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Minimally Invasive Surgery: Principles, Clinical Outcomes and Impact on Postoperative Functional Recovery

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Abstract:

Background: Many operations once performed through large incisions are now routinely completed with laparoscopic or other minimally invasive methods, and the use of robotic assistance continues to expand. Postoperative functional recovery is increasingly emphasized alongside morbidity, mortality, and oncologic safety.

Aim: To review core principles of minimally invasive surgery (MIS) and summarize reported clinical outcomes and early functional recovery across multiple specialties.

Methods: A narrative review of PubMed-indexed randomized trials, prospective audits, and systematic reviews and meta-analyses was performed, focusing on colorectal, abdominal wall, urologic, gynecologic, thoracic, bariatric, and selected cardiac procedures. Evidence on learning curves, conversion, perioperative stress and inflammatory responses, and comparisons between laparoscopy and robotics was integrated.

Results: Across many procedures, MIS has frequently been associated with lower short-term pain and opioid requirements, shorter hospitalization, and earlier mobilization compared with open surgery, although effects appear procedure and context dependent. Conversion from a minimally invasive procedure to an open operation, meaning cases that begin laparoscopically or robotically but must be completed through a larger incision, remains clinically relevant and may influence reported outcomes.

Conclusions: The current literature generally suggests that MIS is an important component of contemporary surgical care and a foundation for ongoing technological integration. Additional high-quality comparative studies and health-economic analyses may help define where robotic assistance provides meaningful added value.

Keywords: minimally invasive surgery; laparoscopic surgery; postoperative recovery; surgical outcomes; functional recovery; robotic surgery; clinical complications

1. Introduction

Minimally invasive surgery (MIS) includes operative approaches intended to achieve the therapeutic goals of open surgery while reducing access-related tissue trauma through smaller incisions, endoscopic visualization, and specialized instrumentation. In many contemporary pathways, the value of MIS is judged not only by perioperative safety and disease control but also by the pace and quality of return to function, including mobility, independence in daily activities, and health-related quality of life.

Clinical priorities have expanded in tandem with technological change. In addition to conventional laparoscopy and thoracoscopy, robotic-assisted platforms have extended beyond early niche applications and are now used across multiple abdominal and thoracic operations. An updated systematic review of robot-assisted surgery across thoracic and visceral procedures highlights that the evidence base remains variable, with procedure-specific differences in trial availability, effect direction, and the types of end points emphasized (clinical, functional, economic, and occupational) [66]. For this reason, minimally invasive surgery should not be considered a single entity, but a group of distinct techniques whose effects depend on procedure and context.

This narrative review examines core principles of MIS, procedure-level outcomes across major surgical specialties, and the relationship between MIS and postoperative functional recovery. A final section discusses current limitations, the transition toward robotic-assisted surgery, and areas where further research is needed.

2. Principles of Minimally Invasive Surgery

A defining principle of MIS is the attempt to limit access trauma by minimizing incision size, soft-tissue retraction, and wound surface area while preserving adequate exposure through image-guided visualization. From a recovery standpoint, these structural changes are commonly believed to reduce pain and facilitate earlier mobilization, although the magnitude of benefit often depends on the specific procedure, disease context, and perioperative care protocols.

In abdominal MIS, pneumoperitoneum is central because it creates operative workspace and can improve visualization, but it also influences cardiopulmonary physiology and may affect inflammatory signaling. The RECOVER randomized controlled trial evaluated low-pressure versus standard-pressure pneumoperitoneum during laparoscopic colorectal surgery and assessed quality of recovery as well as innate immune homeostasis, illustrating how intraoperative technical parameters can be studied as potentially modifiable determinants of recovery quality and physiologic homeostasis [4].

MIS performance depends heavily on instrumentation and the learning curve. Tasks such as intracorporeal suturing, complex dissection planes, and hemostasis under camera-based visualization can be technically demanding, making outcomes sensitive to surgeon experience and team coordination. In minimally invasive hepatectomy, a systematic review and meta-regression examined learning curves and compiled how operative performance metrics evolve as case volume increases [1]. Standardizing how learning curves are assessed and reported has been proposed as a way to improve comparability across centers and potentially guide safer dissemination of complex minimally invasive liver surgery [2]. In advanced colorectal surgery, learning curve evaluation has also been applied across laparoscopic, robot-assisted, and transanal total mesorectal excision approaches, supporting the idea that technique-specific proficiency trajectories should be considered when judging comparative outcomes and training requirements [3].

3. Clinical Applications Across Surgical Specialties

Evidence supporting MIS varies by specialty, disease context, and clinical endpoints. The studies summarized below illustrate how oncologic safety, perioperative morbidity, function-oriented outcomes, conversion, and evolving robotic integration have been evaluated across several high-volume procedures.

3.1 Laparoscopic colorectal surgery

In colon cancer, long-term randomized outcomes have compared laparoscopic and open colectomy. The long-term report from the Colon Cancer Laparoscopic or Open Resection trial provides a randomized benchmark for survival following laparoscopic versus open surgery in selected patients [17]. In locally advanced disease, adoption and effectiveness may be more variable. A population-based analysis described differences in effectiveness and use of laparoscopic surgery in locally advanced colon cancer, suggesting variability in uptake and outcomes across patient subgroups and care contexts [18]. These issues are relevant when considering minimally invasive approaches for more technically challenging disease. A meta-analysis focusing on locally advanced T4 colon cancer compared laparoscopic and open colectomy across clinical and oncologic outcomes, reflecting ongoing interest in defining boundaries of safe and effective minimally invasive resection in high-risk anatomy and tumor stage [19]. Population-based analyses have also compared short-term outcomes after laparoscopic versus open colon cancer surgery and have reported procedure-level advantages for laparoscopy in selected cohorts, though such findings can be sensitive to confounding by selection and institutional factors [20].

Rectal cancer surgery introduces additional technical complexity, including narrow pelvic anatomy and the need for high-quality mesorectal excision. A systematic review and meta-analysis compared short-term outcomes of laparoscopic versus open rectal excision, a domain particularly relevant for early recovery, length of stay, and complication burden [22]. Another meta-analysis focusing on randomized trials evaluated oncologic outcomes for laparoscopic versus open rectal resections, reflecting the need for oncologic safety appraisal when evaluating minimally invasive approaches in rectal cancer [23]. Trial-level evidence continues to expand; the LASRE randomized clinical trial compared laparoscopy-assisted and open surgery for low rectal cancer and reported short-term outcomes that help define the perioperative risk and recovery profile of minimally invasive rectal excision in a technically demanding subgroup [24]. A more recent systematic review and meta-analysis concluded that laparoscopy is non-inferior to open surgery for rectal cancer in its aggregated comparisons, while also underscoring how conclusions depend on inclusion criteria, trial design, and endpoints selected [25].

Conversion from minimally invasive to open colorectal surgery remains clinically important and can influence recovery trajectories. A focused review discussed conversion in laparoscopic colorectal cancer resections, raising clinically relevant questions about short-term outcomes and survival and emphasizing that conversion often reflects underlying complexity and therefore complicates interpretation [13]. Large-scale prospective audit data from the European Society of Coloproctology evaluated the impact of conversion on the risk of major complications following laparoscopic colonic surgery, strengthening the evidence base around conversion as a meaningful event for outcomes and quality measurement [14].

Robotic colorectal approaches have been studied as an extension of MIS, often motivated by the desire to improve instrument dexterity and visualization in pelvic work. A randomized trial evaluating surgical stress response in robot-assisted versus laparoscopic colon cancer surgery illustrates that platform comparisons can be assessed through physiologic and inflammatory markers in addition to traditional endpoints [7]. For clinical effectiveness, a trial sequential meta-analysis of randomized trials comparing robotic and laparoscopic colorectal cancer surgery provides a structured approach to evaluating when evidence is sufficient and where uncertainty remains due to sample size and event rates [26]. A systematic review, meta-analysis, and meta-regression incorporating randomized trial data has also compared robotic and laparoscopic surgery for colorectal disease, reflecting ongoing efforts to connect technical differences to clinical outcomes and to explain variability across trial designs and patient groups [28].

3.2 Laparoscopic hernia repair

Inguinal hernia repair is high volume and therefore a key context for evaluating recovery outcomes such as pain and time to return to usual activities. An overview of systematic reviews of randomized trials compared open and laparoscopic inguinal hernia repair and brought together outcomes relevant to chronic symptoms and recurrence, while also emphasizing variability in technique and follow-up [33]. Within laparoscopic inguinal hernia repair, a Cochrane review compared transabdominal preperitoneal (TAPP) and totally extraperitoneal (TEP) techniques, supporting technique-specific decision-making and underscoring that “laparoscopic repair” is not a single uniform intervention [34]. Robotic inguinal hernia repair has been evaluated as well. A meta-analysis compared robotic-assisted and laparoscopic TAPP repair for inguinal hernia and articulated effectiveness and safety outcomes relevant to platform selection [35]. Randomized data also exist: the ROGER trial compared robotic and laparoscopic minimally invasive inguinal hernia repair, providing direct evidence on comparative short-term outcomes and recovery metrics [36].

For ventral hernia, a multicenter, blinded randomized trial compared robotic and laparoscopic ventral hernia repair, strengthening causal inference for recovery-related and complication outcomes in a technically variable field [37]. A systematic review and meta-analysis comparing open and laparoscopic approaches for primary ventral hernia repair provides broader comparative data and may inform shared decision-making when randomized comparisons are limited by technique variability and center effects [38].

3.3 Radical prostatectomy

In prostate cancer surgery, urinary continence and sexual function are central functional recovery domains, and quality-of-life endpoints can be particularly salient for patient counseling. The LAP-01 multicenter randomized controlled trial compared quality of life after robotic-assisted and laparoscopic radical prostatectomy and illustrates the feasibility of randomized design for patient-centered recovery outcomes in a procedure where early perioperative differences may be subtle [45]. Comparative analyses across study designs have further informed this field. A systematic review and meta-analysis integrating randomized and non-randomized studies compared robotic-assisted and laparoscopic radical prostatectomy and evaluated both perioperative and functional recovery outcomes [46]. Another meta-analysis examined oncologic and functional results together, underscoring that radical prostatectomy cannot be assessed by a single endpoint alone [48].

3.4 Hysterectomy and minimally invasive gynecologic surgery

For benign gynecologic disease, a Cochrane review compared hysterectomy approaches and assessed outcomes relevant to complications, pain, and return to normal activity [39]. The LAVA randomized controlled trial compared laparoscopic and open abdominal hysterectomy for benign conditions and provides trial evidence relevant to recovery profiles, adverse events, and health service utilization [40]. In gynecologic oncology, a Cochrane review compared laparoscopy and laparotomy for early-stage endometrial cancer, reflecting the recurring need to balance oncologic safety, staging objectives, and recovery outcomes in surgical oncology decision-making [41]. Cervical cancer surgery highlights that minimally invasive access may not be uniformly favored across tumor types and procedure extents; a secondary outcome analysis from the LACC trial evaluated quality-of-life outcomes after open versus minimally invasive radical hysterectomy, underscoring that patient-reported recovery can be evaluated even when oncologic debates dominate clinical decision-making [43]. Professional guidance has also addressed robotics in benign gynecology, including considerations related to training, credentialing, and resource use, as summarized in a committee opinion from American College of Obstetricians and Gynecologists and the Society of Gynecologic Surgeons [44].

3.5 Thoracic minimally invasive surgery

Thoracoscopic approaches for pulmonary lobectomy have been evaluated against open thoracotomy for safety and survival. A systematic review and meta-analysis compared survival after thoracoscopic surgery and open lobectomy, supporting the feasibility of thoracoscopic resection in selected lung cancer populations [49]. As robotics expands in thoracic surgery, comparative evidence has accumulated. A meta-analysis comparing robot-assisted thoracic surgery and video-assisted thoracoscopic surgery (VATS) for lobectomy or segmentectomy in non-small cell lung cancer evaluated perioperative and oncologic outcomes [50]. An updated systematic review and meta-analysis further compared robotic and VATS lung resection, offering additional comparative data that may reflect evolving technology platforms and case selection patterns over time [51]. Long-term outcomes have also been assessed using reconstructed patient data in systematic review form, comparing robotic and VATS lobectomy and extending analysis beyond early morbidity to longer-term cancer outcomes and survival measures [53].

3.6 Bariatric surgery

Bariatric surgery is predominantly performed laparoscopically, and robotic platforms are increasingly used in some centers. Analyses have reported clinically comparable outcomes between robotic-assisted and laparoscopic bariatric surgeries in contemporary practice, providing a basis for evaluating robotics adoption under conditions where early outcome differences may be limited [30]. Procedure-specific evidence supports a more granular appraisal. A systematic review and meta-analysis compared primary robotic and conventional laparoscopic Roux-en-Y gastric bypass, evaluating outcomes relevant to both safety and recovery [31]. In contrast, an 8-year analysis reported higher complication rates for robotic sleeve gastrectomy compared with laparoscopic sleeve gastrectomy, illustrating that robotic adoption does not necessarily confer uniform benefits and that adverse event profiles require procedure-specific scrutiny [32].

3.7 Minimally invasive cardiac surgery

A systematic review and meta-analysis compared right lateral minithoracotomy and sternotomy and evaluated recovery-related outcomes, including complications and resource use [54]. High-quality comparative evidence includes the UK Mini Mitral multicenter randomized trial comparing thoracoscopically guided right minithoracotomy and conventional sternotomy for mitral valve repair, supporting evaluation of minimally invasive access through randomized health-technology assessment methods and pragmatic end points [55]. Robotic mitral valve repair represents another extension of minimally invasive access. A decade of experience with echocardiographic follow-up demonstrates programmatic feasibility for long-term assessment in a technically complex robotic repair pathway [56]. Comparative and indication-focused analyses have evaluated robotic mitral repair for degenerative mitral regurgitation [57] and have compared robotic repair with sternotomy in older adults using adjusted analyses, informing discussions about whether minimally invasive and robotic options may offer differential benefits across age and risk strata [58].

For coronary revascularization, technique options include conventional on-pump CABG, off-pump CABG, and related variants. A network meta-analysis of randomized controlled trials compared outcomes across conventional CABG, off-pump CABG, and on-beat techniques, providing a comparative framework for interpreting technique selection and recovery trade-offs [59].

4. Impact on Postoperative Functional Recovery

Postoperative functional recovery can be conceptualized as the pace and completeness with which patients regain mobility, self-care capacity, and usual activities, while experiencing acceptable symptom control and adverse event burden. Pain and opioid exposure are particularly relevant because they can influence mobilization, sleep, ileus, and engagement in rehabilitation. Evidence summaries from the PROSPECT Working Group have emphasized that surgical technique is one determinant of postoperative pain in abdominal surgery, supporting a link between access strategy, tissue handling, analgesic requirements, and early recovery milestones [5]. An additional analysis of two randomized trials examined the relationship between pain, opioid use, and postoperative mobilization, suggesting that effective pain control and opioid stewardship may influence early recovery [8].

Physiologic stress and inflammatory responses have been studied as mechanistic correlates of recovery. A systematic review and meta-analysis characterized the cortisol stress response induced by surgery and highlighted variability across procedures and study designs, providing a biologic rationale for evaluating whether access strategy or technique can modulate endocrine stress responses in certain contexts [6]. Vascular surgery offers a relevant example beyond typical abdominal and pelvic MIS comparisons: a randomized trial substudy compared the acute-phase response after laparoscopic versus open aortobifemoral bypass surgery, suggesting that access strategy can be examined in relation to inflammatory pathways and early physiologic recovery domains [12]. In colorectal surgery, inflammatory kinetics have also been evaluated. A substudy from a randomized clinical trial examined C-reactive protein as a predictor of major postoperative complications and explored whether predictive dynamics differ between open and minimally invasive colorectal surgery, linking biomarker surveillance to outcome prediction and potentially recovery trajectory [9].

Patient-reported outcomes provide an integrated view of recovery that can persist beyond discharge. In gastric cancer surgery, randomized trial evidence comparing open and minimally invasive total gastrectomy evaluated health-related quality of life, demonstrating how operations with major physiologic impact can be assessed against longer-term symptom burden and functional well-being rather than only early event rates [10]. A secondary analysis from the LOGICA randomized trial compared pain and opioid consumption after laparoscopic versus open gastrectomy, underscoring that early pain outcomes remain measurable and relevant in major oncologic operations and can plausibly influence early function [11]. In gynecologic oncology, a randomized trial compared markers of tissue damage and inflammation after robotic and abdominal hysterectomy in early endometrial cancer, illustrating how biologic markers can be used to complement patient-centered recovery outcomes and potentially provide mechanistic interpretation for observed recovery differences [42].

Taken together, these data support the plausibility that MIS can contribute to accelerated early functional recovery through reduced pain, lower opioid requirements, and potentially altered physiologic stress and inflammatory responses. However, recovery measurement remains variable across studies, and future comparative work may benefit from harmonized endpoints that integrate patient-reported recovery measures, objective mobility metrics, and mechanistic physiologic markers.

4.1 Enhanced Recovery After Surgery (ERAS) Pathways

Recovery endpoints after minimally invasive surgery are influenced not only by operative access but also by perioperative care pathways that prioritize early mobilization, opioid-sparing analgesia, and supportive physiologic recovery principles often grouped under Enhanced Recovery After Surgery (ERAS) frameworks. Evidence in your reference set supports that perioperative physiology and stress signaling are measurable and clinically relevant contexts for interpreting recovery. A systematic review and meta-analysis describes the surgical cortisol stress response across procedures, supporting the broader premise that perioperative management interfaces with endocrine stress pathways [6]. Within minimally invasive colorectal surgery, recovery-focused outcomes have also been evaluated through measures of postoperative quality and immune homeostasis, indicating that intraoperative and perioperative choices can be linked to recovery-relevant profiles [4]. In addition, systematic evidence from PROSPECT reviews addresses how surgical and perioperative technique selection contributes to postoperative pain reduction in abdominal surgery, which is directly relevant to pathway-based recovery goals [5].

Clinical trials and secondary analyses in your reference list further support cautious interpretation of recovery metrics as multifactorial rather than solely technique-dependent. Post hoc trial analyses have examined associations between pain, opioid consumption, and mobilization, reinforcing that mobilization, a core recovery endpoint often targeted by ERAS-type approaches, tracks with perioperative analgesic patterns [8]. Procedure-specific randomized data in gastric surgery similarly evaluate pain and opioid consumption after laparoscopic versus open approaches, highlighting that recovery trajectories can be assessed through analgesia-linked endpoints rather than length of stay alone [11]. Finally, platform comparisons in colon cancer have evaluated surgical stress response between robotic-assisted and laparoscopic surgery, illustrating that perioperative physiologic endpoints can be used to contextualize downstream recovery differences without assuming a single causal driver [7]. Taken together, these findings support framing postoperative recovery as arising from an interaction between operative approach and perioperative management, while avoiding over-attribution of recovery differences to access technique alone [4–8,11].

5. Limitations and Transition Toward Robotic-Assisted Surgery

Minimally invasive surgery has expanded across multiple specialties and clinical contexts. However, interpretation of outcomes and implementation across healthcare systems require careful consideration of methodological, technical, and economic constraints. Limitations inherent to laparoscopy, as well as system-level factors influencing adoption, shape both clinical results and the evolving transition toward robotic-assisted platforms.

5.1. Limitations and implementation challenges

Several limitations influence both how MIS is implemented and how comparative outcomes should be interpreted. Access technique is only one contributor to recovery, and differences in perioperative pathways, analgesic protocols, discharge criteria, and rehabilitation resources may modify or overshadow access-related effects.

Some potential benefits of MIS may be counterbalanced by longer operative times during early adoption phases, technical constraints in certain anatomies, and the resource requirements associated with specialized equipment and team training.

Conversion to open surgery represents a recurring practical and interpretive challenge. Even in common index operations such as cholecystectomy, conversion risk is influenced by patient factors and anatomical difficulty. A systematic review and meta-analysis identified preoperative risk factors associated with conversion from laparoscopic to open cholecystectomy, illustrating that conversion risk may be partially anticipated during patient selection and preoperative planning and that conversions frequently reflect operative complexity rather than isolated technical failure [16].

In addition to conversion, safety considerations may arise when new platforms diffuse into routine practice. A national comparative analysis assessed safety outcomes of robotic-assisted versus laparoscopic cholecystectomy and provided a population-level evaluation of adverse events, reinforcing the importance of structured monitoring during periods of technological adoption [63].

Economic constraints remain a major limitation. MIS frequently requires specialized instrumentation, and incremental costs may become particularly relevant when technologies expand beyond high-volume anchor indications. A systematic review and meta-analysis comparing minimally invasive and open pancreatic resections demonstrated that cost-effectiveness is context-dependent and influenced by complication rates, length of stay, and local cost structures [61].

Furthermore, national analyses comparing robotic-assisted and laparoscopic abdominal operations have shown persistent cost differentials between platforms, suggesting that financial considerations may significantly influence implementation strategies and institutional adoption patterns [62].

Collectively, these constraints indicate that reported advantages in postoperative recovery should be interpreted alongside transparent evaluation of resource utilization and local healthcare system capacity.

5.2. Transition toward robotics

Robotic-assisted surgery is often described as a technological evolution intended to address perceived limitations of conventional laparoscopy, including restricted instrument articulation, ergonomics, and two-dimensional visualization. Randomized controlled trials across abdominal and pelvic surgery have been summarized in systematic reviews, indicating that differences between robotic and laparoscopic surgery are procedure-specific and that additional benefits vary by indication [64].

Earlier meta-analyses of randomized trials similarly reported that robot-assisted surgery does not consistently show superior results and that differences often depend on procedural complexity and the outcomes measured [65].

Adoption of robotic platforms is influenced not only by patient-level outcomes but also by occupational and institutional factors. National cost analyses have documented persistent disparities in hospitalization costs between robotic and laparoscopic approaches, with widening differentials over time in some procedural categories [62].

Ergonomic and cognitive considerations may also contribute to platform selection. A systematic review examining musculoskeletal and cognitive demands in minimally invasive surgery compared conventional laparoscopy and robotic-assisted approaches and suggested that robotic systems may reduce surgeon strain in selected contexts [67]. Complementary empirical investigation evaluating muscular load, cardiovascular demand, posture, perceived workload, and discomfort during robotic versus laparoscopic surgery further expanded understanding of occupational implications associated with platform choice [68].

Taken together, the transition toward robotics may be interpreted as a response to both technical and occupational constraints of conventional laparoscopy. However, the magnitude and consistency of patient-level recovery benefits remain variable and appear dependent on procedural context. Continued evaluation through procedure-specific trials, high-quality registries, structured economic analyses, and standardized training frameworks remains important as robotic platforms continue to diffuse within surgical practice.

5.3 Cost and Cost-Effectiveness Considerations in Robotic vs Laparoscopic Surgery

Robot-assisted surgery is frequently discussed in terms of incremental clinical benefit relative to additional resource use, and cost considerations may be relevant when interpreting platform adoption across specialties. A national analysis of major abdominal operations reported higher hospitalization costs for robotic-assisted procedures compared with laparoscopic approaches, while differences in complications and length of stay were comparatively modest and varied by procedure type [62]. These findings support treating cost as an explicit dimension of platform comparison rather than an implicit assumption, particularly when outcomes are otherwise similar across minimally invasive approaches.

Economic evaluations in rectal cancer surgery have also attempted to compare open, laparoscopic, robotic-assisted, and transanal total mesorectal excision, highlighting that cost estimates depend on study design and the included cost components such as operative time, consumables, and downstream resource utilization [27]. Broader value appraisals in minimally invasive surgery further suggest that "cost-effectiveness" may shift depending on the comparator and procedure context, including whether the alternative is open surgery or another minimally invasive approach, and whether differences in recovery translate into measurable reductions in complications or length of stay [61]. In practice, these data support a cautious interpretation in which potential advantages of robotic platforms are considered alongside resource implications, and where conclusions remain procedure-specific rather than generalized across all robotic applications [27,62].

6. Discussion and Conclusions

Across specialties, minimally invasive surgery is often associated with improved early recovery, including better pain control, earlier mobilization, and shorter hospital stay. Longer-term outcomes and patient-reported well-being, however, vary by procedure and are influenced by disease stage, complications, and perioperative care. A practical implication is that "MIS benefit" should be communicated as conditional, dependent on procedure, disease context, and institutional experience, rather than assumed to be uniform across specialties.

Conversion and approach selection illustrate the importance of context. A multicenter analysis across ten common procedures in different specialties evaluated how the type of minimally invasive approach influences open conversion patterns, suggesting that conversion is not solely a patient or pathology factor but is also shaped by platform choice, procedure type, and program implementation features [15]. In colorectal oncology, long-term analyses have examined whether recurrence patterns differ after laparoscopic versus open surgery by evaluating recurrence over time. This approach provides a lens on time-dependent oncologic outcomes and highlights the value of evaluating recurrence beyond binary "recurrence yes or no" endpoints [21].

Long-term outcomes in other domains reinforce the need for extended follow-up. In urology, a prospective randomized trial reported ten-year functional and oncologic outcomes comparing laparoscopic and robot-assisted radical prostatectomy, supporting the feasibility of long-horizon evaluation for both cancer control and functional recovery domains such as continence and potency [47]. In thoracic surgery, a large multicenter cohort study compared ninety-day mortality after thoracoscopic versus open lobectomy, extending the safety discussion beyond in-hospital and 30-day endpoints and reinforcing the role of longer perioperative windows for capturing clinically meaningful postoperative events [52]. In cardiac surgery, a large cohort study reported long-term survival, cardiovascular, and functional outcomes after minimally invasive coronary artery bypass grafting, providing evidence beyond short-term morbidity and highlighting that functional outcomes can be tracked longitudinally in minimally invasive cardiac programs [60].

Healthcare system implications are increasingly central as MIS and robotics diffuse in settings with constrained operating room capacity and variable access to capital-intensive technology.

In rectal cancer, an economic analysis compared open, laparoscopic, robot-assisted, and transanal total mesorectal excision and evaluated economic outcomes and cost drivers, supporting the view that advanced minimally invasive approaches should be assessed not only for clinical endpoints but also for resource use and cost-effectiveness [27]. As robotic adoption grows in bariatric surgery, efforts to define global benchmarks for primary robotic bariatric procedures have been proposed, suggesting one strategy for quality measurement and transparency as volumes increase across diverse health systems [29].

Conclusions: The referenced literature is broadly consistent with MIS being a major component of contemporary surgical practice across multiple specialties, with frequent reported associations with improved early functional recovery and patient-centered recovery outcomes. At the same time, variability in outcomes, learning curve effects, conversion risk, procedure-specific safety signals, and health-system resource constraints argue for continued procedure-level evaluation and careful implementation. Future research priorities include (i) higher-quality, adequately powered comparisons where uncertainty remains, (ii) standardized recovery endpoints that are comparable across trials, and (iii) transparent integration of economic and occupational outcomes into technology assessments.

Disclosure

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