “indication creep”

Under the influence of optimistic expectations during the dissemination phase, TaTME was applied in some centers to complex cases that were not ideally suited to this approach, including locally advanced tumors (cT4b fixed to surrounding organs), large anterior tumors with extensive invasion, severe pelvic anatomical abnormalities, or patients with prior definitive pelvic radiotherapy. These cases inherently carry higher technical difficulty and a higher risk of local recurrence, and their unfavorable outcomes may confound the objective assessment of TaTME's oncological safety as a surgical technique.³⁵

6.1.3. Lack of unified “best practices” and quality control for key technical details

In the early stage of technical development, several operative details potentially affecting oncological safety lacked evidence-based standardization. For example, substantial inter-center variability existed in transanal pneumorectal carbon dioxide pressure settings (excessively high pressure may increase dissemination risk), whereas insufficient pressure compromises visualization, the choice

and application of intraoperative pelvic irrigation, and specimen extraction route (transanal vs. transabdominal). Such procedural heterogeneity may increase exposure to potential risks and create conditions that facilitate adverse outcomes.^{14,78}

6.1.4. Absence of systematic registries, audits, and feedback mechanisms

During the early dissemination period, a globally unified, mandatory case registration and long-term outcome audit system had not yet been established. Consequently, adverse events and suboptimal outcomes were not consistently identified, aggregated, and communicated to the surgical community promptly, thereby limiting opportunities for early warning and intervention.

Notably, subsequent analyses of the international TaTME registry indicate that centers initiating TaTME after 2018—following global safety alerts and the implementation of stricter standards—have reported a downward trend in local recurrence rates.⁴³ Similarly, countries such as the Netherlands have observed improved oncological outcomes after adopting stringent center accreditation, patient selection standards, and mandatory registration and follow-up systems.⁷⁹ Collectively, these data support the view that the risks associated with TaTME are, to some extent, controllable through strengthened structured training, rigorous patient selection, standardized key procedural steps, and effective quality monitoring and feedback mechanisms, with corresponding improvement in oncological outcomes. These findings suggest important implications for the future development of TaTME: the core issue is not simply rejecting the technique, but establishing and implementing a high-quality framework for safe adoption and regulation.

6.2. Objectifying the definition of the “difficult pelvis” and developing case selection optimization models

With advances in imaging, modern high-resolution MRI has become an important tool for objective preoperative evaluation of pelvic anatomy and tumor characteristics.⁸⁰ Future TaTME case selection should be guided by comprehensive scoring models. An ideal preoperative model would integrate: anatomical factors (MRI-based pelvic measurements, prostate volume), tumor characteristics (distance from anal verge, cTNM stage, location, size, MRF relationship), patient profiles (sex, body mass index, comorbidities, baseline anorectal function), and treatment variables (neoadjuvant therapy use and response).

Based on existing evidence and expert consensus, the

ideal indication profile for TaTME is becoming increasingly defined. It primarily includes patients with mid- and low-rectal cancer (tumor lower edge < 10–12 cm from the anal verge), clinical stage cT1–3 (or downstaged ypT1–2 after neoadjuvant therapy), relatively small tumor diameter (e.g., <5 cm), and at least one clearly defined “difficult pelvis” feature such as male sex, body mass index > 30, or a high MRI-based pelvic narrowness score.^{70,81} Conversely, for cT4 tumors, extreme cases requiring intersphincteric resection due to involvement of the sphincter complex, or patients with severe pelvic deformity or dense pelvic adhesions from multiple prior operations, conventional transabdominal approaches (open, laparoscopic, or robotic-assisted surgery), or abdominoperineal resection should be prioritized after a careful risk–benefit assessment, with oncological radicality maintained as the primary objective.⁸²

6.3. Potential mechanisms of atypical recurrence patterns: From physical dissemination to the biological microenvironment

Mechanistic exploration of TaTME-associated atypical recurrence patterns—such as multifocal distribution, anterior dominance, and early recurrence—has increasingly become an important research direction bridging surgical technical characteristics and tumor biological behavior.

6.3.1. Alterations in the local immune microenvironment

Beyond physical dissemination, biological factors such as surgery-induced alterations in the local immune microenvironment are also under investigation.⁸³ For example, postoperative monitoring of immune cell changes or cytokine levels, combined with other tumor biomarkers, may become a tool for predicting recurrence.

6.3.2. A refined balance between oncological radicality and functional preservation

In specific situations, heightened attention to neurovascular structures may lead to relatively constrained resection in certain local areas, potentially increasing the risk of microscopic residual disease (e.g., R1 microscopic involvement), thereby providing a substrate for subsequent local recurrence. In the future, intraoperative frozen-section assessment, minimal residual disease testing, and fluorescence imaging-guided navigation may help more precisely evaluate margin safety while preserving function.⁸⁴

6.3.3. Tumor cell aerosolization and vortex-related implantation

In recent years, computational fluid dynamics simulations

and more refined *in vitro* experimental models have suggested that, under specific carbon dioxide flow parameters (such as pressure and flow rate), tumor cells or tissue fragments may become aerosolized and generate localized vortices within the pelvic gas cavity, leading to deposition and implantation in unintended regions such as the anterior compartment or pelvic sidewalls.⁸⁵ Although these findings are primarily based on simulations and experimental models, they have prompted re-evaluation of intraoperative gas management strategies, including low-pressure insufflation (<10 mmHg), gas humidification, and the use of smoke evacuation systems equipped with filtration devices. Clinically, filtered smoke evacuation systems and gas humidification strategies may reduce intraoperative tumor cell spread and thereby lower the risk of postoperative recurrence.

Overall, further validation of these mechanistic hypotheses will require interdisciplinary collaboration. Through refined intraoperative sampling of irrigation fluid or gas, the establishment of prospective biobanks, and integration with advanced molecular assays (such as next-generation sequencing-based detection of circulating tumor DNA), the biological basis of TaTME-associated atypical recurrence patterns may be further elucidated within a translational medicine framework.⁸⁶

7. Future directions: Toward a new era of standardized, intelligent, and individualized precision surgery

Integrating prior evidence with current controversies, the future development of TaTME should explicitly focus on three core goals: improving technical reproducibility, ensuring patient safety, and achieving treatment precision. Its long-term success is unlikely to depend on isolated refinements of a single technique, but rather on synergistic innovation and deep integration across surgical technology platforms, training and credentialing systems, and research paradigms.

7.1. The establishment of structured training and quality accreditation systems through global and regional collaboration

In recent years, professional organizations such as the International Society of University Colorectal Surgeons and the European Society of Coloproctology have begun to promote the development of such training and accreditation frameworks and cross-regional mutual recognition. Some initiatives have also attempted to enhance accessibility and standardization through online educational platforms (e.g., E-Academy).⁸⁷ In China, national TaTME training programs and related expert consensus documents have

likewise been released in succession.⁸⁸ Looking ahead, a key challenge will be to further institutionalize and normalize these training systems, while strengthening long-term outcome surveillance and quality feedback for credentialed surgeons, to ensure that training effects are sustainably maintained in real-world clinical practice.

7.2. Deep integration and intelligent upgrading of technical platforms

7.2.1. Robotic-assisted transanal total mesorectal excision

The emergence of single-port robotic systems (e.g., the da Vinci SP) has created new technical possibilities for transanal single-port surgery. These technical features are considered to have the potential to shorten the learning curve and confer possible benefits in nerve preservation and functional outcomes. Several prospective studies and matched comparative investigations published recently (2024–2025) have preliminarily reported favorable perioperative safety, high rates of CRM negativity, and adequate lymph node dissection quality with robotic TaTME, with some indicators outperforming conventional laparoscopic TaTME; however, its long-term oncological and functional advantages require confirmation in higher-quality studies.⁸⁹

7.2.2. Image guidance and augmented/mixed reality

By registering and integrating these models with real-time intraoperative laparoscopic or transanal endoscopic imaging, augmented/mixed reality technologies may provide surgeons with real-time spatial navigation support, assisting in the precise identification of anatomical planes and planning of resection pathways, thereby reducing the risk of entering incorrect planes or injuring neural structures. At present, these applications remain largely at an early exploratory clinical stage but have shown potential for nerve preservation and lateral pelvic maneuvers under complex anatomical conditions.⁹⁰

7.2.3. Artificial intelligence and big data-assisted decision support

Artificial intelligence is increasingly incorporated into various components of the TaTME-related diagnostic and treatment workflow. In the preoperative setting, AI models based on radiomic features can be integrated with clinical parameters to predict CRM involvement risk, the probability of lateral pelvic lymph node metastasis, and response to neoadjuvant therapy, thereby supporting individualized treatment planning.^{5,91} Intraoperatively, computer vision-based AI systems may enable real-time analysis of surgical video streams, automated recognition

of key anatomical structures, and warning prompts when approaching high-risk regions, functioning as a “virtual assistant” to support the surgeon.⁹² Postoperatively, AI may also facilitate pathological assessment through automated evaluation of digitized slides, enabling more objective determination of margin status, tumor regression grade, and lymphovascular invasion, thereby supporting prognostic assessment and adjuvant treatment decision-making.⁹³

7.3. Individualized surgical decision-making within a precision medicine framework

With the increasing integration of precision medicine into rectal cancer management, surgical decision-making is gradually shifting from a technique-centered, “one-size-fits-all” model toward individualized strategies guided by patient characteristics and tumor biological behavior. In this context, TaTME should be considered an option in the surgical toolbox. Whether and how it is applied should be embedded within a precision decision framework centered on molecular subtyping, treatment response, and functional expectations.⁹⁴

Beyond anatomical and biological considerations, patient-centered factors are critical in determining whether TaTME can be safely and effectively implemented. Psychological acceptance is crucial for the successful adoption of TaTME, given its innovative nature and benefits like minimal invasiveness and faster recovery. Effective preparation involves educating patients on the procedure's benefits and challenges through multimedia, testimonials, and consultations. For anxious or resistant patients, personalized support such as counseling or support groups can ease distress and foster a positive attitude. Building trust through open communication further enhances confidence, while ongoing support and post-surgery education help patients adjust and solidify their acceptance of the method.

7.3.1. Strategy adjustment based on molecular subtyping and response to systemic therapy

For locally advanced rectal cancer patients with microsatellite instability-high/mismatch repair-deficient tumors, neoadjuvant immune checkpoint inhibitor therapy (e.g., programmed cell death protein 1 monoclonal antibodies) has recently shown high rates of pathological complete response.⁹⁵ In patients achieving clinical complete response (cCR), a “watch and wait” strategy has become an important treatment option. Within this pathway, the future role of TaTME is more likely to be that of a highly precise local salvage tool for managing regrowth lesions detected during surveillance, rather than a first-line radical surgical approach.

In contrast, for locally advanced rectal cancer patients requiring intensified neoadjuvant chemoradiotherapy (e.g., cT3c/d, cT4, or cN2), the feasibility and safety of TaTME in a post-radiotherapy pelvic environment characterized by marked fibrosis and obscured anatomical planes should be evaluated more cautiously in multidisciplinary discussions. Such cases often impose higher demands on surgeon experience and technical maturity, indicating that TaTME use must be stringently matched to risk level.⁹⁶

7.3.2. Precise assessment of post-neoadjuvant response and optimization of surgical timing

By integrating functional MRI (e.g., diffusion-weighted imaging), positron emission tomography-computed tomography, and circulating tumor DNA testing, tumor regression after neoadjuvant therapy can be assessed with greater granularity. For patients achieving cCR or near-cCR with a strong preference for sphincter preservation, local excision (e.g., transanal minimally invasive surgery) or entry into a “watch and wait” pathway may be considered under strict surveillance. For patients with partial response who remain candidates for sphincter preservation, TaTME—owing to its clear distal visualization and favorable control of resection margins—may represent an attractive surgical option.⁹⁷

7.3.3. Routine implementation of functional prognosis prediction models

Integrating established functional outcome prediction models (such as the Pre-Operative Low Anterior Resection Syndrome Score and related LARS risk prediction tools) into electronic medical records or clinical decision support platforms could enable preoperative generation of individualized probabilities for developing moderate-to-severe LARS based on patient-specific parameters.^{4,62} Such data-driven risk quantification can elevate preoperative counseling from experience-based descriptions to a more visualized and comprehensible decision-support process. This not only facilitates shared decision-making but also helps identify high-risk patients early, enabling intensified prehabilitation strategies before surgery and more proactive functional rehabilitation planning after surgery.

8. Conclusion

Transanal total mesorectal excision represents a major conceptual innovation and a technical pathway for rectal cancer surgery, offering a potentially advantageous solution to the long-standing anatomical challenge of the “difficult pelvis.” After more than a decade of development, controversy, and critical reflection, the available body of moderate- to high-level evidence collectively suggests that, in carefully selected patients and when performed

by colorectal surgeons who have undergone systematic and structured training within high-volume centers equipped with comprehensive quality assurance systems, TaTME can achieve oncological radicality comparable to that of standard transabdominal approaches. Its technical advantages in achieving precise distal margin control and high CRM negativity in ultra-low rectal cancer have enabled a subset of patients—previously considered unlikely candidates for sphincter preservation—to avoid permanent stoma formation.

A review of the developmental trajectory of TaTME clearly demonstrates that the clinical value of a new surgical technology depends not only on the innovativeness of its underlying concept and access route, but also—critically—on the rigor of quality control and the depth of evidence-based evaluation during its dissemination. The steep learning curve renders TaTME particularly sensitive to execution quality, and the oncological safety concerns arising from early, inadequately regulated expansion have provided the surgical community with important systemic lessons on how to balance innovation, ethical responsibility, training infrastructure, and continuous quality monitoring during the introduction of new techniques. Moreover, the relatively high incidence of LARS further underscores that, in contemporary rectal cancer surgery, success can no longer be defined solely by tumor removal or anatomical sphincter preservation, but must encompass systematic attention to functional outcomes and proactive management of long-term quality of life. Taken together, the mechanistic hypotheses summarized in [Table 1](#) and the heterogeneous oncological outcomes collated in [Table 2](#) collectively indicate that the ongoing controversy surrounding TaTME reflects a complex interaction between technical execution, learning curve dynamics, and system-level governance, underscoring that its clinical application should be guided by rigorous training, careful patient selection, and evidence-informed decision-making rather than simplistic judgments of inherent safety or risk.

Looking forward, the continued evolution of TaTME should remain firmly grounded in the principles of evidence-based medicine, comprehensive process-level quality control, and prioritization of patient-reported outcomes. Future refinements of TaTME may benefit from integrating emerging biomedical technologies, such as fluorescence-guided surgery. Real-time visualization of perfusion and tumor margins could improve intraoperative decision-making and help address current limitations in margin assessment and anastomotic safety. Such approaches may support a transition toward more biologically informed precision surgery.

At present, it remains essential to await and rigorously

interpret the long-term oncological and functional outcomes of pivotal randomized controlled trials such as COLOR III and GRECCAR 11 to define the true value of TaTME across different patient subgroups with higher-level evidence. Concurrently, the strict global implementation of structured training and credentialing systems remains the cornerstone for ensuring the safe, orderly, and homogeneous application of this technique. With the progressive integration of emerging technologies—including single-port or multi-port robotic platforms, image-guided navigation, and AI—the technical stability, precision, and safety of TaTME may be further enhanced, potentially driving the development of new surgical paradigms and training models.

Overall, TaTME should not be regarded as a “universal” technique intended to replace other surgical approaches, but rather as an important yet highly selective precision tool within the modern multidisciplinary management of rectal cancer. Clinical decision-making regarding its use should be based on a comprehensive preoperative multimodal assessment that integrates anatomical conditions, tumor biological characteristics, functional risk profiles, and individual patient values, aiming to achieve a personalized balance among oncological radicality, functional preservation, and long-term quality of life. Only through sustained basic and clinical translational research, rigorous training and credentialing, prudent case selection, standardized technical execution, and systematic functional rehabilitation support can TaTME fully realize its potential to improve long-term comprehensive outcomes for rectal cancer patients and establish a rational and durable role in the evolving era of minimally invasive surgery and precision medicine.

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