

Smartband use during enhanced recovery after surgery facilitates inpatient recuperation following minimally invasive colorectal surgery

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Abstract

Background Enhanced recovery after surgery (ERAS) is valuable in perioperative care for its ability to improve short-term surgical outcomes and facilitate patient recuperation after major surgery. Early postoperative mobilization is a vital component of the integrated care pathway and is a factor strongly associated with successful outcomes. However, early mobilization still has various definitions and lacks specific strategies.

Methods Patients who underwent minimally invasive surgery for colorectal cancer followed our perioperative ERAS program, including mobilization from the first postoperative day. After perioperative care skills were improved in our well-established program, compliance, inpatient surgical outcomes, and complications associated with adding smartband use were evaluated and compared with the outcomes for standard protocol. Quality of recovery was evaluated using patient-rated QoR-40 questionnaires the day before surgery, on postoperative day 1 and 3, and on the day of discharge.

Results Smartband use after minimally invasive colorectal surgery failed to increase compliance with early mobilization or reduce the occurrence of postoperative complications significantly compared with standard ERAS protocol. However, when smartbands were utilized, quality of recovery was optimized and patients returned to their preoperative status earlier, at postoperative day 3. The duration of theoretical hospital stays and hospital stays of uncomplicated patients wearing smartbands was also reduced by 1.1 and 0.9 days, respectively ($P = 0.0091$ and 0.049).

Conclusions Smartbands enable enhanced communication between patients and surgical teams and strengthen self-management in patients undergoing minimally invasive colorectal resection surgery. Accelerated recovery to preoperative functional status can be facilitated by integrating smartbands into the process of early mobilization during ERAS.

Background

For both malignant and benign diseases, the most common postoperative complications after colorectal surgery are prolonged ileus, pneumonia, difficulty weaning from ventilation, and urinary tract infection. Minimally invasive surgery (MIS) improves some short-term surgical outcomes (fewer wound infections and lower wound dehiscence rate) and long-term outcomes (fewer early and late postoperative bowel obstructions). However, the typical length of hospital stay (LOS) after major colorectal surgery still varies.

Since the 1990s, alongside the development of regional anesthetic techniques and the widespread use of minimally invasive laparoscopic techniques, the concept of enhanced recovery after surgery (ERAS) has also become increasingly valued. The original ERAS study group was established in 2001 to improve patients' recovery after major operations (1). In 2010, the ERAS society was founded in Sweden; thereafter, the guidelines for an integrated care pathway for colonic and rectal resection were outlined in 2012. These combined a range of simple evidence-based interventions aimed at improving postoperative recovery for patients of major colorectal surgery. Early mobilization is one intervention that is significantly associated with successful ERAS outcomes (2). Although no randomized control trial has supported the direct benefits of postoperative mobilization, prolonged immobilization increases the risk of pneumonia, insulin resistance, and muscle weakness (3). However, early mobilization still varies in definition and lacks specific strategies. The autonomy and involvement of patients are difficult to assess objectively. The discrepancy between instruction and actual practice may further interfere the effectiveness of this important element and the quality of recovery.

Wearable devices are popular and commonly used in outdoor sports. They are also increasingly being used in medical contexts. For example, the use of step counters in patients of obstructive lung disease increases physical activity and improves exercise capacity (4). The use and feasibility of wearable activity trackers to monitor and enhance postoperative early mobilization was also evaluated in a trial regarding to major visceral surgery (5). This article investigates whether smartbands, a popular wearable device, are helpful in ERAS programs and improve recovery in patients receiving MIS for colorectal resection.

Methods

This was a prospective nonrandomized study. Patients who had undergone MIS for colorectal cancer in a single tertiary medical center by an identical colorectal surgical team were eligible for inclusion in this study. Patients were excluded if they were aged <18 years or >80 years, had an American Society of Anesthesiologist (ASA) classification of ≥ 4 , could not fully understand or follow instructions, had difficulty completing the required questionnaire, had received emergency operations, or were admitted to the intensive care unit after operation. This study was approved by the institutional review board of our hospital (KMUHIRB-F(II)-20180098). Informed consent was obtained from each patient before the integrated care pathway was carried out. All of the patients followed our perioperative ERAS protocol for elective colonic or rectal surgery, as recommended by the ERAS society (3, 6). At least 2 members of our surgical team evaluated each patient's discharge safety. Patients were allowed to leave the hospital after they had met all of the associated criteria (adequate pain control with non-opioid oral analgesic medication, absence of fever, adequate oral intake, passage of stool, mobilization as preoperative status) and accepted of discharge. To adjust for the

potential impact of nonmedical variables (ie, social problem, nursing home waiting list, etc) on LOS, a theoretical LOS was also assessed, regardless of acceptance by patients when they complied with the predefined discharge criteria (7).

All patients whose data underwent analysis were allocated serial numbers and were grouped into 3 sequential stages: patients 1–30 formed the initialization stage (stage 1), 31–60 formed the maturation stage (stage 2), and 61–90 formed the experimental stage (stage 3) and were assigned smartbands (Xiaomi Mi 2[®], Xiaomi Corp., China) every day postoperatively (Figure 1). Namely, stage 2 and 3 represented that the perioperative care skill was mature and the ERAS program was well-established, while stage 1 represented that the program was initially operated and the skill was still raw. The primary endpoint of this study was the compliance of ERAS program, especially focused on that of early mobilization. The secondary endpoint was short-term surgical outcomes and quality of recovery. Patients' characteristics, compliance with each protocol item, and short-term surgical outcomes (including LOS, time to recovery of bowel function, time to resuming oral intake, 30-day complications, and readmission) were compared for each stage. The quality of recovery was compared between stages 2 and 3.

ERAS protocol of our practice

1. Detailed preoperative information, education, and counseling should be provided.
2. Patients should abstain from smoking for the 24 h preceding surgery.
3. Routine mechanical bowel preparation (MBP) should not be applied for right-side colonic surgery; oral antibiotics should be combined with MBP in left-side colonic surgery.
4. Routine prophylaxis with intravenous antibiotics should be administered 30–60 min before colorectal surgery.
5. A standard anesthetic protocol for rapid awakening should be used.
6. Normothermia should be maintained intraoperatively.
7. Fentanyl (a short-acting opioid) patient-controlled analgesia (PCA) is recommended. If intravenous opioids are used, the dose should be titrated to minimize the risk of side effects.
8. A multimodal approach to postoperative nausea and vomiting (PONV) prophylaxis should be adopted for all patients.
9. Postoperative nasogastric (NG) tubes should not be used routinely. NG tubes inserted during surgery should be removed before anesthesia reversal.
10. Transurethral bladder drainage within 1 day after colonic surgery and 3 days after rectal surgery is recommended.
11. Postoperative ileus should be prevented (including use of postoperative laxatives).
12. Postoperative multimodal analgesia should be used to limit the use of opioids.
13. Postoperative early enteral feeding should be undertaken (clear liquid diet within 24 h and full diet within 48 h).
14. Intravenous fluids should be discontinued as soon as is practicable.
15. Early mobilization should be encouraged.

Smartbands

All participants were instructed to be active from postoperative day 1 (POD1). Standard care dictated at least 30 min of out-of-bed activity at POD1 and 1 h thereafter. Patients in stage 3 wore Xiaomi Mi bands on their wrists postoperatively. The cumulative number of steps taken, walking time, and walking distance were displayed on the screen and could easily be read by patients or their caregivers. Our team recorded the parameters daily using smartphones and apps (Mi Band App).

Quality of recovery score

The quality of recovery score (QoR-40) is a recovery-specific and patient-rated questionnaire containing 40 items measuring 5 dimensions: physical comfort (12 items), emotional state (9 items), physical independence (5 items), psychological support (7 items), and pain (7 items). The QoR-40 was originally developed and validated in Australia in 2000 (8). The total score and those for subscales of the QoR-40 are measured using a 5-point Likert scale (for positive items: 1 = *none of the time*, and 5 = *all of the time*; for negative items, the scoring is reversed). Individual scores are then summed, with the minimum and maximum scores being 40 and 200 points, respectively. The QoR-40 has also been validated in east Asian countries for evaluating the quality of recovery after surgery and the quality of anesthesia methods, (9, 10). Patients in our study completed the questionnaire the day before operation (baseline), on POD1, on POD3, and on the day of discharge.

Statistical analysis

Qualitative variables are expressed as numbers and percentages, and quantitative variables are expressed as the median and standard deviation (SD). Comparisons between stages were performed using the χ^2 test for categorical variables and the F-test for quantitative variables. Tukey's honest significance test was used for post hoc testing between each pair of stages. For comparison of QoR-40 test scores, Student's *t*

test was used to evaluate changes between measurements. The α error was set at 0.05. Statistical analysis was performed using JMP 13.0.0 (SAS Institute, Cary, NC, USA) for Windows. A P value of <0.05 was considered statistically significant.

Results

Data were collected from May 2017 to February 2019. A total of 105 patients were enrolled for evaluation of eligibility, and 90 patients entered the ERAS protocol and were ultimately analyzed (Table 1). Early mobilization was observed in 20 (66.7%) patients in stage 1, and this proportion increased to 80% in stage 2. Of the patients in stage 3 wearing smartbands, 25 (83.3%) achieved early mobilization. Compliance with respect to early mobilization was not significantly increased in patients with smartbands compared with patients without them (Table 2). All patients but one consumed clear liquid diets for the 24 h preceding surgery and took commercial Bowklean[®] powder suspension (magnesium oxide + sodium picosulfate + citric acid anhydrous; Genovate Biotechnology, Taiwan) in split doses for MBP. Oral metronidazole and neomycin were added to the MBP. PCA with intravenous fentanyl was used in 10, 13, and 20 (33.3%, 43.3%, and 66.7%) patients in stage 1, 2, and 3, respectively, for 3 days (range 2–4 days) postoperatively. Widespread use of PCA was discouraged mostly due to personal consideration of patients. Multimodal analgesia was applied to all patients to avoid excessive opioid use. However, 9 (30%), 2 (6.7%), and 4 (13.3%) patients in stages 1, 2, and 3, respectively, received additional opioid treatment postoperatively for pain relief. Significantly lower proportions of patients received additional opioid treatment in stages 2 and 3 compared with the proportion of patients receiving opioid treatment in stage 1 ($P = 0.0452$). Removal of transurethral bladder drainage 1 day after colonic surgery and 3 days after rectal surgery was recommended. At least 90% of patients in each stage followed this recommendation, and only one episode of urinary retention was recorded. The prohibition of routine NG tube use was adhered to. If decompression was indicated, the NG tubes were removed before reversal of anesthesia. This was undertaken in 23, 24, and 29 (76.7%, 80%, and 96.7%) patients in stages 1, 2, and 3, respectively, and compliance was significantly improved ($P = 0.0405$) after the implementation of ERAS. In terms of diet, 87 of 90 (96.7%) patients resumed early enteral feeding, starting with a clear liquid diet 24 h after operation. The goal of a full diet within 48 h postoperatively was achieved for 86.7% to 93.3% of patients. After improvement of our skill in ERAS protocol, compliance was greater than or equal to 80% for all items, except for the PCA ratio after stage 2 (stage 2 and 3).

The mean total LOS in stage 1 was 11.4 days (SD = 2.8 days), which significantly decreased to 10.1 days (SD = 1.0 days; $P = 0.0230$) in stage 2 and to 10.0 days (SD = 1.3 days; $P = 0.0159$) in stage 3 (Table 3 and Figure 2a). The total LOS in stage 3 and in stage 2 was almost identical ($P = 0.9896$). After cases with complications were excluded, the LOS in uncomplicated patients decreased from 10.7 days (SD = 2.1 days) in stage 1 to 10.0 days (SD = 0.9 days) in stage 2, without statistical significance ($P = 0.1800$). However, the LOS of uncomplicated patients wearing smartbands in stage 3 exhibited a further decrease to 9.8 days (SD = 0.7 days) compared with stage 1 ($P = 0.0489$). Theoretical LOS also significantly shortened from 8.9 days (SD = 1.6 days) in stage 1 to 7.8 days (SD = 1.4 days) in stage 3 ($P = 0.0091$). Meanwhile, theoretical LOS in stage 2 was 8.5 days (SD = 1.0 days) without significant decreasing compared with that in stage 1 ($P = 0.4396$). The time to recovery of bowel function, including time to flatus passage and time to stool passage, was not shortened after implementation of the ERAS protocol or after introduction of smartbands during perioperative care. Patients started to drink clear liquid 1 day after MIS in stages 1 and 2. A full diet was resumed 2.6 days (SD = 1.4 days) postoperatively in stage 1 and 2.1 days (SD = 0.6 days; $P = 0.1265$) in stage 2. Patients in stage 3 had similar outcomes in early enteral feeding compared with those in stage 2.

The number of complications in each stage in our study tended to decrease after implementation of ERAS (Figure 2b). The total complication rate was 13.3%, 10.0%, and 6.7% in stages 1, 2, and 3, respectively ($P = 0.6860$). In stage 1, 4 cases had complications. Symptomatic anastomotic leakage was observed 6 days after robotic LAR in a 46-year-old male patient, and he developed deep surgical site infection (SSI) and sepsis with a total LOS of 19 days. Another 3 patients developed chylous ascites with ileus, urinary tract infection, and pneumonia, respectively. In stage 2, 3 medical complications were observed. A 60-year-old female patient who received concurrent chemoradiotherapy and robotic LAR exhibited intraabdominal infection (IAI) and ileus after being discharged from her ward (postoperative LOS, 6 days). She was readmitted for antibiotic treatment. SSI and prolonged postoperative ileus developed in a 61-year-old male patient with diabetes. Acute urinary retention is another example of complications occurring in stage 2. A 59-year-old female patient with a BMI of 30 who received laparoscopic RH in stage 3 developed anastomotic leakage and severe IAI. Reoperation was performed with a total LOS of 16 days. A patient in stage 3 also experienced prolonged ileus.

To evaluate the quality of recovery after surgery and anesthesia, QoR-40 was used to measure each patient's health status preoperatively, at POD1, at POD3, and on the day of discharge. Scores were compared only between stages 2 and 3 when the enhanced recovery program had been well established and ERAS skills were enhanced in our surgical team. In the stage 2 group, the preoperative total baseline score was 178.3 points, and this decreased to a minimum of 156.8 points at POD1 (–21.5 points, $P < 0.0001$; Table 4 and Figure 3). All dimensions decreased synchronously except for psychological support. The total score recovered to 170.4 points (–7.9 points) by POD3, but this was still significantly lower than the baseline score ($P = 0.0463$). The scores for emotional state (35.1 points, –2.9, $P = 0.0370$) and physical independence (19.6 points, –3.8, $P < 0.0001$) remained much lower than they had been preoperatively. Scores in all dimensions returned to or were better than baseline scores by the day of discharge. The total score was 181.9 points (plus 3.6, $P = 0.3692$) at the day of discharge in the stage 2 group.

QoR-40 score was also recorded in stage 3 when patients were assigned to wear smartbands postoperatively. The total preoperative score was 182.1 points; similarly, this significantly declined to a minimum of 161.9 (-20.2 , $P < 0.0001$) by POD1. At POD3, the total score and scores for all 5 dimensions recovered to the baseline level. The scores for emotional state (37.5 points, -1.9 , $P = 0.1749$) and physical independence (22.0 points, -1.2 , $P = 0.1822$) in POD3 seemed to improve more rapidly postoperatively after the introduction of smartbands into ERAS perioperative care. Compared with the total QoR-40 score of patients in stage 2, that of patients in stage 3 recovered to an adequate level by POD3 (175.4 points, -6.8 , $P = 0.0988$). The average score on the day of discharge was 183.5 points, 1.4 points higher than the baseline score ($P = 0.7409$), with all dimensions exhibiting recovery to baseline of higher scores.

Discussion

Wearable devices have wide-ranging clinical applications, including cardiopulmonary and vascular monitoring, glucose monitoring, neurological function monitoring, physical therapy, and rehabilitation. Smartbands augment the physician–patient relationship, increase the autonomy and involvement of patients with respect to their health care, and enable the application of novel remote monitoring techniques (11). In the management of osteoarthritis, wearable devices exert psychosocial effects by improving clinician–patient communication and empowering patients to undertake self-management (12).

In the current study, the integration of smartbands into a perioperative ERAS program did not significantly increase patient compliance in terms of early mobilization. The effect of integrating smartbands into an ERAS program on the short-term surgical outcomes and quality of recovery might work in a different way other than increasing patient compliance of early mobilization. Through exchangeable and objective information, smartbands ostensibly enable more effective communication between patients and surgical teams, and they enhance self-management in patients receiving MIS for colorectal resection. Earlier return to preoperative functional status, especially with respect to emotional state and physical independence, was facilitated at POD3 through postoperative smartband use. LOS in uncomplicated patients and theoretical LOS decreased after introduction of smartbands in our well-established ERAS program. Further reduced effective LOS was not observed in this study but is reasonably anticipated.

ERAS is composed of 10 to more than 20 elements. These perioperative care measures are usually divided into 3 phases: preoperative, intraoperative, and postoperative. Only a few involve the surgical procedure itself, but several diverge from conventional perioperative care. Several meta-analyses and systemic reviews have compared the ERAS program to traditional care for colorectal surgery (13). Zhuang *et al.* reviewed 13 randomized control trials with at least 7 documented ERAS elements and concluded that ERAS reduced LOS (by 2–3 days) without increasing the readmission rate. It also reduced the occurrence of general and medical complications. Mortality rate was not higher than that observed in conventional care, and bowel function recovery was faster (1 day) with ERAS (14).

The introduction of the ERAS protocol in perioperative care for laparoscopic colorectal surgery is a gradual process. The average compliance improves the longer an ERAS protocol has been active. LOS is inversely correlated with compliance. Pedziwiatr *et al.* reported that at least 30 patients and a period of 6 months were required to meet an average compliance level of 80% (15). This conclusion informed the basic design of our study.

With consideration of health economics and quality of life, ERAS can be recommended because it is likely to reduce costs and improve the quality of recovery. To assess the quality of life after surgery for colorectal cancer, King *et al.* used the European Organisation for Research and Treatment of Cancer core quality of life questionnaire (colorectal module), a valid measure that has been used on in cancer patients. The role function score, physical functional score, pain score, and fatigue score tended to demonstrate more favorable results in enhanced recovery programs than in conventional care (16).

Early mobilization is a crucial ERAS element in almost all fields. It reduces chest complications and counteracts insulin resistance (17). The combination of mobilization and nutritional support results in improved muscle strength after colorectal surgery (18). Following laparoscopic colorectal surgery, a lack of early mobilization is significantly associated with prolonged hospital stay (19). However, appropriate ambulation goals (e.g., for steps, distance, or duration) for early mobilization are undefined. The question remains whether specific strategies (e.g., accompanied walks or supervised exercise) benefit patients receiving minimally invasive colorectal surgery. Wiklund *et al.* observed that goals for steps did not significantly improve bowel function recovery or shorten LOS in patients undergoing gastric-bypass surgery (20). Staff-assisted facilitation of early mobilization also did not improve outcomes compared with traditional ERAS care for colorectal surgery (21).

To the best of our knowledge (according to a search of PubMed websites until March 2020), this is the first study to investigate the effectiveness of integrating smartbands into a perioperative ERAS program after MIS for colorectal resection. Nonetheless, this study had some limitations including the nonrandomized design and the insufficient representation of patients enrolled. The impact of improving compliance in other ERAS elements (e.g., higher proportion of PCA use and less postoperative NG tube indwelling) on the short-term surgical outcomes and quality of recovery in our patients was also not completely analyzed. The actual efficacy and extended applications of smartbands in ERAS should be investigated in the future.

Conclusions

Smartbands enhance communication between patients and surgical teams and strengthen self-management in patients undergoing MIS for colorectal resection. Accelerated recovery to preoperative functional status can be facilitated by integrating smartbands into the process of early mobilization in a well-established ERAS program. Further reductions in effective LOS are reasonably anticipated.

List Of Abbreviations

ERAS: enhanced recovery after surgery, MIS: minimal invasive surgery, LOS: length of (hospital) stay, ASA: American society of anesthesiologist, MBP: mechanical bowel preparation, PCA: patient-controlled analgesia, PONV: postoperative nausea and vomiting, NG: nasogastric, POD: postoperative day, SD: standard deviation, LAR: low anterior resection, AR: anterior resection, LH: left hemicolectomy, RH: right hemicolectomy, CCRT: concurrent chemoradiotherapy, SSI: surgical site infection, IAI: intraabdominal infection, BMI: body mass index, CEA: carcinoembryonic antigen, OA: oral antibiotics, MBD: may be discharged

Declarations

Ethics approval and consent to participate

This study was approved by the institutional review board of Kaohsiung Medical University Hospital (KMUHIRB-F(II)-20180098). Written informed consent was obtained from each patient before the integrated care pathway was carried out.

Consent for publication

The consent of publication was included in the written informed consent obtained from each patient.

Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

TCY, being the first author of this manuscript, designed this study, analyzed the

data, and wrote the manuscript. CWH, HLT, WCS, CJM and TKC made substantial contributions in terms of the data acquisition, interpretation and statistical analyses, in addition to assisting with the manuscript preparation. JYW, being the corresponding author for this manuscript, also participated in the study design and coordination, in addition to making critical revisions to the manuscript. All have reviewed and approved submission of the final version of the manuscript.

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Tables

Table 1 Demographic data of patients in each stage

	Stage 1 (initialization stage)	Stage 2 (maturation stage)	Stage 3 (experimental stage)	P value
Age (SD)	57.6 (10.4)	61.6 (6.8)	59.8 (9.1)	0.2172
Male (%)	16 (53.3)	14 (46.7)	19 (63.3)	0.4244
BMI (SD)	25.4 (4.4)	24.3 (2.7)	24.0 (4.0)	0.3134
ASA 1/2/3 (%)	2/23/5 (6.7/76.7/16.7)	0/20/10 (0/66.7/33.3)	0/21/9 (0/70.0/30.0)	0.1651
Robot/Laparoscopic (%)	19/11 (63.3/36.7)	26/4 (83.7/13.3)	23/7 (76.7/23.3)	0.1043
RH/AR/LAR (%)	4/5/21 (13.3/16.7/70.0)	3/4/23 (10.0/13.3/76.7)	4/6/20 (13.3/20.0/66.7)	0.9373
CEA, ng/mL (SD)	2.51 (2.04)	2.65 (2.28)	2.34 (1.69)	0.8512
Albumin, mg% (SD)	4.36 (0.28)	4.36 (0.31)	4.39 (0.29)	0.8710
CCRT (%)	15 (50)	18 (60.0)	17 (56.7)	0.7299

BMI: body mass index, ASA: American society of anesthesiologists, RH: right hemicolectomy, AR: anterior resection, LAR: low anterior resection, CEA: carcinoembryonic antigen, CCRT: concurrent chemoradiotherapy

Table 2 Compliance for ERAS program components at each stage

ERAS items	Stage 1	Stage 2	Stage 3	P value
No smoking/cessation (%)	30 (100)	30 (100)	30 (100)	-
No MBP in right side colonic surgery / MBP + OA in left side colonic surgery (%)	30 (100)	30 (100)	29 (96.7)	0.3296
Prophylaxis antibiotics (%)	30 (100)	30 (100)	29 (96.7)	0.3296
PCA (%)	10 (33.3)	13 (43.3)	20 (66.7)	0.0280*
No additional opioid (%)	21 (70.0)	28 (93.3)	26 (86.7)	0.0452*
Ileus prevention (%)	28 (93.3)	29 (96.7)	26 (86.7)	0.3378
PONV prophylaxis (%)	29 (96.7)	25 (83.3)	29 (96.7)	0.0990
Early mobilization (%)	20 (66.7)	24 (80)	25 (83.3)	0.2808
Remove Foley as schedule (%)	27 (90)	29 (96.7)	27 (90.0)	0.4408
No NG / Remove NG before reversal of anaesthesia (%)	23 (76.7)	24 (80.0)	29 (96.7)	0.0405*
Clear liquid diet in 24 hrs after operation (%)	29 (96.7)	29 (96.7)	29 (96.7)	1.0000
Full diet in 48 hrs after operation (%)	28 (93.3)	28 (93.3)	26 (86.7)	0.5943

MBP: mechanical bowel preparation, OA: oral antibiotics, PCA: patient-controlled analgesia, PONV: postoperative nausea and vomiting, NG: nasogastric

Table 3 Short-term surgical outcomes and complications for each stage

Outcome measurement	Stage 1	Stage 2	Stage 3	Stage 2 vs. stage 1	Stage 3 vs. stage 2	Stage 3 vs. stage 1
Total LOS, days (SD)	11.4 (2.8)	10.1 (1.0)	10.0 (1.3)	P = 0.0230*	P = 0.9896	P = 0.0159*
Total LOS, uncomplicated, days (SD)	10.7 (2.1)	10.0 (0.9)	9.8 (0.7)	P = 0.1800	P = 0.8207	P = 0.0489*
LOS, theoretical, days (SD)	8.9 (1.6)	8.5 (1.0)	7.8 (1.4)	P = 0.4396	P = 0.1770	P = 0.0091*
Clear liquid diet since, days (SD)	1.0 (0.4)	1.0 (0.4)	1.1 (0.3)	P = 1.0000	P = 0.5466	P = 0.5466
Full diet since, days (SD)	2.6 (1.4)	2.1 (0.6)	2.2 (0.6)	P = 0.1265	P = 0.8405	P = 0.3427
Flatus passage since, days (SD)	1.5 (0.6)	1.5 (0.8)	1.6 (0.9)	P = 0.9835	P = 0.8609	P = 0.7666
Stool passage since, days (SD)	2.1 (1.0)	2.2 (0.9)	2.4 (1.0)	P = 0.8585	P = 0.7881	P = 0.4652
Medical complications (%)	4 (13.3)	3 (10.0)	2 (6.7)	P = 0.6860		
Surgical complications (%)	1 (3.3)	0 (0)	1 (3.3)	P = 0.4394		
Total complications (%)	4 (13.3)	3 (10.0)	2 (6.7)	P = 0.6860		
Reoperation (%)	1 (3.3)	0 (0)	1 (3.3)	P = 0.4394		
Readmission (%)	0 (0)	1 (3.3)	0 (0)	P = 0.3296		
Mortality (%)	0 (0)	0 (0)	0 (0)	-		

LOS: length of (hospital) stay

Table 4 Total scores and subscales for QoR-40 in patients with and without postoperative smartband use

Stage 2 (without smartband)

	Preoperative	POD1	POD3	MBD	POD1 - Preoperative	<i>P</i> value	POD3 - Preoperative	<i>P</i> value	MBD - Preoperative	<i>P</i> value
Physical comfort (60)	52.2	46.4	52.4	54.4	-5.8	<0.001*	+0.2	0.8716	+2.2	0.0838
Emotional state (45)	38	33.6	35.1	39	-4.4	0.0018*	-2.9	0.0370*	+1.1	0.4463
Physical independence (25)	23.4	16	19.6	23	-7.4	<0.0001*	-3.8	<0.0001*	-0.4	0.6121
Psychological support (35)	31.8	31.2	31.2	32.3	-0.6	0.5172	-0.7	0.4829	+0.4	0.6658
Pain (35)	32.9	29.5	32.1	33.3	-3.4	<0.0001*	-0.8	0.1261	+0.3	0.533
Total (200)	178.3	156.8	170.4	181.9	-21.5	<0.0001*	-7.9	0.0463*	+3.6	0.3692

Stage 3 (with smartband)

	Preoperative	POD1	POD3	MBD	POD1 - Preoperative	<i>P</i> value	POD3 - Preoperative	<i>P</i> value	MBD - Preoperative	<i>P</i> value
Physical comfort (60)	53.3	47.3	52.7	55.3	-6.0	0.0002*	-0.6	0.6888	+2.0	0.2161
Emotional state (45)	39.4	35.9	37.5	39.8	-3.5	0.0132*	-1.9	0.1749	+0.4	0.7602
Physical independence (25)	23.1	17.5	22.0	23.1	-5.6	<0.0001*	-1.2	0.1822	-0.1	0.9525
Psychological support (35)	32.5	31.2	31.6	32.7	-1.3	0.1375	-0.9	0.2818	+0.2	0.8220
Pain (35)	33.4	29.9	31.9	32.6	-3.5	<0.0001*	-1.5	0.0549	-0.7	0.3550
Total (200)	182.1	161.9	175.4	183.5	-20.2	<0.0001*	-6.8	0.0988	+1.4	0.7409

POD: postoperative day, MBD: may be discharged

Figures

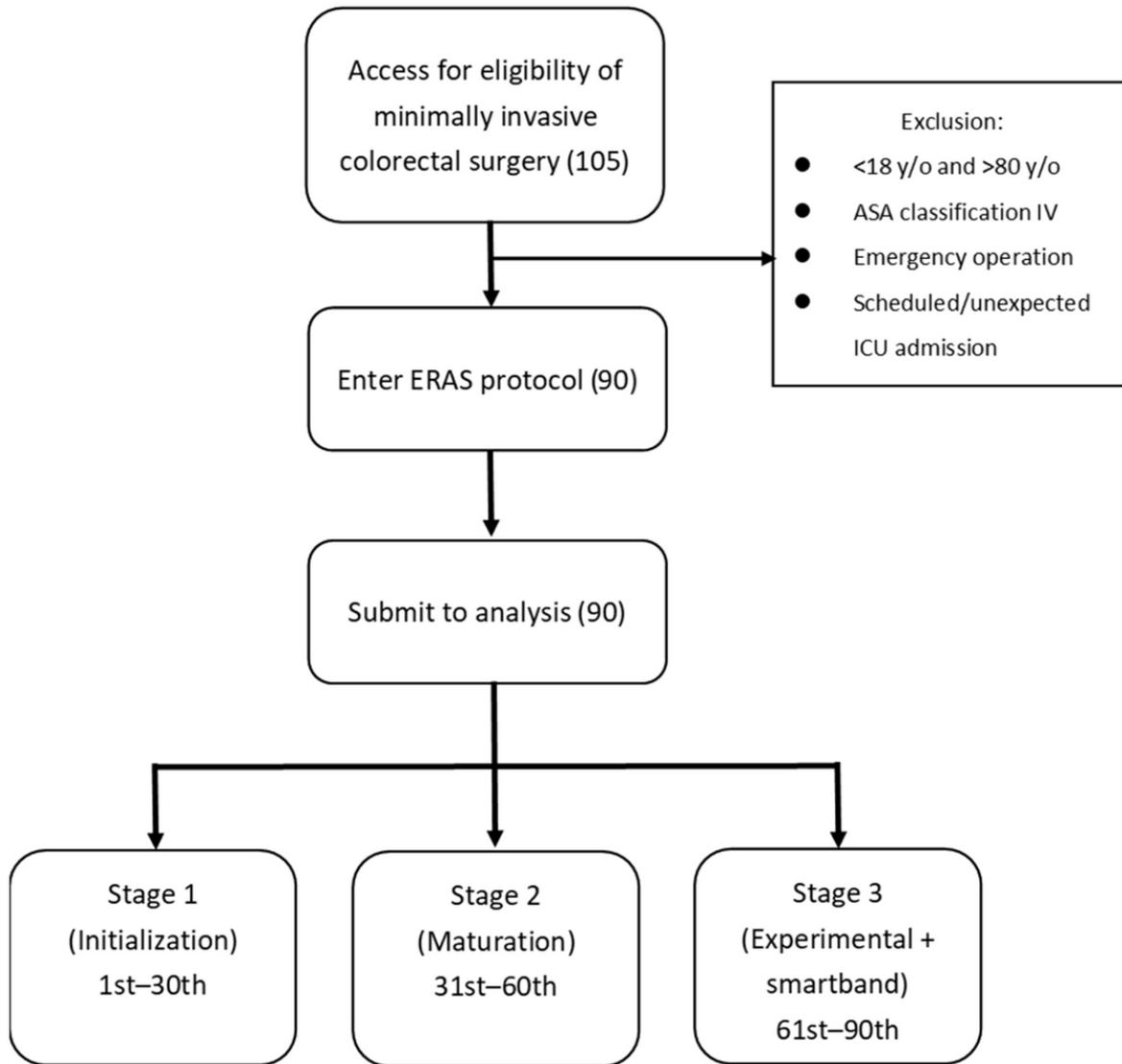


Figure 1

Consort diagram

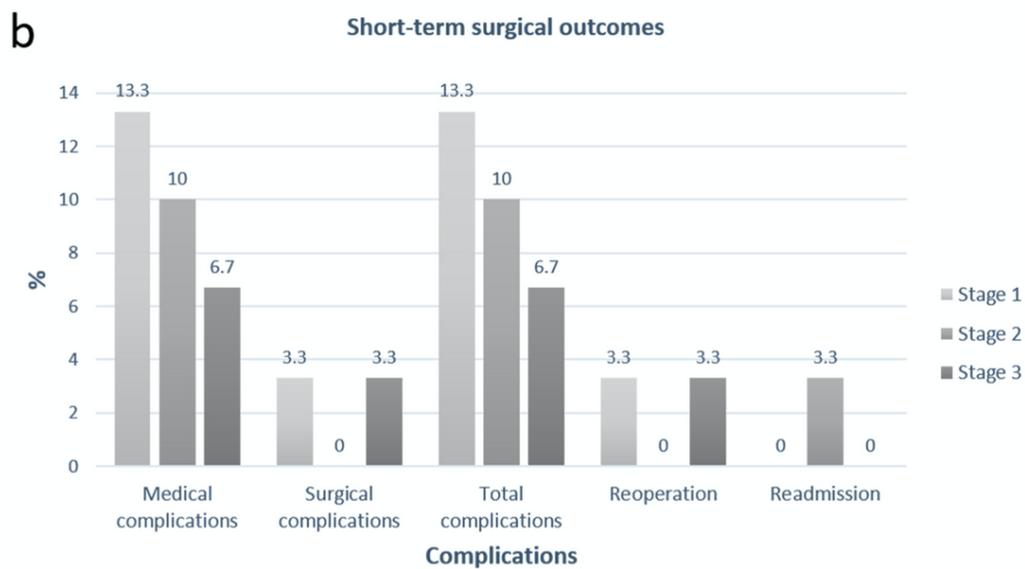
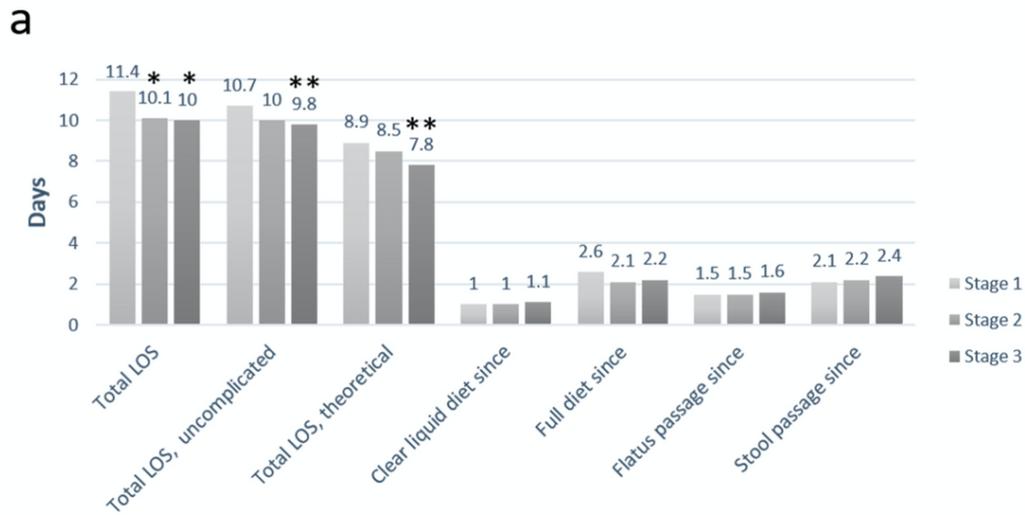


Figure 2

Short-term surgical outcomes (a) and complications (b) in the initialization stage (stage 1), maturation stage (stage 2), and experimental stage (stage 3). asterisks: LOS significantly decreased in stage 2 and stage 3 compared with stage 1 ($P = 0.0230$ and 0.0159 , respectively); double asterisks: LOS in uncomplicated patients and theoretical LOS significantly decreased in stage 3 compared with stage 1 ($P = 0.0489$ and 0.0091 respectively); LOS: length of hospital stay

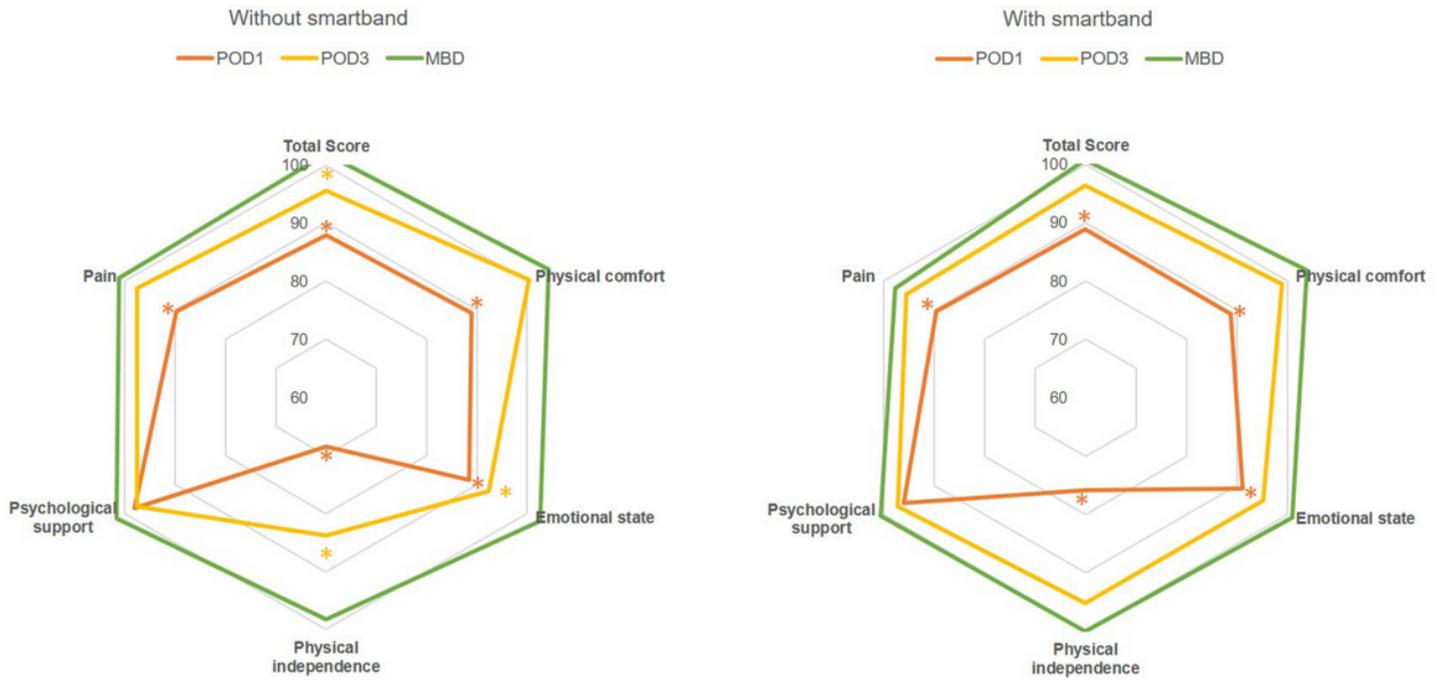


Figure 3

Rader chart of total score and scores for subscales (physical comfort, emotional state, physical independence, psychological support, and pain) of QoR-40 with and without smartband integration in a perioperative ERAS program following minimally invasive colorectal surgery. The grid lines mark the percentage of each dimensional score compared with the preoperative measurement. Asterisks: significant difference ($P < 0.05$) compared with preoperative functional status; POD: postoperative day, MBD: may be discharged