The impact of adherence to enhanced recovery pathway elements on outcomes following bowel surgery

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List of Abbreviations

ERP: Enhanced recovery pathway

BMI: Body mass index

GI: Gastrointestinal

IBD: Inflammatory bowel disease

LOS: Length of stay

ASA: American Society of Anesthesiologists

TNM: Tumor Node Metastasis

MBP: Mechanical bowel preparation

IV: Intravenous

PONV: Postoperative nausea and vomiting

NSAIDs: Nonsteroidal anti-inflammatory drugs

TED: Thromboembolic disease

PCA: Patient controlled analgesia

TIVA: Total intravenous anesthesia

IPAA: Ileal pouch-anal anastomosis

IQR: interquartile range

Abstract

Introduction: Enhanced recovery pathways (ERPs) are evidence-based, multimodal, standardized care plans that integrate multiple steps and interventions in the perioperative period aiming to improve patient recovery after surgery. International guidelines recommend the incorporation of a large number of interventions into ERPs. However, the impact of overall adherence to the pathway and the relative contribution of each intervention are unclear. The objective of the research contained within this thesis is two-fold: (1) to estimate the extent to which adherence to care process is associated with outcomes, and identify key ERP elements associated with successful recovery following bowel resection; (2) to assess the validity and usability of a novel mobile device app for patient education and self-reporting of adherence within an established ERP.

Methods: A review of prospectively collected data entered in a registry specifically designed for ERPs was performed. Patients undergoing elective bowel resection between 2012 and 2014 at the Montreal General Hospital treated within an ERP comprising 23 care elements were included in the study. Primary outcome was successful recovery defined as: absence of complications, discharge by postoperative day 4 and no readmission. Secondary outcomes were: length of hospital stay (LOS), 30-day morbidity and severity (Comprehensive complication index, CCI, 0-100). Subsequently, we performed a prospective pilot study implementing a novel mobile device app specifically designed to provide patients with daily recovery milestones and to record adherence to different ERP processes and patient reported outcomes (PROs). Validity was measured by the agreement index (Cohen's kappa coefficient for categorical, and interclass correlation coefficient (ICC) for continuous variables) between

patient reported data through the app and data recorded by a clinical auditor. Acceptability and usability of the app were measured by the System Usability Scale (SUS).

Results: In our retrospective study, we analyzed data from 347 patients, with a median length of hospital stay of 4 days (IQR 3–7), and median adherence to 18 (IQR 16–20) elements. There was a positive association between adherence and successful recovery with no hospital readmission, length of stay, 30-day postoperative morbidity and the complication severity. Laparoscopy, early mobilization out of bed, and early termination of IV fluid infusion were significantly associated with improved outcomes. In our app validation study, we included 45 patients undergoing bowel surgery. Overall, patients completed 89% of the available perioperative questionnaires through the app. Substantial (kappa > 0.6) or almost-perfect agreement (kappa > 0.8) and strong correlation (ICC > 0.7) between data collected through the app and by the clinical auditor was found for 14 out of 15 ERP processes and 4 out of 6 PROs. Patient reported usability and satisfaction was high, and only few patients needed technical support to use the app. Forty (89%) patients found that the app was helpful to achieve their daily goals, and 34 (76%) thought it increased their motivation to recover after surgery.

Conclusion: In an established ERP where overall adherence was high, we found that increased adherence to ERP interventions was associated with successful early recovery and a reduction in postoperative morbidity and complication severity. Given the significant impact of adherence to postoperative elements, we successfully piloted a novel mobile device app which proved to be a valid tool to record patient adherence and patient reported outcomes, and had high usability and patient satisfaction. Our findings suggest that future studies should investigate the use of mobile device apps as strategies to increase adherence to ERP interventions and improve outcomes.

Resumé

Introduction: Les programmes multidisciplinaires de récupération accélérée (PMRA) sont des plans de soins standardisés, multimodaux et fondés sur des preuves. Ils intègrent plusieurs étapes et interventions dans la période péri-opératoire qui visent à améliorer le rétablissement des patients après la chirurgie. Les directives internationales recommandent l'incorporation de nombreuses interventions dans les PMRA. Cependant, l'impact de l'adhésion à ces programmes ainsi que la contribution relative de chaque intervention ne sont pas clairs. L'objectif principal de cette thèse est double: (1) estimer dans quelle mesure l'adhésion au processus de soins est associé aux résultats, et identifier les éléments clés de PMRA qui sont associés au rétablissement après une résection intestinale; (2) évaluer la validité et la convivialité d'une application mobile novatrice utilisée pour l'éducation des patients et pour l'auto-déclaration d'adhésion à un PMRA établi.

Méthodes: Un registre spécifiquement conçu pour les PMRA qui contient des données recueillies prospectivement a été révisé. Les patients qui ont subi une chirurgie intestinale élective entre 2012 et 2014 à l'Hôpital général de Montréal et dans le cadre d'un PMRA qui comporte 23 éléments de soins ont été inclus dans l'étude. Le résultat principal a été le rétablissement avec succès défini comme : l'absence de complications, sortie d'hôpital au plus tard le quatrième jour après la chirurgie, et pas de réhospitalisation. Les résultats secondaires ont été: la durée de séjour, la gravité des complications et la morbidité postopératoire *à* 30 jours (l'indice de complication compréhensif, 0-100). Ensuite, nous avons effectué une étude pilote prospective qui met en œuvre une application mobile novatrice conçue pour les patients postopératoire. L'application indique les jalons quotidiens, permet l'enregistrement d'adhésion aux différents processus PMRA et recueillit les résultats déclarés par les patients (« Patient-

reported outcomes », PRO). La validité a été mesurée par l'indice d'accord (le coefficient Kappa de Cohen pour les variables catégoriques, et le coefficient de corrélation interclasse (ICC) pour les variables continues) entre les données recueillies par l'application et les données enregistrées par l'auditeur clinique. L'acceptabilité et la convivialité de l'application ont été mesurées par l'échelle d'usabilité du système (« System Usability Scale », SUS).

Résultats: Dans notre étude rétrospective, nous avons analysé les données de 347 patients, avec une durée médiane de l'hospitalisation de 4 jours (écart interquartile 3-7), et en moyenne, adhésion à 18 éléments du PMRA (écart interquartile 16-20). Il y a eu une association positive entre l'adhésion et le rétablissement sans réhospitalisation, la durée du séjour, et la gravité des complications ainsi que la morbidité postopératoire *à* 30 jours. La laparoscopie, la mobilité précoce, et la cessation précoce des solutions intraveineuses a été associées à de meilleurs résultats de manière significative. Pour notre étude sur la validité de l'application mobile, nous avons inclus 45 patients qui subissent une chirurgie intestinale. En totale, les patients ont rempli 89% des questionnaires péri-opératoire accessibles dans l'application mobile. Un accord substantiel (kappa > 0.6) ou un accord presque parfait (kappa > 0.8) et une forte corrélation (ICC > 0.7) entre les données recueillies par l'application et par l'auditeur clinique ont été retrouvés pour 14 processus du PMRA sur 15 et pour 4 PRO sur 6. Les patients ont déclaré un niveau de convivialité et de satisfaction élevé. Il n'y avait que quelques patients qui avaient besoin de soutien technique pour utiliser l'application. Quarante (89%) patients croyaient que l'application a aidé à atteindre leurs objectifs quotidiens, et 34 (76%) patients croyaient qu'elle a augmenté leur motivation de rétablissement après la chirurgie.

Conclusion: L'étude a conclu que le plus une adhésion aux interventions PMRA a été élevée, le plus elle a été associée à un rétablissement accéléré et à une réduction de la gravité des

complications et la morbidité postopératoire. Ceci est le cas pour un PMRA établi où le niveau d'adhésion globale est élevé. Étant donné l'impact significatif d'adhésion sur les éléments postopératoires, nous avons réussi à piloter une application mobile novatrice et valide, capable d'enregistrer l'adhésion au PMRA et les PRO. Elle est également associée à un haut niveau de convivialité et de satisfaction. Selon nos constations, les recherches futures devraient viser à évaluer l'utilisation des application mobiles comme des stratégies pour l'augmentation d'adhésion aux interventions PMRA et pour de meilleurs résultats postopératoires.

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Preface

This thesis is presented in a manuscript-based format. The first manuscript evaluates the impact of adherence to perioperative care processes on postoperative outcomes following bowel resection. The second manuscript is a pilot study validating the use of a mobile device app for data collection and self-audit in the same perioperative context. The results of both studies were presented at the Society of American Gastrointestinal and Endoscopic Surgeons (SAGES) annual congress in March 2016. Both manuscripts were published in Surgical Endoscopy in April and November 2017.

Contributions of Authors

Dr. Nicolò Pecorelli: Development of study protocols, data extraction/collection/entry, data analysis, drafting and revision of the manuscript.

Dr. Olivia Hershorn: Data collection and entry.

Dr. Gabriele Baldini: Interpretation of data analysis and review of manuscript.

Dr. Julio F. Fiore Jr.: Development of study protocols, review of manuscripts, supervision of data analysis.

Pepa Kaneva: Data collection and entry.

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Dr. Patrick Charlebois: Colorectal surgeon, review of manuscripts.

Dr. A. Sender Liberman: Colorectal surgeon, review of manuscripts.

Dr. Barry Stein: Colorectal surgeon, review of manuscripts.

Dr. Franco Carli: Anesthesiologist, Director of Preoperative Clinic, review of manuscripts.

Dr. Liane Feldman: Development of study protocols, review of manuscripts, supervision of data analysis and interpretation.

CHAPTER 1:

Introduction

1.1 A new era in perioperative care: Enhanced recovery pathways

Despite breakthrough innovations in the field of surgical technique (e.g. minimally invasive technique) and more adequate patient selection, morbidity and mortality following major abdominal surgery remains high. In particular, for colorectal and upper gastrointestinal procedures complications are still frequent. A study performed in 2005-2006 analyzing around 130,000 general surgery procedures from the American College of Surgeons National Quality Improvement Program (ACS-NSQIP) database found that adverse events after colorectal and small bowel resection account for more than one third of the overall complications reported [1]. In recent years, research has shown that the metabolic stress response to surgery leading to increased demand on the patients' physiologic reserves and organ function is one of the mechanisms leading to postoperative morbidity [2]. The pathophysiology involved in surgical stress is complex including a systemic inflammatory response mediated by pro-inflammatory cytokines, and hormonal and metabolic changes mediated by endogenous catecholamine and steroid release leading to increased insulin resistance and protein catabolism [3]. These conditions are further worsened by traditional perioperative care that promotes prolonged fasting before and after surgery, morphine-based analgesia, and postoperative bedrest. These practices are amongst those that have been challenged through multiple pharmacological, nutritional and physical interventions organized in a clinical pathway known as an enhanced recovery pathway (ERP) [4].

In the mid 1990s, Henrik Kehlet's group in Denmark first published a report on nine patients treated with a multimodal program that included epidural analgesia, early oral nutrition

and mobilization [5] after colonic resection. This was the first step that paved the way for the development of ERPs, which have revolutionized the field of perioperative care during the last 15 years. In fact, in the decade following this publication, his group and many others have showed, via randomized trials, that incorporating these interventions in clinical care significantly improves postoperative outcomes [6].

ERPs are defined as evidence-based, multimodal, standardized care plans that integrate multiple steps and interventions in the perioperative period. These pathways represent a paradigm shift from traditional care where the patient moves from one clinician-based expertise silo to the next, to a patient-centered pathway, where the steps of perioperative care are integrated. While their metabolic target is to reduce the perioperative stress response to surgery, limiting insulin resistance and protein breakdown [2], practically they aim to better organize care for patients undergoing a specific procedure, and thereby contribute to reducing unwanted variability in care processes and outcomes.

1.2. Perioperative care elements included in an ERP for bowel surgery

Multiple guidelines for specific surgical procedures have been published from scientific organizations such as the ERAS® society, a European non-for profit medical society promoting the implementation of ERPs in healthcare institutions and the advancement of research in this field [7-9]. These consensuses were drafted following the GRADE Working Group guidelines [10], and recommendations were based on quality of evidence but also on the balance between desirable and undesirable effects. Accordingly, in certain cases, strong recommendations were reached from low-quality data and vice versa. **Table 1-1** summarizes the specific elements that should be included in ERPs for colonic surgery according to the ERAS® Society guidelines [7] and recently published American Society of Colon and Rectal Surgeons (ASCRS) and Society of American Gastrointestinal and Endoscopic Surgeons (SAGES) guidelines [11]. The

evidence has grown in recent years leading to slight modifications in the guidelines, such as a return to preoperative oral bowel preparation with addition of oral antibiotics, weakening of evidence supporting the use of preoperative carbohydrate loading, and increasing evidence advocating the use of alvimopam for postoperative ileus prevention.

Some of the recommended elements are also common for a variety of surgical procedures, others, such as placement of an abdominal drain are procedure-specific. The number of elements in a program per se does not seem to be critical, and success measured by common postoperative outcomes (i.e. length of hospital stay, complications) has been observed with both complex and simpler programs [6, 12]. The growing number of reports published in the literature coming from different countries and healthcare settings have shown that these elements can be implemented with different strategies, but what seems most important is to come together as a team to create a multidisciplinary consensus for each element and phase of perioperative care. Some elements are under the purview of anesthesiology and nursing, whose participation is critical, especially in the postoperative recovery phase as they are the professionals mostly present at the bedside.

Table 1-1. Perioperative care elements for colonic surgery, level of recommendation and quality of evidence per ERAS® society [7], ASCRS-SAGES [11] guidelines**.**

Care element	**Level of Recommendation**		**Quality of evidence**	
	ERAS	**ASCRS**	**ERAS**	**ASCRS**
Preadmission counseling	Strong	Strong	Low	Low
Preoperative optimization	Strong	Weak	Moderate	Moderate
Avoid preop oral bowel preparation	Strong		High	
Oral bowel preparation with antibiotics		Weak		Moderate
Short preoperative fasting	Strong	Strong	Moderate	High
Preoperative carbohydrate loading	Strong	Weak	Low	Moderate
No preanestethic medication	Strong		High	
Surgical Site Infection prevention bundle		Strong		Moderate

Antibiotic prophylaxis	Strong		High	
Thoracic epidural analgesia for open surgery	Strong	Strong	High	High
Thoracic epidural not mandatory, local anesthetic or opioid PCA for laparoscopy	Strong	Strong	Moderate	Moderate
Multimodal opioid-sparing analgesia		Strong		Moderate
PONV prophylaxis in patients at-risk	Strong	Strong	Low	High
Thromboembolic prophylaxis	Strong		High	
Balanced intravenous infusion	Strong	Strong	Moderate	Moderate
Goal direct fluid therapy in high risk patients	Strong	Strong	Moderate	Moderate
No nasogastric intubation	Strong	Strong	High	High
No abdominal drainage	Strong	Strong	High	Moderate
Minimally invasive approach	Strong	Strong	Moderate	High
Early postoperative enteral feeding	Strong	Strong	High	High
Postoperative sham feeding	Strong	Strong	High	High
Alvimopam for ileus prevention	Strong	Strong	Low	Moderate
Early discontinuation of i.v. fluids	Strong	Strong	High	Moderate
Early removal of urinary catheter	Strong	Strong	Low	Moderate
Early and progressive mobilization	Strong	Strong	Low	Low

1.2.1 Preoperative elements

Patient education and engagement

Patient and caregiver preparation is an essential part of an ERP. The goal is to better prepare patients to play an active role in their recovery. In fact, patient knowledge and engagement have the potential to improve adherence to ERP elements, and it has been shown to reduce hospital stay, improve pain control and increase patient satisfaction [13]. Patient should be informed about how they should get ready for surgery, what to expect on the day of surgery, and they should receive objectives for each postoperative day including instructions

about their drains, infusions, diet and mobilization. The format and the way education is delivered can influence the patient's ability to retain information and act accordingly [14]. Written or multimedia information have been shown to have a significant advantage on oral communication alone as information are often forgotten by patients [15].

Optimization of organ dysfunction

The goal of preoperative optimization is to improve physiologic reserve to better tolerate the incoming stress of surgery. Patients at higher risk for postoperative morbidity such as elderly, frail and patients with severe comorbidities should be evaluated in a multidisciplinary setting [16]. Attention should be given to the patient's nutritional status, especially in GI cancer patients and elderly who are at higher risk for malnutrition. Standard validated screening tools such as the NRS 2002 [17], as well as preoperative serum albumin levels are recommended to identify and refer patients at risk to a nutritionist [18]. Routine use of oral nutritional supplements for well-nourished patients does not seem to confer any benefit [19], while patients at higher risk can benefit from a 10-14 days period of nutritional supplementation to optimize stores preoperatively [20]. Older patients should also be screened for delirium risk, and cognitive ability [21]. Hyperglycemia is a risk factor for complications after colorectal surgery [22], and patients with poorly controlled diabetes should be identified with HbA1C and optimized in conjunction with endocrinology. Anemia is another common risk factor that can be optimized preoperatively. In patients undergoing colorectal resection is associated with increased perioperative allogeneic blood transfusions, longer hospital stay and increased postoperative morbidity [23]. The most common form of anemia is due to iron deficiency, thus preoperative iron supplementation with novel parenteral iron formulations appears to be beneficial [24], but further evidence is needed to identify the ideal timing for administration and population to target (i.e. hemoglobin thresholds) [25]. Evidence shows that

smoking increases the risk of pulmonary complications, incisional complications and anastomotic leak after colorectal surgery [26]. Intensive interventions including nicotine replacement beginning at least 4 weeks prior to surgery have a higher chance to have an impact on reducing complications than shorter interventions [27]. Postoperative complications are increased in heavy users of alcohol (>3 alcohol units per day) [28], therefore complete cessation should be encouraged.

Bowel preparation

Traditionally, all patients undergoing gastrointestinal surgery received mechanical bowel preparation. Particularly in colorectal surgery, it was thought to reduce infectious complications by reducing intraluminal bacterial load and limiting potential spilling of bowel content in the abdominal cavity. However, mechanical bowel preparation is uncomfortable and results in fluid losses. The ERAS Society 2013 guidelines, based on a previous Cochrane meta-analysis [29] reported that bowel preparation could safely be omitted as there is no increased risk of infectious complications, leak or other complications. However, these trials did not include oral antibiotics with the mechanical bowel preparation. Recent North American observational data, and a meta-analysis of seven RCTs (1769 patients) comparing mechanical bowel preparation with oral antibiotics versus bowel preparation alone showed a reduction in total surgical site infection and incisional site infection, with no difference in the rate of organ/space infection after elective colorectal surgery [30, 31].

Preoperative fasting/carbohydrate drink

Traditionally patients have been kept fasting from midnight to prevent the risk of aspiration of gastric contents at induction of anesthesia. This leads to dehydration and increases insulin resistance triggering a catabolic state, which is one of the main mechanisms leading to

poor surgical outcomes [32, 33]. Oral intake of clear fluids up to 2 hours before surgery does not increase the risk of aspiration in healthy adults undergoing elective surgery. Anesthesia Society guidelines from multiple countries consistently recommended a 6 hour fast for solids and a 2 hour fast for clear fluids except in for patients with dysphagia, obstruction or gastroparesis [34]. Preliminary evidence supported the administration of a carbohydrate-rich drink before surgery (100 grams the evening before surgery and 50gm 2-3 hours before surgery) to increase insulin sensitivity [35], and to shift cellular metabolism to a more anabolic state [36]. However, according to recently published meta-analyses, there appears to be only a minor advantage associated with preoperative carbohydrate loading in the subgroup of patients undergoing major surgery (i.e. reduced length of hospital stay) [37]. Further data is certainly needed to clarify this issue.

Anesthesia premedication

Long-acting sedative premedication (i.e. benzodiazepines) should be avoided within 12 h of surgery because it affects immediate postoperative recovery by impairing mobility and oral intake. In 2009, a Cochrane review on premedication to reduce anxiety for adult day-surgery cases concluded that patients receiving oral anxiolytics were discharged from hospital successfully but in certain studies psychomotor function was impaired up to 4 h postoperatively, which may reduce the patient's ability to mobilize, eat and drink [38]. Short-acting agents to reduce anxiety before induction of anesthesia or insertion of epidurals may be used selectively.

1.2.2 Intraoperative elements

Minimally invasive surgery

Two recent large multicenter RCTs compared laparoscopic versus open surgery when an ERP is in use, the LAFA study in the Netherlands [39], and the EnRol trial in the UK [40]. The LAFA study allocated 400 patients undergoing colonic segmental resection for cancer to one of four groups combining surgical approach (laparoscopic or open) and perioperative care (enhanced recovery or standard). The combination of laparoscopy and enhanced recovery resulted in shorter length of hospital stay compared to the other groups, with laparoscopy the only independent predictor of reduced length of hospital stay. No differences were found for secondary outcomes including morbidity and quality of life. In the EnRol trial [40], 204 patients planned for colorectal resection were randomized to open or laparoscopic surgery in 12 UK centers applying an extensive ERP with 30 care elements and blinding of patients and assessors. Length of stay was shorter with laparoscopy, but no other differences were seen for physical fatigue, body image and quality of life one month after surgery. The authors concluded that laparoscopic surgery within an ERP is recommended because of the shorter hospital stay. Zhuang et al. [41] recently published a meta-analysis including the aforementioned studies. Pooled data revealed that total hospital stay including post-discharge readmissions was significantly shorter in patients who underwent a laparoscopic procedure. Total number of complications was also reduced for laparoscopy, while no difference was found between open and laparoscopic surgery for the number of patients developing at least one complication.

Although the quality of the evidence is not uniformly high, the data suggest that for colorectal resection, enhanced recovery combined with minimally invasive surgery offers the greatest benefit, both for patients and for the healthcare system. To date, most of the studies have only focused on short-term in-hospital recovery outcomes such as LOS and morbidity [42] and future studies should also include post discharge functional recovery measures to better capture all dimensions of recovery both in the short and longer term [43].

Postoperative nausea and vomiting (PONV) prophylaxis

Nausea and vomit early after surgery impair the return to oral nutrition, and mobilization, thus preventing these symptoms is a key factor for a successful ERP. Ideally, patients should be screened preoperatively for PONV risk factors using a simple risk calculator like the Apfel score and a tailored strategy applied for patients at moderate or high risk [44]. PONV prophylaxis begins during surgery and continues in the first hours postoperatively. Multiple preventive interventions can be used during surgery, such as total intravenous anesthesia (TIVA) with minimization of volatile anesthetics, and the use of loco-regional anesthesia techniques to spare systemic opioids. In addition, prophylaxis protocols include the administration of corticosteroids (e.g. dexamethasone) after induction of general anesthesia, and 5-HT_3 receptor antagonists (e.g., Ondansetron) or butyrophenones (e.g., Droperidol) at the end of surgery.

Balanced intravenous fluid infusions

There is a narrow range for optimal fluid therapy with a goal of maintaining euvolemia and avoiding both underhydration and salt and water excess. Intravenous fluid overload or excessive fluid restriction can significantly impair organ function, increase postoperative morbidity, and prolong hospital stay [45]. Use of a balanced crystalloid solution (e.g. Ringer's lactate) is preferred over "normal saline" which has higher chloride content than extracellular fluid [46]. A "near zero" fluid balance should be the goal, as indicated by minimal weight gain (<2.5 kg) or loss on POD1. Patients in ERPs with limited fasting and selective bowel preparation have minimal deficits to be replaced and maintenance requirements during surgery can be achieved using a balanced crystalloid solution at 1-3 ml/kg/hr [47]. Postoperatively, IV fluids should be discontinued when patients start drinking. Patients with thoracic epidural may

have low blood pressure related to vasodilatation. In the absence of other signs of hypovolemia, vasopressors should be considered to avoid fluid overload [48].

Multimodal analgesia

Optimal pain management avoiding systemic opioids is a key enabler of patient recovery. A multimodal approach is recommended, using multiple strategies before, during and after surgery. For open surgery, neuraxial blockade via thoracic epidural combining local anesthetics and adjuvants reduces the surgical stress response and complications, and provide excellent analgesia [49]. For laparoscopic surgery, the risk-benefit ratio for epidural is less favorable. A recent RCT, comparing thoracic epidural with intravenous opioid patient controlled analgesia in patients undergoing colorectal surgery in the context of an ERP, found similar pain scores between the two groups, but having an epidural delayed inhospital recovery by one day [50]. Other regional anesthesia opioid sparing techniques such as bilateral transversus abdominus plane (TAP) block injecting long acting local anesthetic under ultrasound or laparoscopic guidance can be effective [51, 52]. Postoperatively, patients are prescribed routine oral analgesics such as acetaminophen and nonsteroidal anti-inflammatory agents (NSAIDs), while opioids are reserved to patients with poor pain control.

1.2.3 Postoperative elements

Postoperative ileus prophylaxis

Multiple ERP interventions including laparoscopic surgery, fluid balance and opioid sparing analgesia can favor the preservation of normal bowel function after surgery. Additionally, there is some evidence showing that chewing sugar-free gum may accelerate the return to bowel function. A recent Cochrane review of 81 relevant studies and >9000

abdominal surgery patients found some evidence that patients who chewed gum after an operation had faster return of bowel sounds and were able to pass flatus and have bowel movements sooner than people who did not chew gum [53]. However, there was significant heterogeneity and most of the studies were of poor quality. Nonetheless, chewing gum is a simple low-cost intervention with the potential to improve postoperative gastrointestinal recovery.

Drains and catheters

Nasogastric (NG) tubes should not be used routinely after bowel surgery. Meta-analyses of trials in mainly lower GI surgery found that bowel function was accelerated and pulmonary complications reduced when NGs were not used [54]. Vomiting may be more frequent in patients who do not receive an NG tube, and insertion postoperatively may be required in up to 15% of patients due to prolonged ileus or other complications.

Urinary bladder drainage with transurethral catheters (i.e. Foley's) is routinely used in major abdominal surgery for intraoperative bladder decompression and monitoring of urinary output, and was traditionally kept for multiple days after surgery until the patient had stopped receiving intravenous fluids. Patients who undergo urinary catheterization for >2 days have twice the risk of a postoperative urinary tract infection (UTI) [55]. Even in the presence of a thoracic epidural, urinary catheters can be removed on POD1 in patients at low risk for urinary retention. An RCT including 215 patients with epidural analgesia after abdominal or thoracic surgery showed a significantly decreased rate of UTI among patients with early catheter removal (POD1) compared with removal after discontinuation of epidural analgesia (1.9% vs 13.6%). No significant differences in urinary retention rates between early and late catheter removal were identified in this trial [56].

Another element favoring recovery is the avoidance of abdominal drains, which were routinely placed to prophylactically identify and treat anastomotic leaks. Meta-analyses of published studies demonstrate no significant difference in mortality, anastomotic leak, or other postoperative complications in patients who receive intra-abdominal drainage [57].

Early oral nutrition

Allowing early return to oral nutrition (within 24 hours) after bowel surgery compared to traditional step-wise introduction of oral intake after return of bowel function is associated with decreased complications and no increase in the risk of anastomotic leak, as demonstrated by multiple studies and meta-analyses [58]. A recent RCT also found that starting early with solid food diet compared to clear fluids also reduces nausea and vomiting episodes [59].

Early mobilization

Prolonged bed rest leads to skeletal muscle loss, weakness and predisposes to pulmonary complications [60]. The deconditioning taking place after surgery can largely be prevented by physical activity [61]. Nonetheless, there is limited evidence that implementation of specific interventions to increase mobilization improves outcomes [62]. A recent RCT performed in the context of an ERP randomly allocated colorectal surgery patients to early facilitated mobilization by a dedicated team versus mobilization at patient. The trial found no differences in clinical and functional postoperative outcomes suggesting that, in the context of a care pathway including multiple interventions to enhance recovery, allowing patients to mobilize at will (i.e. as tolerated) after giving instructions may be enough to avoid the negative effects of prolonged bed rest and guarantee best possible outcomes in the majority of patients [63].

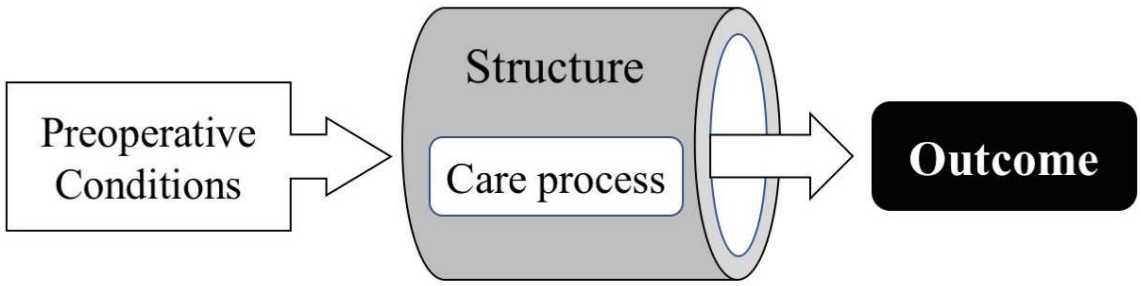
1.3 The value of adherence to care processes in surgery

To understand the value of adherence to care processes, it is fundamental to recall the best-known framework in healthcare, postulated by Dr. Avedis Donabedian in his 1966 publication titled "Evaluating the quality of medical care" [64, 65]. The father of quality assurance research suggested that quality of care be measured through three domains: structure, process and outcomes. Structural measures are variables reflecting the setting or system in which care is delivered. They include hospital resources, staff expertise and organization. In surgery, the association between procedure volume, either at the surgeon or hospital level, and outcomes is typically measured. It is intuitive that institutions with higher volumes in complex operations have better outcomes than their lower-volume counterparts. The advantage of using structure measures relies mostly in their expediency. They can be assessed easily and inexpensively through administrative data; however, most structural variables are not readily modifiable (e.g. it is usually impossible for a hospital to increase the volume of a certain procedure to improve outcomes). Process measures describe the care that patients actually receive and are routinely used as quality indicators in nonsurgical specialties. In perioperative care, process variables include all the interventions that we have previously described as ERP elements. Compared to structural measures, care processes are generally actionable as a quality improvement measure (i.e. an ERP bundle including multiple evidence-based interventions can be implemented). Unfortunately, as mentioned in previous sections, not all processes are supported by the evidence, they may be procedure-specific, and rather complex and expensive to implement. Finally, the direct measurement of outcomes is certainly the most used quality indicator in surgical care. Common outcome measures for surgery include postoperative mortality and morbidity rates, length of hospital stay, hospital readmission rates, patient satisfaction, and other measures of health-related quality of life. Assessing outcomes is advantageous not only because it provides the "bottom line" of how things are done, but also because auditing outcomes alone may already improve them, the so-called Hawthorne effect

[66]. There are also limitations in using outcomes as quality of care indicators; they can be different depending on the type of procedure, and may require a large number of patients to be a reliable indicator and comparator. All domains have unique strengths and limitations, and the type of surgical procedure that is evaluated may be the most important factor to determine the ideal measure of quality of care. Recent literature advocates using care process to evaluate the quality of perioperative care for procedures in which serious postoperative events such as reoperation or mortality are rare, as this is the case for bowel resection [67]. In the context of enhanced recovery, measuring patient adherence to care processes and its impact on outcomes is very relevant. In fact, the ERAS Society® strongly recommends auditing adherence to perioperative elements, referring to it as "a key instrument to assist clinicians implementing an ERP, to direct future education and the modification of other interventions" [7].

The addition of "patient conditions" to the classic Donabedian equation comprising structure, process and outcomes completes the picture. Patient factors, structural components and processes of care are the variables that should be taking into account when evaluating their association to outcomes in the context of surgical care (**Figure 1-1**).

Figure 1-1. The relationship between patient conditions, structure, care process and outcome according to Donabedian's model.



In recent years, the impact of adherence to ERP care processes on outcomes has been investigated by a limited number of retrospective studies focusing on two main objectives; 1) analyzing how the degree of adherence to the whole ERP impacts on postoperative outcomes, 2) identifying which ERP items are significantly associated with better outcomes.

Gustafsson et al. performed a retrospective analysis in one of the first ERAS Society trials from Sweden [68]. Out of 950 patients who underwent colorectal resection within a period ranging from 2002 to 2007 they found a dose-response relationship between level of adherence and postoperative morbidity and readmissions. So, the higher the adherence to the whole protocol, the lower were the complications and post-discharge readmissions. Despite the large sample size, this study was dealing with the early phase of pathway implementation in which overall adherence was low, specially for the postoperative phase. This may not hold true in established pathways were patient adherence is higher.

A more recent report using prospectively collected data from 61 different UK hospitals, analyzed a large number of patients undergoing colorectal, orthopedic, urological and gynecological surgery, found a weak but significant relationship between adherence to elements and length of hospital stay [69]. However, the authors failed to take into account very important confounding factors such as patient preoperative condition and postoperative morbidity. There is certainly no doubt that a patient experiencing a complication early after surgery will be less compliant to postoperative pathway elements, thus it should be accounted for in adjusted analysis.

In 2014, Larson et al. looked at perioperative factors associated with early discharge and postoperative complication in a consecutive series of 541 colorectal resections [70]. In their analysis, laparoscopy, low opioid analgesia usage, and early return to oral nutrition were factors significantly associated with positive outcomes. In another study performed in the Netherlands, factors significantly improving postoperative outcomes in multivariable analysis

included preoperative carbohydrate drinks, no nasogastric tube insertion, early oral nutrition, early mobilization, early removal of urinary catheter, early removal of epidural, and non-opioid oral analgesia [71]. This study, in a similar way to the aforementioned Swedish study, dealt with a long period of protocol implementation (8 years), were adherence rates were fluctuating and rather low.

1.4 Thesis objectives

In the previous sections, we analyzed the rationale behind perioperative care elements implemented in ERPs, and reported existing evidence supporting its implementation. We have also explored the literature regarding the role of adherence to care processes within an ERP, and the individual contribution of single components of the pathway, and found that data are still limited. Studies addressing this topic have mainly dealt with pathways during their implementation phase, where average overall adherence was low. In addition, most studies have failed to thoroughly report the definitions of adherence to each implemented intervention, limiting generalizability of its findings. Therefore, the main objective of this thesis was to estimate, in patients enrolled in an established ERP, to what extent the degree of adherence with ERP interventions impacts on recovery after surgery, and to identify which elements are associated with improved postoperative outcomes. The results of this first study were used to guide the development of a novel mobile device app providing patients undergoing bowel resection with relevant information about their recovery and allow self-audit of their adherence to the pathway. In our second study, we aimed to validate this app as a self-audit tool for pathway adherence and to investigate its usability and acceptability.

CHAPTER 2:

MANUSCRIPT #1: The impact of adherence on outcomes

Impact of adherence to care pathway interventions on recovery following bowel resection within an established enhanced recovery program.

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Keywords: postoperative recovery; postoperative complications; length of stay; outcome and process assessment (Health Care); colorectal surgery; laparoscopy.

2.1 Abstract

Introduction: Guidelines recommend incorporation of more than 20 perioperative interventions within an enhanced recovery program (ERP). However, the impact of overall adherence to the pathway and the relative contribution of each intervention is unclear. The aim of this study was to estimate the extent to which adherence to ERP elements is associated with outcomes, and identify key ERP elements predicting successful recovery following bowel resection.

Methods: Prospectively collected data entered in a registry specifically designed for ERPs were reviewed. Patients undergoing elective bowel resection between 2012 and 2014 were treated within an ERP comprising 23 care elements. Primary outcome was successful recovery defined as absence of complications, discharge by postoperative day 4 and no readmission. Secondary outcomes were length of hospital stay (LOS), 30-day morbidity and severity (Comprehensive complication index, CCI, 0-100). Regression analyses were adjusted for potential confounders.

Results: 347 patients were included in the study. Median primary LOS was 4 days (IQR 3–7). Patients were adherent to median 18 (IQR 16–20) elements. 156 (45%) patients had successful recovery. Morbidity occurred in 175 (50%) patients with median CCI 8.6 (IQR 0–22.6). There was a positive association between adherence and successful recovery (OR 1.39 for every additional element, $p<0.001$), LOS (11% reduction for every additional element, $p<0.001$), 30-day postoperative morbidity (OR 0.78, $p<0.001$), and the CCI (17% reduction, $p<0.001$). Laparoscopy (OR 4.32, $p<0.001$), early mobilization out of bed (OR 2.25, $p=0.021$), and early termination of IV fluid infusion (OR 2.00, $p=0.013$) significantly predicted successful recovery. These factors were also associated with reduced morbidity and complication severity.

Conclusions: Increased adherence to ERP interventions was associated with successful early recovery and a reduction in postoperative morbidity and complication severity. In an established ERP where overall adherence was high, laparoscopic approach, perioperative fluid management and patient mobilization remain key elements associated with improved outcomes.

2.2 Introduction

Enhanced recovery programs (ERPs) incorporate multiple evidence-based interventions aiming to reduce the metabolic stress occurring during surgery, but also to organize care for patients undergoing a particular procedure by limiting unwanted variability in care processes [2]. Guidelines from the ERAS® society recommend the implementation of more than 20 perioperative care components for patients undergoing colorectal surgery [7]. However, compared to traditional care, ERPs have been shown to consistently improve postoperative outcomes regardless of the number, the type, the combination, or the level of evidence of the elements used [12]. Furthermore, each intervention adds complexity to the pathway and may require additional resources.

Monitoring care process to evaluate the quality of perioperative care may be especially relevant for procedures in which serious postoperative events such as reoperation or mortality are rare, as in case for colectomy [67]. In the context of enhanced recovery, the impact of overall adherence to care processes, namely ERP elements, and the relative contribution of each intervention to patient recovery are still questioned. To date, there is preliminary evidence that adherence to care processes is associated with improved patient recovery [68-72]. However, existing reports mainly dealt with early phases of protocol implementation in which overall adherence was low [68], or failed to take into account important confounding factors such as postoperative morbidity [69]. The McGill University Health Centre first implemented an ERP for colorectal patients in 2006 [73] and is currently running a well-established care pathway incorporating a large number of perioperative interventions, which reduces hospital stay and societal costs compared to usual care [74].

The objective of this study was to estimate, in patients enrolled in an established ERP, to what extent the degree of adherence with ERP interventions impacts on recovery after surgery, and to identify which elements are associated with postoperative outcomes.

2.3 Methods

This study was designed and reported following the STROBE guidelines for the conducting and reporting of observational cohort studies [75].

Study design

This is a retrospective review of a prospectively collected database including patients undergoing elective bowel surgery treated within an ERP in a university-affiliated tertiary teaching institution. Study approval was granted by the Institutional Review board (14-170-SDR). Patients who underwent scheduled bowel resection between September 2012 and December 2014 were identified from the institutional operating room database and cross-checked with a prospective database specifically designed to capture adherence to ERP care processes and postoperative outcomes. Patients not followed prospectively by a clinical auditor were excluded from the study.

Enhanced recovery program

In 2006, an ERP for selected patients undergoing laparoscopic colorectal resection was first introduced in our instution [73]. In August 2010 this ERP was modified to include a total of 23 perioperative care components (Table 3-1) and was extended to all patients undergoing elective bowel resection [76].

Patients were admitted to hospital on the day of surgery. All cases were performed by one of three fellowship-trained colorectal surgeons (BS, ASL, PC). Discharge was planned for postoperative day (POD) 3 or earlier if patients achieved the following discharge criteria: tolerance of oral intake, recovery of gastrointestinal function (i.e. passage of flatus), adequate pain control with oral analgesia, ability to mobilize and self-care, and no evidence of complication or untreated medical problems. Final decision on discharge remained at the individual surgeon's discretion.

Data collection

From September 2012 a dedicated, trained clinical auditor prospectively collected patient data up until 30 days after surgery. Data was entered into the ERAS Interactive Audit System (www.erassociety.org, ENCARE, Kista, Sweden), an international web-based registry that was specifically designed for interactive audit and research. Each patient data field contained approximately 140 different variables including preoperative patient characteristics, operative data, adherence to perioperative care processes, and postoperative outcomes. Every 3-4 months the auditor reviewed adherence and outcome data with the ERP team and discussed any new trend or issue arising from the latest time period. A clinical researcher unaware of patient's adherence to ERP components verified postoperative outcome data for each patient by reviewing medical charts and the electronic medical record. Additional information was retrieved from medical records to compute Charlson comorbidity index [77], CR-POSSUM score [78], Apfel postoperative nausea and vomit (PONV) risk score [79], and the Comprehensive Complication Index (CCI) [80], which were not originally included in the ERAS audit system.

Adherence and outcome measures

Adherence to each ERP component was defined as the successful completion of a planned intervention (e.g. a patient planned to have regular food on POD1 actually receives a meal and consumes it). Definitions for each measure of adherence can be found in **Table 2-1**. Adherence to intraoperative intravenous infusions followed recent recommendations [47], taking into consideration the patient ideal body weight, use of mechanical bowel preparation (MBP), surgical approach, duration of surgery and blood loss. Cutoffs for adherence were set at < 3 ml/kg/hr for laparoscopic surgery and < 5 ml/kg/hr for open surgery.

Table 2-1. Perioperative care ERP interventions and definition of adherence.

ERAS intervention	Definition of adherence
Preoperative	
Preadmission education	Patient received preoperative counseling from a nurse and a physician, and a dedicated booklet including information on recovery goals and expectation about hospital stay
Selective MBP	No MBP used for colonic resection. MBP used for patients with a planned stoma formation during rectal resection
Carbohydrate loading	Intake of a preoperative carbohydrate drink up until 2 hours before anesthesia with at least 50 g carbohydrate in at least 400 mL fluid
No long-acting sedation	No long acting sedating medication used before surgery (e.g. opioids, antihistamines, benzodiazepines)
Intraoperative	
Antibiotic prophylaxis	Antibiotic prophylaxis completed prior to surgical incision
Epidural anesthesia	Thoracic epidural analgesia started before surgical incision
Laparoscopic approach	Successfully completed laparoscopic resection
Balanced intravenous fluids	Intraoperative maintenance fluids excluding replacement of blood loss: for laparoscopy <3 ml/kg/hour; for open <5 ml/kg/hour. If bowel preparation is used an extra 1000 ml of fluids are administered to cover losses
PONV prophylaxis	Multimodal prophylaxis administered according to Apfel score [16]
No abdominal or pelvic drainage	No resection-site drainage used
Normothermia	Body temperature measured at the end of surgery >= 36.0 °C
TED prophylaxis	TED prophylaxis with low-molecular-weight heparin
Avoidance of nasogastric tube	Nasogastric tube removed at the end of general anesthesia
Postoperative	
Opioid-sparing multimodal analgesia	Use of opioid-sparing strategies including thoracic epidural analgesia, abdominal trunk blocks, acetaminophen, NSAIDs
Oral liquids on POD 0	Patient received clear liquids on the day of surgery postoperatively
Oral nutritional supplements on POD 0	Patient received one or more nutritional drinks on the day of surgery postoperatively
Early mobilization out of bed	Patient mobilized out of bed within the first 24 hours after surgery
Early termination of IV fluid infusion	Termination of intravenous fluid infusion by the morning of POD 1
Early termination of urinary drainage	Termination of urinary drainage by POD 1
Free diet on POD 1	Patient received at least one meal with regular food by POD 1
Chewing-gum	Patient chewing gum at least three times a day for 30 minutes starting by POD 1
Laxative	Laxative medication (e.g. magnesium hydroxide) started by POD 1
Transition to oral analgesia by POD 2	Successful termination of thoracic epidural analgesia or PCA and transition to oral analgesics by POD 2

Adherence to PONV prophylaxis considered patients Apfel score in accordance with consensus guidelines [44]. Overall adherence to the ERP was also calculated for each patient.

Primary outcome measure of the study was successful recovery, a composite endpoint defined as discharge by POD 4, no occurrence of complications or hospital readmission within 30 days of operation. Secondary outcomes of the study included length of primary hospital stay (LOS), 30-day postoperative morbidity and the comprehensive complication index (CCI). LOS was defined as the number of nights spent in hospital during the primary stay from the day of admission to the day of discharge. Intraoperative and postoperative complications were defined *a priori* (**Appendix 1**). The severity of each complication was graded according to the Dindo-Clavien classification [81] and a CCI was then generated for each patient. This is a validated measure summarizing the complete spectrum of complications occurred and their severity in a single score ranging from 0 to 100 [80].

Statistical analysis

We performed a complete case analysis including patients with data for all ERP adherence variables and outcome measures. Relevant characteristics of the included patients and those excluded from the study were compared using Chi-square test or Fisher's exact test for categorical data, and Student's t-test or Mann-Whitney U test for continuous data, as appropriate.

Univariate analysis (i.e. logistic regression for binary outcomes and linear regression for continuous outcomes) was performed to assess the association of patient or procedure-related variables and ERP interventions with outcomes. To identify ERP elements independently associated with the outcomes of interest we used binary logistic regression (for the outcomes successful recovery and occurrence of 30-day complications) and linear regression (for log-transformed LOS and log-transformed 30-day CCI). Variables significant at $p < 0.10$ were

retained in the final model. Only early postoperative elements (up to POD1) were considered in the analysis because it is difficult to distinguish whether adherence to late care processes are indicators or predictors of poor recovery outcomes. In example, delayed transition to oral analgesia can be a consequence of adverse events leading to poor recovery, and not a cause. In the same way, patient mobilization on late postoperative days represents an outcome rather than indicate the adherence to a care process. In fact, both ability to mobilize and pain control with oral analgesia represent discharge criteria. To evaluate the impact of overall adherence to the pathway (i.e. the overall number of ERP elements to which a patient was adherent) on outcomes, we also ran multivariate analyses adjusted for confounding factors.

All multivariate models were adjusted for relevant prognostic factors known to affect patient adherence and postoperative otucoms such as age, gender, preoperative American Society of Anesthesiologists score, pelvic surgery and inflammatory bowel disease [82].

According to previous research, between 5 and 10 events per independent variable are required to obtain reliable regression coefficients in multivariate logistic regression models [83], and a minimum of 15 subjects per variable for are required for linear regression [84]. As ERP elements may be highly correlated with one another, the risk of multicollinearity was assessed by inspecting correlation matrices between independent variables and by computing the variance inflation factor (VIF). VIF values exceeding 10 indicates serious multicollinearity, and values greater than 4 may be a cause for concern [85]. The discriminative power of the logistic model equations was determined by running a receiver operating characteristic (ROC) curve, and by calculating the relative area under the curve (AUC). The goodness of fit of the predictive models was assessed through the Hosmer-Lemeshow test.

Because of the confounding effect of intra- and postoperative complications on adherence to ERP components, we also performed a sensitivity analysis excluding patients who experienced intraoperative or early postoperative complications (before POD 2).

Descriptive data are reported as mean (95% confidence interval, CI), or median (interquartile range, IQR), otherwise specified. Statistical analysis was performed using STATA® version 13.1 software (StataCorp, College Station, TX, USA). All statistical tests were 2-sided, a "p" value < 0.05 was considered to indicate statistical significance.

2.4 Results

Four hundred and forty patients underwent scheduled bowel resection during the study period. Ninety-three (21%) patients were excluded from the analysis because they were not followed prospectively through the ERAS interactive audit system. The remaining 347 patients were included in this study. Included and excluded patients had similar demographic and clinical features (**Appendix 2**).

Table 2-2 shows baseline characteristics of patients included in the study. One hundred twelve (32%) patients had a low preoperative physical status as measured by ASA score. Two hundred twenty-eight (66%) patients were operated for malignancy, 125 of which (55%) had localized colorectal cancer (TNM stage 0-II).

Table 2-3 includes patients' operative characteristics. One hundred eighty-two (52%) patients underwent segmental colonic resection, while 121 (35%) patients underwent pelvic surgery including low anterior resection, abdominoperineal resection and total proctocolectomy. Two hundred seventy-eight (80%) patients were approached with laparoscopy, 28 (8%) required conversion to an open procedure. Intraoperative complications occurred in 25 (7%) patients.

Table 2-4 shows adherence rates for single ERP elements. Overall, patients were adherent to median 18 (16 – 20) elements. Median adherence was similar for preoperative, intraoperative and postoperative elements (75, 78, and 80 percent, respectively). The only elements with poor adherence (<50%) were intraoperative balanced intravenous infusions and intake of oral nutritional supplementation on the day of surgery postoperatively.

Table 2-2. Patient characteristics

Variables	**n = 347**
Age (years), mean (95% CI)	63.2 (61.6 – 64.8)
75+ years old	81 (23)
Gender (Male : Female)	179 : 168 (52 : 48)
BMI (kg/m^2), mean (95% CI)	26.2 (25.7 – 26.7)
Obesity (BMI ≥ 30)	73 (21)
Currently smoking	37 (11)
Medically treated diabetes	46 (13)
Immunosuppressant use within 6 months	18 (5)
Neoadjuvant chemotherapy	42 (12)
Previous radiotherapy to operating field	41 (12)
Previous abdominal surgery	151 (44)
Received multimodal prehabilitation	45 (13)
ASA score	
I – II	235 (68)
III – IV	112 (32)
Apfel PONV risk score	
0 – 1	149 (43)
2 – 4	198 (57)
Charlson Comorbidity Index, mean (95% CI)	2.1 (1.9 – 2.3)
CR-POSSUM physiologic score, median (IQR)	9 (7 – 10)
CR-POSSUM operative severity, median (IQR)	8 (7 – 11)
Diagnosis	
Malignancy	228 (66)
TNM stage 0 – II	125 (55)*
TNM stage III	83 (36)*
TNM stage IV	18 (8)*
Other malignancy	2 (1)*
Inflammatory bowel disease	49 (14)
Diverticular disease	28 (8)
Other benign disease	42 (12)

Values are number of patients (%) otherwise noted.

*Percentage relative to malignant patients only.

Table 2-3. Operative characteristics

Variables	n = 347
Procedure performed	
Small bowel resection	9 (3)
Ileocecal resection	9 (3)
Right hemicolectomy	103 (30)
Left hemycolectomy	22 (6)
Rectosigmoidectomy	57 (16)
Subtotal / Total colectomy	15 (4)
Low anterior resection	78 (22)
Abdominoperineal resection	20 (6)
Total proctocolectomy ± IPAA	23 (7)
Other colorectal procedure*	11 (3)
Associated major procedures	10 (3)
Surgical approach	
Open	69 (20)
Laparoscopic	250 (72)
Laparoscopic converted to open	28 (8)
New stoma formation	90 (26)
Duration of surgery (minutes), median (IQR)	184 (136 – 261)
Blood loss (ml), median (IQR)	100 (100 – 300)
Intraoperative fluid infusion, mean (95% CI)	
Overall (ml)	2105 (1973 – 2237)
Maintenance fluids (ml/kg per hour)	7.4 (6.8 – 8)
Use of vasopressors	34 (10)
Main type of anesthesia	
Inhalational	320 (92)
TIVA	27 (8)
Intraoperative complications	
Clinically significant haemorrhage	16 (5)
Cardiac or respiratory complication	4 (1)
Bowel injury	3 (1)
Urinary tract injury	1 (0)
Other	3 (1)
Late discharge from PACU (after 6 pm)	105 (30)

Values are number of patients (%) otherwise noted.

*Includes reversal of Hartmann's procedure (n=5), takedown of end ileostomy + ileorectal anastomosis (n=3), enterocutaneous fistula repair (n=1), and fashioning of diverting transverse colostomy (n=1).

Table 2-4. Patient compliance to enhanced recovery program elements

Enhanced recovery program element		n = 347
Preoperative		
	Preadmission education	347 (100)
	Selective MBP	246 (71)
	Carbohydrate loading	213 (61)
	No long-acting sedation	347 (100)
Intraoperative		
	Antibiotic prophylaxis	345 (99)
	Epidural anesthesia	253 (73)
	Laparoscopic approach	250 (72)†
	Balanced IV fluids	90 (26)
	PONV prophylaxis	320 (92)
	Normothermia	223 (64)
	Avoidance of abdominal or pelvic drainage	298 (86)
	TED prophylaxis	346 (100)
	Avoidance of nasogastric tube drainage	344 (99)
Postoperative		
	Opioid-sparing multimodal analgesia	341 (98)
	Oral liquids on POD 0	309 (89)
	Oral nutritional supplements on POD 0	146 (42)
	Early mobilization out of bed	275 (79)
	Early termination of IV fluid infusion	201 (58)
	Early termination of urinary drainage	298 (86)
	Free diet on POD 1	282 (81)
	Chewing-gum	217 (63)‡
	Laxative	210 (61)
	Transition to oral analgesia by POD 2	255 (73)

Values are number of patients (%).
†Refers to successful completion of laparoscopic resection. ‡Missing data for 108 (31%) patients.

Table 2-5 reports postoperative outcomes. One hundred fifty-six (45%) patients had a successful recovery with early discharge, no readmission and no complications. Median length of primary hospital stay was 4 days (3 – 7); 135 (39%) patients were discharged within the

third day after surgery. One hundred seventy-five (50%) patients experienced at least one complication within 30 days after surgery, 56 (16%) patients were treated for a complication after discharge. Hospital readmissions at 30-days occurred in 44 (13%) patients. Most common reasons for readmission were intra-peritoneal or pelvic abscess (n=10, 23%), bowel obstruction (n=7, 16%), anastomotic leak (n=6, 14%) and other gastrointestinal complications (n=6, 14%).

Table 2-5. Postoperative recovery outcomes

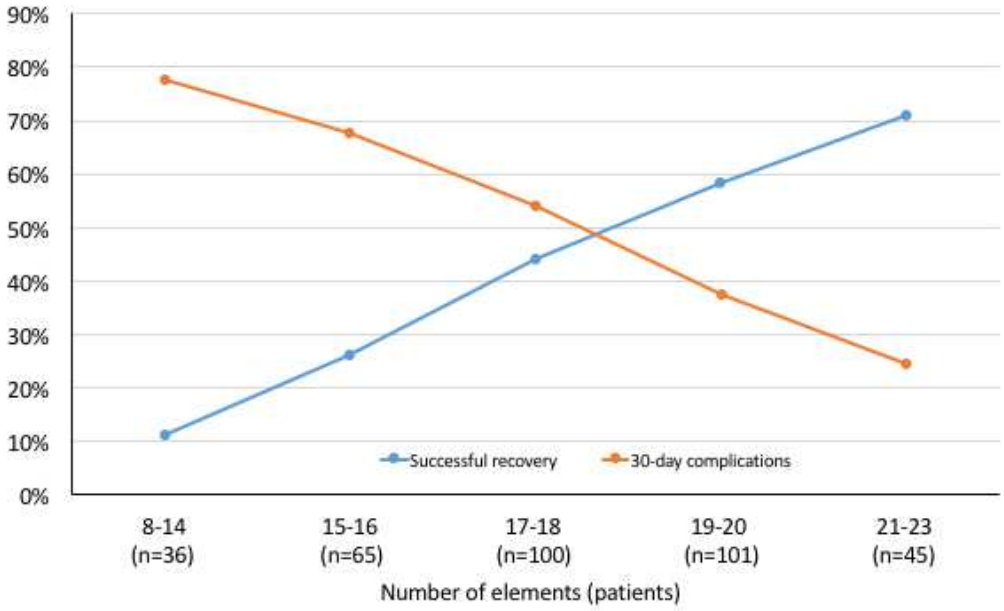
Variables	**n = 347**
Successful recovery	156 (45)
Length of primary hospital stay, median days (IQR)	4 (3 – 7)
Length of total hospital stay, median days (IQR)	4 (3 – 9)
30-day postoperative complications at all	175 (50)
During primary stay	146 (42)
Post-discharge	56 (16)
Timing of first complication (hours), median (IQR)	39 (19 – 80)
Within 24 hours postoperatively	60 (17)
Type of postoperative complications	
Medical complications	93 (27)
Cardiovascular	20 (6)
Respiratory	21 (6)
Other	69 (20)
Infectious complications	72 (21)
Surgical complications	110 (32)
Anastomotic leak	18 (5)
Bleeding	13 (4)
Ileus	71 (20)
Other	19 (5)
30-day reoperations	19 (5)
30-day severe complications (Clavien III-V)	43 (12)
30-day comprehensive complication index, median (IQR)	8.6 (0 – 22.6)
30-day emergency department visits	68 (20)
30-day hospital readmissions	44 (13)

Values are number of patients (%) otherwise noted.

The impact of overall adherence on outcomes

Figure 2-1 shows the significant association between overall adherence to ERP elements and recovery outcomes. There was a positive association between adherence and successful recovery (adjusted OR 1.39 (95%CI 1.24 to 1.57) for every additional element, p<0.001). An inverse relationship was found between adherence and LOS (11% reduction, 95%CI -14 to -8%, p<0.001), 30-day postoperative morbidity (OR 0.78, 95%CI 0.70-0.87, p<0.001), and the CCI (17% reduction, 95%CI -23 to -10%, p<0.001). There was no association between overall adherence to ERP and hospital readmission (adjusted OR 1.03 (95%CI 0.89 to 1.18) for every additional element, p=0.726).

Figure 2-1. Relationship between overall adherence, successful recovery and 30-day complications



Predictors of recovery outcomes

Table 2-6 reports univariate logistic regression for predictors of successful recovery including patient- and procedure-related confounding factors such as age, gender, ASA score, type of surgery, and intraoperative complications. At multivariate analysis (**Table 3-7**), laparoscopy (OR 4.32, 95% CI 2.26 to 8.27, p<0.001), early mobilization out of bed (OR 2.25, 95% CI 1.13 to 4.47, p=0.021), and early termination of IV fluid infusion (OR 2.00, 95% CI 1.16 to 3.45, p=0.013) were significantly associated with successful recovery. These factors

were also key elements associated with reduction in LOS, 30-day postoperative morbidity and complication severity index as measured by the CCI. In addition, intraoperative balanced IV fluids was associated with a 21% reduction in LOS, while epidural anesthesia prolonged LOS by 19%.

Table 2-6. Univariate analysis for predictors of successful recovery

Variables	Univariate analysis		
	OR	95% CI	P value
Patient characteristics			
Age ≥ 75 years	0.570	0.340 to 0.955	0.033
Male gender	0.673	0.440 to 1.029	0.068
Obesity (BMI ≥ 30)	1.203	0.744 to 2.094	0.400
ASA physical status 3+	0.403	0.251 to 0.651	< 0.001
Charlson comorbidity index 3+	0.529	0.321 to 0.868	0.012
Previous abdominal surgery	0.442	0.285 to 0.685	< 0.001
Inflammatory bowel disease	0.491	0.257 to 0.940	0.032
Procedural factors			
Pelvic surgery	0.495	0.313 to 0.782	0.003
New stoma	0.370	0.219 to 0.623	< 0.001
Intraoperative complications	0.213	0.072 to 0.635	0.005
Late discharge from PACU (after 6pm)	0.647	0.419 to 1.067	0.091
Enhanced recovery elements			
Selective MBP	1.082	0.679 to 1.727	0.738
Carbohydrate loading	1.295	0.837 to 2.005	0.246
Epidural anesthesia	0.564	0.350 to 0.909	0.019
Laparoscopic surgery	4.977	2.843 to 8.712	< 0.001
Intraoperative balanced IV fluids	1.033	0.638 to 1.673	0.894
Selective PONV prophylaxis	0.741	0.337 to 1.626	0.455
Normothermia	0.693	0.455 to 1.077	0.103
Avoidance of abdominal drainage	3.274	1.612 to 6.649	0.001
Oral liquids on POD 0	5.031	2.046 to 12.376	< 0.001
Oral nutritional supplements on POD 0	1.492	0.971 to 2.292	0.068
Early mobilization out of bed	3.022	1.686 to 5.416	< 0.001
Early termination of IV fluid infusion	2.917	1.860 to 4.575	< 0.001
Early termination of urinary drainage	5.057	2.293 to 11.151	< 0.001
Free diet on POD 1	3.695	1.957 to 6.978	< 0.001
Chewing-gum	1.381	0.889 to 2.145	0.151
Laxative	1.686	1.087 to 2.617	0.020

Table 2-7. Multivariate regression models for independent predictors of successful recovery, length of hospital stay, morbidity and comprehensive complication index

Outcome measure	**Adjusted multivariate models***		
Enhanced recovery program element	OR† / Beta‡	95% CI	P value
Successful recovery[a]			
Laparoscopic surgery	4.322†	2.260 to 8.267	< 0.001
Early mobilization out of bed	2.249†	1.130 to 4.474	0.021
Early termination of IV fluid infusion	1.997†	1.158 to 3.445	0.013
Early termination of urinary drainage	2.365†	0.956 to 5.854	0.063
Free diet on POD 1	2.045†	0.952 to 4.393	0.067
Length of primary hospital stay			
Epidural anesthesia	0.186‡	0.034 to 0.339	0.017
Laparoscopic surgery	- 0.326‡	- 0.481 to - 0.172	< 0.001
Intraoperative balanced IV fluids	- 0.214‡	- 0.363 to - 0.066	0.005
Early mobilization out of bed	- 0.241‡	- 0.403 to - 0.079	0.004
Early termination of IV fluid infusion	- 0.293‡	- 0.436 to - 0.149	< 0.001
30-day morbidity[b]			
Laparoscopic surgery	0.253†	0.140 to 0.456	< 0.001
Early mobilization out of bed	0.504†	0.268 to 0.948	0.033
Early termination of IV fluid infusion	0.501†	0.302 to 0.830	0.007
30-day comprehensive complication index			
Laparoscopic surgery	- 0.874‡	- 1.123 to - 0.521	< 0.001
Intraoperative balanced IV fluids	- 0.542‡	- 0.675 to 0.019	0.064
Early mobilization out of bed	- 0.443‡	- 0.820 to - 0.065	0.022
Early termination of IV fluid infusion	- 0.859‡	- 0.859 to - 0.226	0.001

*All models were adjusted for age, gender, ASA score ≥3, pelvic surgery, inflammatory bowel disease.
[a]Model statistics: AUC: 0.793; Hosmer-Lemeshow goodness-of-fit test p = 0.626.
[b]Model statistics: AUC: 0770.; Hosmer-Lemeshow goodness-of-fit test p = 0.451

Sensitivity analysis

Excluding patients who experienced intraoperative or early complications (n=71), the positive association between overall adherence to the pathway and successful recovery remained significant (OR 1.37 (95% CI 1.20 to 1.57) for every additional element, p<0.001). At multivariate analysis, laparoscopy (OR 4.61, 95% CI 2.28 to 9.33, p<0.001) and early mobilization (OR 2.22, 95% CI 1.06 to 4.66, p=0.035) were the only factors significantly associated with successful recovery.

2.5 Discussion

This study relying on prospectively collected data in a tertiary Canadian university hospital showed that increased adherence to ERP interventions is independently associated with successful recovery, reduced LOS and complications following bowel surgery. In this large series of patients treated between 2012 and 2014, where mean adherence to the pathway was high, laparoscopic surgery, early mobilization out of bed and perioperative fluid management resulted as key elements correlating with improved postoperative outcomes.

When compared to traditional perioperative care, ERPs in colorectal surgery have been shown to improve postoperative outcomes in terms of accelerating recovery, reducing LOS, medical complications [6], and societal costs [74]. Positive results for ERPs seem to be achieved regardless of the number, type or the combination of interventions implemented in different series [12]. This may suggest that it is not the effect of single ERP elements or the number of elements, but simply the coordination of care into an organized pathway that reduces variability and is sufficient to improve outcomes. In our study, we assessed the relationship between adherence to ERP elements and postoperative results and identified key processes facilitating recovery in order to consider whether additional resources should be allocated to increase adherence to those elements (e.g. dedicated personnel for patient mobilization).

In previous series, adherence was usually lower for postoperative elements [68, 70, 86]. In fact, compliance with postoperative interventions may be influenced by patient symptoms and by the occurrence of complications. In the current series, adherence was high and similar throughout the different perioperative phases reflecting a well-organized and established clinical pathway. In addition, only early postoperative interventions (i.e. within the first 24 hours) were considered in the analysis to limit the potential influence of adverse events on adherence. Low adherence was found for intraoperative fluid infusions and intake of oral nutritional supplements on the day of surgery postoperatively. The former may be related to the lack of a specifically dedicated anesthesia team for colorectal surgery but also to the adoption of a strict definition of adherence following recently published guidelines [87]. The latter represents an organizational problem (e.g. product availability, patient arriving to the surgical ward late in the day). Both elements represent targets for improvement.

Gustafsson and colleagues [68] previously demonstrated that adherence to more than 70% of the planned care processes was associated with lower morbidity and shorter LOS compared to lower adherence. However, they used arbitrary adherence thresholds and did not adjust for the confounding effect of postoperative complications. In our series, patients with higher adherence to the pathway had a greater chance of a successful recovery. In fact, we found a strong association between adherence and outcomes even when patients experiencing intraoperative or early morbidity where excluded from the analysis. For every additional element to which patients were compliant, LOS and 30-day morbidity decreased, confirming results from a large UK study [69] that found a significant inverse relationship between the mean adherence to the ERP and LOS in multiple surgical subspecialties. In our analysis, we chose a composite endpoint as a proxy for successful postoperative recovery, taking into account not only primary hospital stay and morbidity but also hospital readmission, which is a key post-discharge outcome associated with delayed patient recovery and increased healthcare

costs [88]. The use of LOS as measure of postoperative recovery is debated as it may be influenced by non-clinical factors such as surgeon's preference and hospital tradition [42]. An alternative and valid measure of short-term postoperative recovery could have been the time to readiness for discharge (i.e. the time to achieve standardized discharge criteria) [89], but this variable was not part of our database and could not be reliably collected retrospectively.

It is still unclear if there is an ideal combination of perioperative interventions, or if there are single items with a greater impact on recovery within an ERP. In a study including mostly open colonic surgery [71], early mobilization, urinary catheter removal and early oral diet were found as independent predictors of early discharge. However, the lengthy study period including a phase of implementation, and the lack of controlling for confounding factors and postoperative complications are potential sources of bias. In a recent multicenter study by the ERAS compliance group [72], where only preoperative and intraoperative items were considered, carbohydrate loading, laparoscopy and restrictive intravenous fluids were found as independent factors associated with reduced LOS and morbidity, while epidural analgesia delayed discharge. In our cohort, laparoscopic approach, early mobilization and discontinuation of intravenous fluids were key elements associated with successful recovery and reduced 30-day morbidity and complication severity. Epidural analgesia was the only ERP element delaying discharge, corroborating recent evidence from a randomized controlled trial [50]. For laparoscopic colorectal surgery within an ERP, the use of transversus abdominis plane blocks has been proposed as a new opioid-sparing strategy to prevent epidural catheter management issues that may delay discharge [90].

Research shows that laparoscopy in the context of ERPs is associated with reduced pain, ileus [91], and attenuated inflammatory response [92] compared to open surgery. Evidence supports that the combination of laparoscopy and enhanced recovery is associated with improved outcomes. However, ERPs significantly reduce the gap in postoperative results

between open and minimally invasive surgery [40]. Early mobilization after surgery is considered a key component of ERPs. It is well known that staying in bed leads to deconditioning that can largely be prevented by physical activity [61]. However, there is little evidence that the implementation of specific interventions to increase mobilization improves outcomes [62]. In our analysis, simply mobilizing out of bed once on the first day after surgery was a significant predictor of early discharge and reduced morbidity. Future studies are warranted to clarify the impact of mobilization on postoperative recovery and verify if there is a dose-effect relationship.

Adherence to postoperative elements of the pathway may be difficult to interpret as it is confounded by the patient's recovery status. For example, a patient symptomatic for postoperative ileus is less likely to start early oral nutrition and feel like ambulating. Thus, in our regression models we only considered early postoperative elements (up to 24 hours after surgery) that are potentially less influenced by the development of complications, and also performed a sensitivity analysis excluding patients with intraoperative or early postoperative morbidity as previously reported by Larson et al [70]. In this analysis, laparoscopy and early mobilization remained significant factors associated with successful recovery.

Notably, post-discharge complications occurred in 16% of our cohort resulting in a considerable number of patients returning to the emergency department (ED) (20%) and eventually being readmitted (13%). These results corroborate with recent enhanced recovery colorectal surgery series where hospital readmissions ranged between 9 and 13% [40, 93, 94]. In a previous study, compliance to ERP greater than 93% was found as a protective factor for readmission [93]. In our series, adherence to ERP had no effect on post-discharge outcomes. More than half of emergency visits resulted in hospital readmission, mostly because of late infectious and surgical complications requiring in-hospital management. Patients who returned to the ED but were not readmitted represent a target for quality improvement, as they could

have been managed in an outpatient setting or through the local community services or family physicians. Patient information regarding post-discharge care can certainly be improved. In addition, establishing a dedicated follow-up service may also be considered in order to anticipate any serious clinical issue or to prevent unnecessary ED visits.

Strengths and limitations

Although data was prospectively collected and patients were followed by an independent auditor not involved in clinical activities, this analysis carries intrinsic limitations of all observational studies. Sample size may be considered insufficient for the regression analysis we carried out because of the high number of predictors included. However, we limited our series to 2 consecutive years to avoid time-related bias since ERPs are constantly evolving through time, and new elements are added or removed according to the evidence. Around 20% of patients who underwent colorectal resection in our institution in the target period were not included in this series as their data was not prospectively collected. These patients were randomly missed because of personnel unavailable to record data. While retrospective chart review can provide reliable postoperative outcome data, it does not provide patient reported information regarding adherence. Thus, it was decided to exclude these patients from the study to ensure a high quality of the data. Notably, no difference in preoperative characteristics and postoperative outcomes was found between included and excluded patients.

Main strengths of this study were that it followed recent recommendations for reporting and used clear definitions of adherence and outcome measures [95]. In fact, most of the existing works on enhanced recovery fail to thoroughly report the definitions of adherence to each implemented interventions. Other strengths and unique features of this study include the use of sensitivity analysis, and the choice of a composite endpoint encompassing different clinically-relevant recovery outcomes allowing us to better ascertain the role of adherence to ERP

elements and its association with postoperative results. Furthermore, all multivariate models were adjusted for relevant factors influencing adherence and postoperative outcomes including patient comorbidities and procedural factors as previously described [82, 96].

The findings of this study confirm the positive impact of ERP interventions on recovery and suggest that auditing adherence to the pathway is a key metric to assess the effectiveness of an ERP. Our results should encourage the allocation of resources towards strategies likely to increase adherence. For example, adopting a structured pathway for all bowel resection patients with standardized sets of perioperative clinical orders minimizes the variability of patient care favoring adherence to care processes. In addition, reinforcing perioperative education and patient engagement in the pathway may prove effective in improving adherence to elements requiring a high degree of self-management such as mobilization and diet.

Conclusions

In this retrospective study relying on prospectively collected data within an established ERP, increased adherence to enhanced recovery interventions was associated with successful early recovery and a reduction in postoperative morbidity and complication severity. Laparoscopic approach, perioperative fluid management and patient mobilization were key elements associated with improved outcomes. Our findings suggest that further measures should be implemented to increase adherence to ERP interventions.

CHAPTER 3:

Tools to improve adherence to ERP elements

The previous chapter included the results of a large retrospective study we performed at the Montreal General Hospital using patient-level data to assess the value of adherence to perioperative ERP elements. In our analysis, we found that increased adherence to care processes is associated with shorter length of hospital stay, less complications and successful 30-day recovery. In addition, we found that certain postoperative ERP elements highly dependent on patient participation (e.g. mobilization out of bed) are key determinants for a successful recovery.

Adherence may be influenced by multiple factors, at patient (e.g. age, physical status, level of education), procedural (e.g. type of surgery), organizational (e.g. number of nurses per patient, availability of beds), and outcome (e.g. postoperative symptoms, complications) level. Feroci et al. analyzed the relationship of six patient and procedural factors (gender, BMI, age, type of surgery, stoma, pathology) with compliance to a colorectal pathway [82]. They reported that male sex and older age were independent factors affecting adherence to urinary catheter removal, while low preoperative physical status (i.e. ASA 3+) was associated with poorer early mobilization and early oral feeding. A more recent study performed by our research group found that the extent of surgical resection (i.e. rectal vs. colonic surgery), a late arrival at the surgical ward because of late recovery room discharge, and the occurrence of PONV in the first 24 hours after surgery were independently associated with poor adherence to the pathway interventions [97]. In particular a late arrival at the ward was associated with poor adherence to patient dependent elements such as early mobilization.

Adherence appears to be a key factor influencing postoperative outcomes in the context of an ERP, but remains suboptimal and difficult to achieve. Therefore, it is recommended to implement strategies to improve protocol adherence. These may include:

- Auditing clinical practice: in order to optimize adherence to ERP interventions and improve the quality of the care provided, real-time, patient-level information about adherence to care processes and outcomes is required [7]. Currently, there is a lack of reliable, validated, and cost-effective audit tools that can be used to report patients' experiences, thus representing a barrier to the optimization of ERPs. The ERAS Society® has developed a sophisticated audit tool, the ERAS interactive audit system (EIAS - accessible at https://www.encare.net/healthcare-professionals/products-and-services/eras-interactive-audit-system-eias). However, this tool requires inputting information on over one hundred variables, precluding many centers from implementation due to the cost of the system and resources required for collecting and entering the data.
- Allocating additional personnel: adding more healthcare personnel to assist the patient in reaching daily milestones is another option. This may include allocating extra nurse assistants or physiotherapists to the ward in order to increase patient activity and achievement of nutritional and mobilization outcomes during recovery. It is important to point out that postoperative ERP element can be considered 'passive' (i.e. requiring little or no personal endeavor from the patient, but largely dependent on the clinical team, such as intravenous fluid management and urinary catheter) or 'active' (i.e. requiring significant effort from the patient, such as maintaining an adequate oral intake or mobilizing for a certain amount of time on a specific postoperative day) [97, 98]. Recent research suggests that adherence to 'active' elements is harder to achieve, but is significantly associated with improved postoperative outcomes [98]. Despite these results, an RCT where patients in the intervention group had early mobilization facilitated by a health professional did not show

improvement in postoperative outcomes [63]. These findings showed that allocating additional resources to ensure early mobilization does not translate in better clinical or patient reported outcomes, suggesting that different strategies should be investigated. In this sense, the focus may shift on interventions that increase patient information and engagement in their own recovery.

- Patient directed interventions: as most of the postoperative ERP elements require the patient active participation, it makes sense that interventions should be directed at increasing patient involvement in their own recovery process. This can be done by increasing the information available before and after the surgery, or by using different motivational strategies to increase patient understanding of how important is their participation. Currently, patient education at the McGill University Health Centre includes a preoperative multidisciplinary education session including written information about the upcoming surgery, protocol interventions and expected recovery targets. Patients are also given an illustrative booklet, which incorporates a patient diary to self-record achievement of daily recovery goals (www.muhcpatienteducation.ca). Although counseled to do so, patients frequently do not use the booklet during the hospital stay and the patient diary is rarely completed [99]. In the last decade, there has been increasing interest in the use of mobile technology, such as smartphone and tablet computer apps, as platforms to deliver health education material and capture patient-reported outcome (PRO) data [100]. Recent studies suggest that the use of such technology has the potential to foster behaviour change and improve patient compliance with treatment guidelines [101]. When used for data collection, mobile technology may increase administrative efficiency as information entered directly by patients in their mobile device can be transferred automatically to a secure database. In 2013, the Mayo Clinic tested the use of a new care information platform delivered on an electronic tablet for patient education during surgical recovery after major

cardiac surgery, reporting high patient acceptability and satisfaction [102]. Utilization of electronic devices for patient assessment allows secure data collection, ease of use, and perhaps less resource burden. Output from self-reported questionnaires can be stored directly in electronic databases, and data is readily retrieved for audit and research [103]. A 2013 pilot study by the Cleveland Clinic showed the acceptability and utility of tablet computer – based quality of life and self-reported symptoms questionnaires in 20 cancer patients [104]. The high completion rate and short completion times associated with the direct data transfer from the device to a secure database supported the advantages of this system.

The use of mobile apps to deliver educational material and capture information regarding the achievement of recovery milestones has the potential to change patients' behavior, enhancing their engagement with ERPs, increasing process adherence, and improving postoperative outcomes. This approach may also increase satisfaction with care as it empowers patients as the main stakeholders in the recovery process. At the Steinberg-Bernstein Centre for Minimally Invasive Surgery we developed a customized mobile app to support the Montreal General Hospital ERP for bowel surgery. In the next chapter, we present the manuscript regarding a prospective single-group feasibility pilot study testing a new health information technology system designed to support surgical recovery and record patient adherence to the ERP. The study focused on validation of the app for data collection and tested its usability and acceptability.

CHAPTER 4:

MANUSCRIPT #2: App pilot study assessing validity and usability

An app for patient education and self-audit within an enhanced recovery program for bowel surgery: a pilot study assessing validity and usability

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Article category: Original article, prospective cohort pilot study.

Key-words: mobile applications; health education; outcome and process assessment (Health Care); colorectal surgery; enhanced recovery.

4.1 Abstract

Introduction: While patient engagement and clinical audit are key components of successful enhanced recovery programs (ERPs), they require substantial resource allocation. The objective of this study was to assess the validity and usability of a novel mobile device application for education and self-reporting of adherence for patients undergoing bowel surgery within an established ERP.

Methods: Prospectively recruited patients undergoing bowel surgery within an ERP used a novel app specifically designed to provide daily recovery milestones and record adherence to 15 different ERP processes and 6 patient reported outcomes (PROs). Validity was measured by the agreement index (Cohen's kappa coefficient for categorical, and interclass correlation coefficient (ICC) for continuous variables) between patient reported data through the app and data recorded by a clinical auditor. Acceptability and usability of the app were measured by the System Usability Scale (SUS).

Results: Forty-five patients participated in the study (mean age 61, 64% male). Overall, patients completed 159 of 179 (89%) of the available questionnaires through the app. Median time to complete a questionnaire was 2 min 49 s (i.q.r. 2'32''- 4'36''). Substantial (kappa>0.6) or almost-perfect agreement (kappa>0.8) and strong correlation (ICC>0.7) between data collected through the app and by the clinical auditor was found for 14 ERP processes and 4 PROs. Patient reported usability was high; mean SUS score was 87 (95%CI 83-91). Only 6(13%) patients needed technical support to use the app. Forty(89%) patients found the app was helpful to achieve their daily goals, and 34(76%) thought it increased their motivation to recover after surgery.

Conclusions: This novel application provides a tool to record patient adherence to care processes and patient reported outcomes, with high agreement with traditional clinical audit, high usability and patient satisfaction. Future studies should investigate the use of mobile device apps as strategies to increase adherence to perioperative interventions.

4.2 Introduction

Enhanced recovery programs (ERP) are standardized, multimodal pathways incorporating evidence-based perioperative interventions to improve patient recovery after surgery [4]. In patients undergoing elective colorectal resection, ERPs are now considered the best available perioperative care bundles, following evidence from randomized controlled trials showing reduced postoperative morbidity and shorter length of hospital stay (LOS) compared to traditional care.[6] Recent studies suggest that the degree of adherence to the pathway interventions correlates with the degree of improvement in outcomes [68, 105]. In particular, compliance with postoperative diet and mobilization goals, which strongly rely on patient collaboration, have been identified as independently associated with LOS and complications[70, 105].

Patient education and audit are integral components of ERPs. As suggested by the Enhanced Recovery After Surgery (ERAS) Society® guidelines, patients should receive dedicated preoperative counseling, including information about their surgery and what to expect during their recovery [7]. This is a key element to increase patient knowledge, self-management and engagement to the pathway. In addition, auditing the degree of adherence to care processes is crucial to identify gaps in the pathway and optimize perioperative interventions. The importance of monitoring patient-reported outcomes (PROs) is also increasingly recognized in the literature as a mean to improve patient-centered care [106]. However, currently available tools to collect audit and PRO information are resource intensive, requiring dedicated personnel to prospectively gather, enter and collate data. As a result, this information is often not available at the point of care.

In the last decade, the use of mobile computing and communication technologies in healthcare and public health has been constantly expanding. Mobile device applications for health can target professionals, patients, or the general population [100]. They can serve patients both in everyday life, and during hospitalization or rehabilitation. Recent studies

suggest that the use of mobile technology can improve patient information as well as compliance with treatment guidelines, and can increase administrative efficiency [101]. A few centers successfully tested mobile device technology to inform surgical patients about their daily plan during postoperative hospital stay, or to monitor their conditions after hospital discharge, showing high patient acceptability and satisfaction [102, 107, 108]. In the context of ERPs, an app for education and self-auditing has the potential to be a resource-efficient way to increase patient engagement with ERP, improve adherence and collect PRO data to inform care.

The objective of the present study was to validate a novel mobile device application to improve patient knowledge and allow for self-reported adherence, and test its usability and acceptability in patients undergoing bowel surgery within an established ERP.

4.3 Methods

Study design

This is a prospective, single group, pilot study testing the implementation of a new health information technology system designed to support surgical recovery and record patient adherence to an ERP for bowel surgery. Adult patients (≥ 18 years) scheduled for elective bowel surgery at a university-affiliated tertiary teaching institution were considered for inclusion. Patients were ineligible if they were planned to receive a stoma, were unable to understand or read English or French, or were included in another clinical intervention trial. Study approval was granted by the Institutional Review board (14-240-SDR), and patients signed a written informed consent.

Mobile device app

A mobile device app developed by SeamlessMD® (Seamless Mobile Health Inc., https://seamless.md) was customized to the Montreal General Hospital ERP for colorectal

surgery. This app includes reminders of daily recovery milestones (**Figure 4-1a**); questionnaires to track patient adherence to ERP processes and assess patient reported outcomes (PROs) (**Figure 4-1b**); and contains a patient education section. At the end of each questionnaire, the app provides feedback on the adherence to individual ERP elements (**Figure 4-2a**), achievement of criteria for hospital discharge (**Figure 4-2b**), and encourages the patient to reach daily goals.

Figure 4-1. a) Daily milestones for postoperative day 1 as shown in the app. **b)** Questionnaire to self-record adherence to perioperative care processes

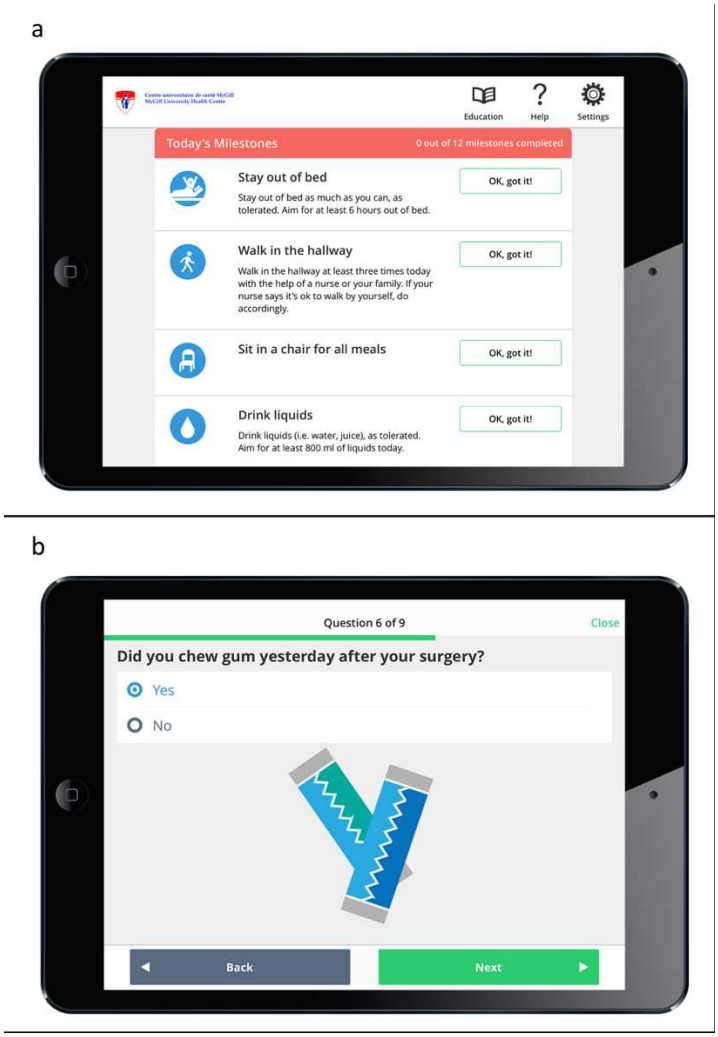
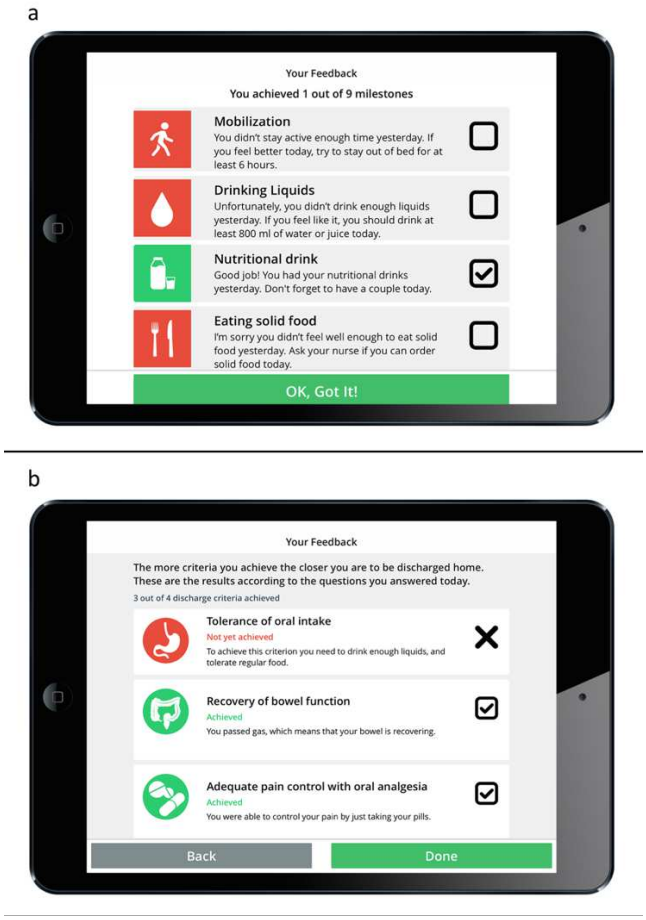


Figure 4-2. a) Feedback after completing a daily questionnaire on adherence to ERP items. **b)** Achievement of criteria for hospital discharge based on daily questionnaire responses



The educational content of the app was developed in collaboration with the multidisciplinary Surgical Recovery Research Group at the Montreal General Hospital. It was partly derived from the educational booklet (available at http://www.muhcpatienteducation.ca/surgery-guides.html) that is routinely given to the patients at the preoperative visit. The app was created in both French and English. It uses simple language consistent with the low health-literacy level in many patients targeting U.S. school grade 7 according to Flesch–Kincaid readability test, and includes compelling illustrations to further support understanding and engagement with the app content.

Data recorded by the patients on the application were stored in the mobile device's own secure application database, and were transmitted through an encrypted connection to a secure

data server. At any time, the study investigators could access an online interface to visualize data and monitor the patient's progress through the ERP.

Intervention

Patients involved in the study were treated within the standards of care at our institution, following a well-established ERP for bowel surgery [105] with a targeted length of hospital stay (LOS) of 3 days. The pathway includes multidisciplinary counseling done at the preoperative clinic, where patients are given an illustrated booklet comprising daily milestones to achieve during their recovery.

At the preoperative clinic, consenting patients underwent a brief education session on the use of the mobile device and the study app. During hospital stay, when they returned to the ward after the end of surgery, patients received a tablet (i.e. iPad®, Apple®, Cupertino, CA) loaded with the application, and a single-page instruction manual to facilitate the use of the app. The device was presented in a sealed disposable plastic cover and remained in the patient's hospital room until discharge. Every morning until discharge, the patient was prompted by the app to complete a short questionnaire about adherence to the previous day's milestones and other postoperative outcomes. The full questionnaires are available as **Appendix 3**. Throughout the day, patients received multiple notifications from the mobile device to remind them of their daily recovery targets, and to review the education material. To encourage the use of the mobile device, patients were also allowed to use the tablet for internet browsing, messaging and other functionalities. Once a day, a member of the research team visited the patient to verify that the device was functioning properly and provided technical assistance with the app if needed. On POD 3, or at time of discharge (whichever came first), patients were prompted to complete a feedback questionnaire regarding their experience using the app. At

any time, patients could ask for help via email through a specific tab available on the app dashboard.

Outcome assessment and data collection

Patients were assessed at baseline (at the preoperative clinic), during hospital admission, and 4 weeks after surgery (phone follow-up). Demographic and clinical data were obtained from the medical records. Patient health literacy was measured using specific questions previously validated to screen patients with low health literacy levels [109]. Patients were also queried about their comfort and experience using smartphones.

To contribute evidence for the validity of the app to record patient adherence to the ERP care processes and PROs, we measured the agreement rate between patient self-reported data collected via the app with those collected by a clinical auditor. The latter data was recorded by an assessor unaware of the patient's responses through the app and with no access to the online app interface. To balance the potential recall bias related to questions regarding ERP milestones of the previous day, both the app questionnaire and the clinical auditor data collection took place at a similar time during the morning.

The usability of the app was measured with the System Usability Scale (SUS) (Digital Equipment Co Ltd., Reading, UK).[110] This is a ten-item 5-point Likert scale giving a global assessment of usability, defined as the subjective perception of interaction with a system. This tool considers three different aspects of usability as defined by the International Organization for Standardization (ISO) 9241: effectiveness (i.e. can users successfully achieve their objectives); efficiency (i.e. how much effort and resource is consumed in achieving those objectives); satisfaction (i.e. subjective reaction with this experience). The scale yields a score from 0 to 100. According to Bangor et al [111], mean SUS scores greater than 70 reflect good

usability, and above 85 excellent usability. Factor analysis of SUS item structure supports the use of two sub-scales: an 8-item "Usability" and 2-item "Learnability" scale [112].

Usability and acceptability of the app were further assessed evaluating app utilization parameters including overall usage time, time to complete the questionnaires, rate of completed questionnaires, and need for technical assistance.

Patient satisfaction was measured via a short likert scale questionnaire, and the NET promoter score (Bain & Company Inc., Boston, MA), which is a customer loyalty metric calculated based on responses from 1 to 10 to a single question: "How likely is it that you would recommend our company/product/service to a friend or colleague?". Individuals responding with a score of 9 or 10 are called "Promoters"; those with a score of 7 or 8 are considered "Passive"; responses of 6 or less are labeled "Detractors". The NET promoter score is calculated by subtracting the percentage of Detractors from the percentage of Promoters, and ranges from -100 to 100.

Statistical analysis and sample size

Statistical analysis was performed using Stata (Version 13, StataCorp, College Station, Texas). $P<0.05$ was considered statistically significant.

Descriptive data are reported as mean (95% confidence interval, CI), or median (interquartile range, IQR), unless otherwise specified.

Validity was assessed by evaluating the Cohen's kappa coefficient for categorical variables, and the intraclass correlation coefficient (ICC) for continuous numerical variables. Kappa coefficients between 0.61 and 0.80 indicate "substantial agreement" and between 0.81 and 1.00 indicate "almost perfect agreement". ICC coefficients of 0.70 or higher indicate good reliability [113]. In addition, the absolute agreement rate between patient self-reported responses collected via the app with those collected by a clinical auditor was also reported.

Sample size requirement was estimated to obtain kappa values of 0.8 (considering the null value of kappa to be 0.4) and to achieve 80% power [114]. According to this estimate, a sample of 42 participants was considered sufficient for our analysis. A sample size of 45 participants was targeted to account for possible missing data.

4.4 Results

The study took place between May and October 2015. Of 89 patients screened for eligibility, 38 did not meet eligibility criteria, 6 were eligible but did not consent, and 45 received the intervention and were included in the study (**Figure 4-3**).

Figure 4-3. Flow chart of the study

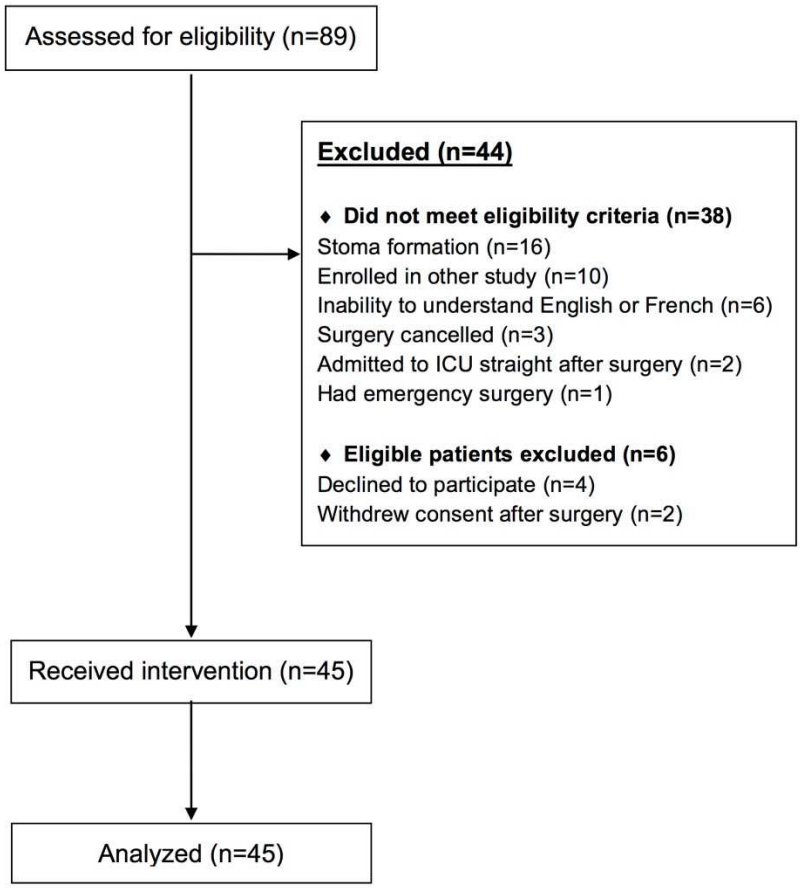


Table 4-1 shows patient demographics and clinical characteristics. Twelve (27%) patients included in the study were older than 70 years. Most patients underwent a stoma closure (n=18, 40%) or a segmental colectomy (n=17, 38%). Cancer was the most frequent indication for surgery (n=30, 67%). Postoperatively, 17 patients (38%) experienced a complication within 30 days of surgery.

Table 4-1. Demographics and clinical variables

Variables	**n = 45**
Age: 50 years old or less	11 (24)
50-70 years	22 (49)
> 70 years old	12 (27)
Male gender	29 (64)
BMI (kg/m^2), mean (95% CI)	27.6 (25.9 – 29.3)
Previous abdominal surgery	27 (60)
ASA score III+	9 (20)
Diagnosis	
Malignancy	30 (67)
Inflammatory bowel disease	9 (20)
Diverticular disease	2 (4)
Other benign disease	4 (9)
Procedure performed	
Stoma closure*	18 (40)
Segmental colectomy	17 (38)
Rectosigmoidectomy	5 (11)
Low anterior resection	5 (11)
Surgical approach	
Open	8 (18)
Laparoscopic	23 (51)
Approach through existing stoma	14 (31)
Intraoperative complications	5 (11)
30-day postoperative complications at all	17 (38)
Type of postoperative complications	
Infectious	4 (9)
Cardiorespiratory	3 (7)
Ileus	3 (7)
Bowel obstruction	3 (7)
Anastomotic leak	1 (2)
Other medical complications	5 (11)
Length of hospital stay, median (IQR)	3 (2 – 4)
30-day hospital readmission	7 (16)

Values are number of patients (%) otherwise noted; BMI, body mass index; ASA, American Society of Anesthesiologists.

*Includes closure of ileostomy (n=14), takedown of end ileostomy + ileorectal anastomosis (n=3), and Hartmann reversal (n=1).

Seventeen patients (38%) had no prior experience with mobile device technology. Seven patients (16%) reported some difficulty in learning about their medical condition and filling out medical forms, while 8 patients (18%) sometimes needed help to read hospital materials (**Table 4-2**).

Table 4-2. Patient characteristics and health literacy.

Variables	**n = 45**
First language	
English	21 (47)
French	16 (35)
Other	8 (18)
Level of education	
Less than high-school	4 (9)
High-school graduate	15 (33)
University graduate	26 (58)
Experience with a smartphone or tablet	
None	17 (38)
One year or less	5 (11)
More than a year	23 (51)
"Problems learning about medical condition" *	
"Never" or "Occasionally"	38 (84)
"Sometimes"	4 (9)
"Often" or "Always"	3 (7)
"Needs help to read hospital materials" †	
"Never" or "Occasionally"	37 (82)
"Sometimes"	5 (11)
"Often" or "Always"	3 (7)
"Confidence filling out medical forms" ‡	
"Quite a bit" or "Extremely"	38 (84)
"Somewhat"	3 (7)
"Not at all" or "A little bit"	4 (9)

Values are number of patients (%)

* "How often do you have problems learning about your medical condition because of difficulty understanding written information?"

† "How often do you have someone help you read hospital materials?"

‡ "How confident are you filling out medical forms by yourself?"

Table 4-3 includes the results of the validation of the app for self-audit of adherence to ERP care processes. Almost perfect (k > 0.8) or substantial (k > 0.6) agreement between data collected through the app and by the clinical auditor, and good reliability (ICC > 0.7) was found for all care processes except for the reporting of pain control with oral analgesia (k=0.578, 95% C.I. 0.39 – 0.77). Absolute agreement rates ranged from 56% (i.e. reporting of amount of time spent in a chair) to 100% (i.e. reporting of preoperative counseling done and urinary catheter removal).

Table 4-3. Assessment of validity of the adherence to care processes reported by the patient through the app compared to that recorded by a clinical auditor

Elements of the pathway assessed	Agreement rate	Agreement index*	95% C.I.
Preoperative elements			
Preoperative counselling	100%	k = 1.000	1.0 – 1.0
Preoperative carbohydrate drink	91%	k = 0.661	0.44 – 0.88
Preoperative fasting	86%	k = 0.722	0.52 – 0.93
Preoperative mechanical bowel preparation	89%	k = 0.733	0.51 – 0.95
Postoperative elements			
Oral liquids intake (mL)	62%	ICC = 0.726	0.63 – 0.80
Nutritional drink intake	94%	k = 0.910	0.84 – 0.96
Solid food intake	95%	k = 0.897	0.82 – 0.98
Chewing gum	94%	k = 0.825	0.70 – 0.95
Urinary catheter removal	100%	k = 1.000	1.0 – 1.0
Intravenous fluids infusion	87%	k = 0.734	0.58 – 0.89
Use of laxative	91%	k = 0.802	0.66 – 0.94
Breathing exercises	94%	k = 0.808	0.67 – 0.94
Pain control with oral analgesia	80%	k = 0.578	0.39 – 0.77
Amount of time sitting in a chair (minutes)	56%	ICC = 0.879	0.83 – 0.91
Distance walked (number of hallway laps)	79%	ICC = 0.929	0.90 – 0.95

*Agreement indices are Cohen's kappa (κ) values for categorical variables and intraclass correlation coefficient (ICC) for continuous measures.

Validity was supported for self-reporting of 4 PROs (i.e. nausea and pain VAS scores, and passage of stool and flatus). The agreement index was suboptimal for reporting of ability to get out of bed independently (k=0.318, 95% C.I. -0.16 – 0.79), and ability to go to the bathroom independently (k=0.517, 95% C.I. 0.16 – 0.88) (**Table 4-4**).

Table 4-4. Validity of patient reported outcomes collected through the app compared to those collected by the clinical auditor.

Patient reported outcomes	Agreement rate	Agreement index*	95% C.I.
Nausea VAS score	74%	ICC = 0.864	0.81 – 0.90
Pain VAS score	54%	ICC = 0.781	0.70 – 0.84
Passage of flatus	92%	k = 0.821	0.68 – 0.95
Passage of stool	88%	k = 0.751	0.60 – 0.90
Ability to get out of bed independently	95%	k = 0.318	-0.16 – 0.79
Ability to go to the bathroom independently	93%	k = 0.517	0.16 – 0.88

*Agreement indices are Cohen's kappa (κ) values for categorical variables and interclass correlation coefficient (ICC) for continuous measures.

Table 4-5 reports data on app acceptability and usability. During their hospital stay, patients used the application a median 10 minutes per day (IQR 5-16). Overall, patients completed 159 of 178 (89%) available questionnaires. Thirty-four patients (76%) completed all their questionnaires, 11 (24%) missed one or more questionnaires. Reasons for not completing a questionnaire included: ongoing postoperative complication (n= 8); patient forgot (n=7); patient didn't understand the task (n=2); technical issue with the tablet or app (n=2). Six patients (13%) asked for technical support while using the app. Reasons for technical support were due to patients unintentionally logging out of the app (n=4), and mobile device malfunctioning (n=2). Mean overall SUS score was 85 (83 - 91), while the usability and learnability domain mean scores were 88 (83 - 94) and 84 (77 - 91), respectively.

Table 4-5. App usability and acceptability measures.

Parameters	n = 45
Accessing the app (times per day), median (IQR)	2 (1 – 3)
Time spent using the app (minutes per day), median (IQR)	10 (5 – 16)
Questionnaires completed, n (%)	159 (89)*
Time to complete a questionnaires (seconds), median (IQR)	169 (152 – 276)
Need for technical support	6 (13)
Assisted by a family member	4 (9)
SUS overall score, mean (95% CI)	87 (83 – 91)
SUS usability domain, mean (95% CI)	88 (83 - 94)
SUS learnability domain, mean (95% CI)	84 (77 – 91)

Data are number of patients (%), otherwise specified.

SUS System usability scale.

* Percentage refers to 178 overall questionnaires available.

Table 4-6 includes the SUS and patient satisfaction questionnaires in details. Forty (89%) patients found that the app was very helpful to understand and achieve their recovery goals. Thirty-four (76%) patients reported that the app increased their motivation to recover after surgery. The NET promoter score was +47. Twenty-four (53%) patients were considered promoters (score 9-10), 15 (33%) passive (score 7-8), 4 (9%) detractors (score 0-6), and 2 (4%) didn't answer the question.

Table 4-6. System usability scale and patient satisfaction questionnaires

Questions	"Strongly agree" or "agree"	Neutral	"Strongly disagree" or "disagree"	Did not respond
System Usability Scale				
"I think I would like to use this system frequently"	33 (73)	3 (7)	7 (16)	2 (4)
"I found the system unnecessarily complex"	2 (4)	1 (2)	40 (89)	2 (4)
"I thought the system was easy to use"	38 (84)	3 (7)	2 (4)	2 (4)
"I think I would need the support of a technical person to be able to use this system"	3 (7)	8 (18)	32 (71)	2 (4)
"I found the various functions in this system were well integrated"	36 (80)	5 (11)	2 (4)	2 (4)
"I thought there was too much inconsistency in this system"	0	3 (7)	40 (89)	2 (4)
"I would imagine that most people would learn to use this system very quickly"	39 (87)	3 (7)	1 (2)	2 (4)
"I found the system very cumbersome to use"	1 (2)	1 (2)	41 (91)	2 (4)
"I felt very confident using the system"	37 (82)	4 (9)	2 (4)	2 (4)
"I needed to learn a lot of things before I could get going with this system"	3 (7)	4 (9)	36 (80)	2 (4)
Patient satisfaction				
"I felt very informed about what to do during my recovery after surgery"	37 (82)	3 (7)	3 (7)	2 (4)
"This app was very helpful to understand and achieve my recovery goals"	40 (89)	2 (4)	1 (2)	2 (4)
"This app increased my motivation to recover after surgery"	34 (76)	7 (16)	2 (4)	2 (4)
"The information contained in this app was consistent to what my nurse and surgeon told me"	41 (91)	2 (4)	0	2 (4)

Values are number of patients (%)

4.5 Discussion

This prospective pilot study contributes evidence for the validity of a novel mobile device app created to guide patients through an ERP for bowel surgery, record their adherence to perioperative care processes, and establish a platform for real-time assessment of PROs. Patients participating in the trial reported high usability and satisfaction with the app; most of them felt that the app was very helpful to understand and achieve their recovery goals and motivate them to recover from surgery. Future studies should investigate if the implementation of patient-centered customized apps within an ERP can increase adherence to care processes and improve recovery outcomes and satisfaction with care.

ERPs include multiple perioperative interventions, adherence to which has been shown to yield better clinical outcomes [68, 105]. Adherence depends on multiple organizational (e.g. clinical team coordination, use of standardized clinical orders, availability of high nurse staffing), procedural (e.g. type of surgery, occurrence of postoperative complications or symptoms), and patient-related factors (age, functional capacity, comorbidity) [72]. Interestingly, Thorn et al. differentiated between 'passive' ERP elements (i.e. requiring little or no personal endeavor from the patient, such as intravenous fluid management and laparoscopic surgery) and 'active' ones (i.e. requiring significant effort from the patient such as maintaining an adequate oral intake or mobilizing for a certain amount of time on a specific postoperative day) [98]. In their study, adherence to 'active' elements was harder to achieve, but was significantly associated with improved postoperative outcomes. Likewise, previous colorectal surgery series pointed out that adherence to 'active' elements such as early oral intake and mobilization out of bed were independently associated with reduced morbidity and LOS [70, 105]. These findings suggest that patients are the main actors in the surgical recovery process, and their education and full engagement in the pathway are key aspects for positive outcomes.

The approach to education (setting, educator), mode of delivery (written, electronic, face-to-face, etc.) and timing may affect patient's ability to retain information [14]. Education is most effective when the content is personalized, when multiple delivery means are utilized, and when delivery occurs in multiple sessions. Previous research also suggests that the addition of multimedia material is associated with greater patient satisfaction and maximizes information gain [15]. In our well-established ERP, patient education has been carried out via a preoperative multidisciplinary informative session and an illustrative booklet incorporating information about the upcoming surgery, protocol interventions, expected recovery targets, and a patient diary to self-record achievement of daily recovery goals. Although advised to do so, patients frequently forget to use the booklet during the hospital stay and the patient diary is rarely completed [99]. In this pilot trial, we developed an app that prompted patients to report their daily activities through simple multiple choice questions, allowing us to assess adherence to care processes instantly. The app also provided a list of daily milestones to achieve and encouraged patients to reach their goals, thus engaging them throughout their hospital stay as main stakeholders of their own recovery. Despite the limited amount of accesses per day, and effective time in which patients actively used the app, our trial yielded encouraging results in terms of usability, and satisfaction. Mean usability score measured by a widely-used tool (i.e. SUS) was 85, which is considered 'excellent' per a recently proposed adjective rating scale for SUS scores [111], and higher then other health-related apps. For example, in a 2014 report on a mobile app developed to support cancer patients in illness management, the average SUS ratings were 72 [115].

Patient satisfaction is increasingly regarded as an important quality indicator in patient-centered care, gaining much attention in both anesthesia [116] and surgery [117]. Satisfaction is a complex construct influenced by cultural, cognitive, emotional factors [118], and it mainly relates to patient expectations. Accordingly, patient information and communication are the

most important factors influencing patient satisfaction [117]. In this pilot study, more than 80% patients felt well informed about their perioperative period, and around 90% of them reported that our app was very helpful to understand and achieve their recovery goals. This resulted in a positive NET promoter score, where most patients would recommend the use of our app to others.

Measuring compliance to perioperative care processes is a fundamental aspect in improving the quality of surgical care. Accordingly, the ERAS Society® guidelines recommend auditing adherence to perioperative elements, referring to it as "a key instrument to assist clinicians implementing an ERP, to direct future education and the modification of other interventions" [7]. However, there is a lack of reliable and validated audit tools that can be used to report patients' experiences and outcomes, thus representing a barrier to the optimization of ERPs. Furthermore, the auditing process for adherence is resource-intensive, requiring dedicated clinical auditors to prospectively collect patient-reported data each day. Our app proposed a new mechanism to record adherence to ERP aiming to obviate this problem. In the current study, self-reported data through the app had high agreement with those recorded by a clinical auditor, which may be considered the "gold standard" in prospective data collection. Thus, in the context of an ERP for bowel surgery, self-recording adherence to perioperative care processes and responses to selected PROs via our app should be considered as valid as those prospectively collected in person by a researcher. In addition, the app sent frequent interactive reminders not only to increase patient engagement but also to limit the amount of missing data from questionnaires. In a previous ERP study from our institution, more than 20% patients were excluded because of missing data, simply because our clinical auditor was unavailable to collect it [105], while missing data was only around 10% in this pilot study. These missing data mostly occurred in patients with ongoing postoperative complications, who were unable to complete the questionnaire because of poor physical

conditions. Notably, few patients required technical assistance, mostly because they were unintentionally logging out of the app. This problem was fixed by the software company during the pilot study, and never occurred again after the first ten patients.

To our knowledge, this is the first prospective study assessing a patient-centered mobile app to support postoperative recovery and self-assess adherence to processes of care and PROs in the context of an ERP for bowel surgery. In recent times, many apps have been developed to aid patients in chronic diseases management and to monitor personal lifestyle (e.g. apps for weight loss and physical exercise) [119]. They seem to facilitate patient monitoring with the potential to improve clinical outcomes. In fact, a mobile app for postoperative monitoring of patient recovery after ambulatory spine surgery was useful to minimize the number of follow-up visits at the outpatient clinic [107]. Interestingly, a recent multicenter phase III randomized trial, showed that the use of a web-based monitoring app, prompting individualized follow-up through an algorithm based on self-reported symptoms, improved overall survival in advanced lung cancer patients due to early relapse detection and better performance status at time of relapse [120]. In our study, PROs and self-assessed adherence to ERP interventions were used for the sole purpose of this research, but could have been readily available for clinicians and eventually influence their clinical decisions. This modality would prove even more useful in outpatient perioperative settings: i) to monitor patient compliance in the context of a prehabilitation program (i.e. optimization of patient conditions before surgery through physical exercise, nutritional supplements intake, etc.); and ii) to facilitate post-discharge follow-up by improving patient-physician communication and potentially reducing unnecessary ambulatory visits.

Also importantly, patient-centered apps have the potential to improve adherence to care processes such as taking medications or completing tasks. In a multicenter RCT, a smartphone app for diabetic patients increased medication adherence and frequency of blood glucose

testing compared with usual care [121]. In similar fashion, our app has the potential to increase adherence to perioperative care interventions, but this needs to be tested in future comparative studies.

Strengths and limitations

Main strengths of this pilot study were its prospective design, including sample size calculation to validate self-audit, and the implementation of this app in a well-established ERP where patient education and perioperative care had already been standardized. In addition, participation was high (i.e. only four eligible patients refused to participate in the study) even in elderly individuals who had never used a tablet before, and patients with limited health literacy levels, further reinforcing the high-level usability of our app.

The present study also carries some limitations. First, patients had a relatively brief time to familiarize with the app before surgery, which may have reduced the patients' ability to interact with the system. Furthermore, patients receiving a new stoma were not included in the study, as this would have required other specific app modules (i.e. stoma education). Satisfaction was measured with the NET promoter score and generic likert scale questions, which are not formally validated to assess surgical care processes. The recently implemented Consumer Assessment of Healthcare Providers and Systems surgical care survey (S-CAHPS) developed by the Surgical Quality Alliance of the American College of Surgeons would have provided stronger and more thorough evidence, but may have generated greater missing data because of its complexity and length [117].

Conclusions

This novel mobile device application provides a tool to record patient adherence to care processes and patient reported outcomes, with high agreement with traditional clinical audit,

high usability and patient satisfaction. Future studies should investigate the use of mobile device apps as strategies to increase adherence to ERP interventions and improve outcomes.

CHAPTER 5:

Conclusions and future direction

Enhanced recovery pathways incorporate numerous perioperative interventions aiming at improving patient recovery after surgery. In colorectal surgery, the implementation of a pathway has proved to ameliorate postoperative outcomes regardless of the number, the type, the combination, or the level of evidence of the elements used. However, poor adherence to ERP elements remains a challenge and benefits may decrease with lower adherence.

In our first study, we assessed the relationship between adherence to ERP elements and postoperative results and identified key processes facilitating recovery, in order to consider whether additional resources should be allocated to increase adherence to those elements. We found that increased adherence to enhanced recovery interventions was associated with successful early recovery and a reduction in postoperative morbidity and complication severity. Laparoscopic approach, perioperative fluid management and patient mobilization were key elements associated with improved outcomes. Our findings suggested that further measures should be implemented to increase adherence to ERP interventions.

As several ERP elements are self-managed and highly dependent on patient engagement (e.g. food intake and early mobilization), educating patients about their care process is considered key to increase adherence, and ensure the successful implementation of ERPs. In addition, to improve the quality of the care provided, real-time, patient-level information about compliance is required. Therefore, we designed and piloted a new mobile device application for patients, tailored on our ERP for bowel surgery. The prospective study we performed showed that the app is a valid tool to record patient adherence to care processes and patient reported outcomes, with high agreement with traditional clinical audit, high usability and patient satisfaction. This suggests that the novel mobile app has the potential to reliably collect

patient-reported recovery information, engaging patients as stakeholders in their recovery process. The impact of using this emerging technology as a tool to increase adherence to the ERP interventions and assist postoperative recovery, however, is still to be determined. A randomized controlled trial (ClinicalTrials.gov identifier NCT03277053) has therefore been planned and performed at this same institution to evaluate to what extent the use of our mobile device app impact on adherence to postoperative ERP elements in comparison to standard preoperative education. The primary hypothesis is that the use of this mobile device application will result in greater adherence to relevant postoperative ERP elements.

Apps can certainly be used in multiple other ways in the perioperative setting. They may prove even more useful in an outpatient setting. For example, an app could be designed to monitor patient compliance in the context of a prehabilitation program (i.e. optimization of patient conditions before surgery through physical exercise, nutritional supplements intake, etc.); in similar fashion, an app could facilitate post-discharge follow-up by improving patient-physician communication and potentially reducing unnecessary ambulatory visits. All these proposals would require validation in the context of a prospective clinical trial.

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Appendix 1: Definitions of complications for bowel surgery

INTRAOPERATIVE COMPLICATIONS [122]

- *Clinically significant hemorrhage:* intraoperative bleeding requiring transfusion of packed red blood cells (PRBC) during surgery or within 24 hours after surgery
- *Bowel injury:* injury of the small or large bowel requiring intraoperative repair or additional resection.
- *Urinary tract injury:* injury of the ureter or bladder requiring intraoperative repair
- *Vascular injury:* injury of any major vessel (e.g. iliac artery or vein) requiring intraoperative repair
- *Cardiac or respiratory complications:* any cardiovascular (e.g. cardiac arrhythmia, myocardial infarction) or respiratory (e.g. pneumothorax) complication occurring during surgery.
- *Aspiration of gastric content:* intraoperative pulmonary aspiration of gastric content
- *Other:* any intraoperative injury to other viscera (e.g. spleen, vagina)

POSTOPERATIVE COMPLICATIONS

MEDICAL

Cardiovascular

- *Heart failure:* clinical or radiological signs of congestive heart failure and specific treatment initiated.[123]
- *Acute myocardial infarction**:*** increase in cardiac biomarker values or characteristic ECG changes or imaging evidence of new loss of viable myocardium or new regional wall motion abnormality.[124]
- *Cardiac arrhythmia:* ECG diagnosis of new arrhythmia requiring at least a pharmacologic intervention.[125]
- *Cardiac arrest:* cardiopulmonary resuscitation performed.
- *Deep vein thrombosis:* radiological confirmation of deep vein thrombosis or anticoagulation started due to clinical findings.
- *Pulmonary embolism:* radiological evidence of pulmonary embolism.
- *Cerebrovascular accident:* new focal or global neurologic deficit of cerebrovascular cause that persists beyond 24 h or is interrupted by death within 24 h.[126]

Respiratory

- *Pneumonia:* Hospital acquired pneumonia, defined as presence of lung infiltrate at chest x-ray accompanied with signs of infection and initiation of antibiotic treatment. [127]
- *Lobar atelectasis:* radiological finding of at least one lobar collapse.[125]
- *Pleural fluid:* pleural effusion requiring drainage of the pleural cavity.
- *Respiratory failure:* delayed extubation > 24 hours after primary surgery, or reintubation at any time for ventilatory support.[125]
- *Pulmonary edema:* clinical signs and radiological confirmation.[128]

Other medical

- *Acute Kidney Injury:* increase in serum creatinine ×2 from baseline or reduction of glomerular filtration rate greater than 50%.[129]
- *Urinary retention:* Reinsertion of indwelling urinary catheter after removal attempt or patient discharged with urinary drainage (excluding patients with permanent indwelling urinary catheter).
- *Anemia:* low serum hemoglobin requiring transfusion of PRBC, unrelated to any identified source of bleeding.
- *Hepatic dysfunction:* Increased serum bilirubin concentration > 34 μmol/l (2 mg/dl) compared to preoperative value AND elevated liver enzymes AND has NOT undergone a pancreaticobiliary procedure.[125]
- *Acute Pancreatitis:* diagnosis requires 2 of the following: upper abdominal pain of acute onset often radiating through to the back; increase in serum amylase or lypase (x3 normal value); cross-sectional abdominal imaging consistent with acute pancreatitis.[130]
- *Other gastrointestinal complications:* any other complication of the gastrointestinal tract requiring treatment (e.g. blood per rectum, diarrhea, high stoma output).
- *Neurological complications:* any neurological complication excluding cerebrovascular events or anesthesia-related injuries (e.g. epileptic seizure)
- *Psychiatric complications:* new psychiatric symptoms including delirium and depression, requiring pharmacological treatment.

INFECTIOUS

- *UTI:* upper or lower urinary symptoms and urine culture with no more than two species of organisms, at least one of which is a bacteria of $\geq 10^5$ CFU/ml.[131]

- *Wound infection:* Purulent drainage, with or without positive culture, from the superficial incision or any sign or symptom of infection (e.g. pain or tenderness, localized swelling, redness) and superficial incision is deliberately opened by the surgeon or attending physician. Not included if part of intra-peritoneal abscess.[132]
- *Intra- or retroperitoneal abscess:* Radiologic finding of deep collection of pus associated with systemic signs of infection or finding during reoperation.
- *Sepsis*: at least two SIRS criteria positive and a documented or suspected infection. SIRS criteria are the following: Temperature < 36 or >38 °C; heart rate >90 beats per minute, respiratory frequency >20 breath per minute, leukocytosis (WBC>12) or leukopenia (WBC<4) AND documented or suspected infection.[133]
- *Other infectious complications:* any other documented infectious complication (e.g. Clostridium difficile colitis).

SURGICAL

- *Anastomotic leak: d*ocumentation at reoperation OR documentation by imaging technique (e.g. radiologically, endoscopically) of leakage from the surgical connection between the two bowel ends into the abdomen or pelvis with either spillage and/or fluid collection around the anastomotic site or extravasation through a wound, drain site, or anus.[134] In the case of rectal surgery, a pelvic abscess close to the anastomosis is also considered as anastomotic leakage.[135]
- *Bowel perforation:* documentation at reoperation OR radiologically of perforation of small or large bowel.[128]
- *Mechanical bowel obstruction:* documentation at reoperation OR radiologically of mechanical small or large bowel obstruction.
- *Wound dehiscence:* separation of the abdominal wall muscle fascia large enough to necessitate operative closure of the wound OR incisional hernia diagnosed after primary discharge.[128]
- *Bleeding:* any postoperative bleeding (e.g. intra-abdominal, gastrointestinal) requiring transfusion of at least 2 PRBC after surgery.[136]
- *Ileus (primary postoperative ileus):* abdominal distention OR vomiting associated with intolerance of solid food intake or inability to pass gas or stool beyond POD3 (target day for discharge), unrelated to any other ongoing complication.

– *Other surgical complications:* any other surgical complication necessitating treatment or delaying discharge (e.g. abdominal wall hematoma).

ANESTHESIA-RELATED

– *Post-dural puncture headache:* persistent headache requiring immobilization, related to puncture of the dura mater during epidural catheter placement
– *Epidural hematoma or abscess:* radiologically confirmed epidural hematoma or abscess
– *Other anesthesia-related complications:* any other anesthesia-related complication occurring after surgery (e.g. peripheral nerve injuries).

SYMPTOMS DELAYING DISCHARGE

– *Pain:* uncontrolled pain requiring prolonged treatment delaying discharge, unrelated to any other complication.

Appendix 2. Characteristics of patients included and excluded in the study

Variables	Included n = 347	Excluded n = 93	p-value
Age (years), mean (95% CI)	63 (62 – 65)	62 (59 - 66)	0.602
75+ years old	81 (23)	22 (24)	0.950
Gender (Male : Female)	179:168 (52:48)	49:44 (53:47)	0.850
ASA score			
I – II	235 (68)	67 (72)	0.425
III – IV	112 (32)	26 (28)	
Diagnosis			
Malignancy	228 (66)	60 (65)	
Inflammatory bowel disease	49 (14)	20 (21)	0.830*
Other benign disease	42 (12)	9 (10)	
Diverticular disease	28 (8)	4 (4)	
Procedure performed			
Small bowel resection	9 (3)	4 (4)	
Ileocecal resection	9 (3)	8 (9)	
Right hemicolectomy	103 (30)	19 (20)	
Left hemycolectomy	22 (6)	7 (8)	
Rectosigmoidectomy	57 (16)	18 (19)	0.505†
Subtotal / Total colectomy	15 (4)	3 (3)	
Low anterior resection	78 (22)	13 (14)	
Abdominoperineal resection	20 (6)	5 (5)	
Total proctocolectomy ± IPAA	23 (7)	11 (12)	
Other colorectal procedure	11 (3)	5 (5)	
Surgical approach			
Open	69 (20)	23 (25)	0.307
Laparoscopic	278 (80)	70 (75)	
New stoma formation	90 (26)	28 (30)	0.420
Surgeon			
Surgeon 1	143 (41)	37 (40)	0.750
Surgeon 2	113 (33)	34 (37)	
Surgeon 3	91 (26)	22 (24)	
Length of primary hospital stay, median days	4 (3 – 7)	4 (3 – 8)	0.295
Length of total hospital stay, median days	4 (3 – 9)	4 (3 – 9)	0.587
Length of primary hospital stay ≤ 3 days	135 (39)	31 (33)	0.325
30-day hospital readmission	44 (13)	9 (10)	0.430

*Chi-square for malignancy versus benign disease; †Chi-square for rectal versus colonic resection

Appendix 3. App daily questionnaires

Questionnaire 1 – given on POD 0
Pre-Op Survey
5 Questions Total

1. During your preoperative visit, did you receive oral and written explanations from a nurse about how to get ready for surgery and what to expect during your hospital stay?
    a. Yes / No

2. Did you have a carbohydrate drink (i.e. juice, iced tea) the night before your surgery?
    a. Yes / No

3. Did you have a carbohydrate drink (i.e. juice, iced tea) the morning before your surgery?
    a. Yes / No

4. Did you have anything to drink (including water) up to two hours before surgery?
    a. Yes / No

5. Did you receive a bowel cleansing solution (i.e. laxative) by mouth the day before your surgery?
    a. Yes / No

Questionnaire 2 – given on POD 1
Survey about Day of Surgery (POD 0)
9 Questions Total

1. What is the highest level of nausea that you experienced yesterday after surgery?
    a. (Visual Analogue Scale of Nausea - 0 to 10).

2. What is the highest level of pain in your incision (surgical cut) that you experienced yesterday when moving around? *If you weren't able to move around yesterday, report the highest level of pain while in bed.*
    a. (Visual Analogue Scale of Pain - 0 to 10).

3. How much liquid (i.e. water, juice) did you drink yesterday after your surgery? *One full red cup contains 400 ml of liquid.*
    a. (stepper from 0 to 10 cups (0 ml to 4000+ mL); 1 cup = 400 mL – half a cup (200mL) steps)

4. How many cans of nutritional drink (i.e. Ensure, Boost) did you have yesterday after your surgery?
    a. multiple choice (0, 1, 2, 3 or more) cans of nutritional drink

5. Did you have any solid food yesterday after your surgery?
    a. YES/NO

6. Did you chew gum yesterday after your surgery?
    a. YES/NO

7. How much time did you spend sitting in a chair yesterday after your surgery? *If you didn't sit in the chair at all your answer should be 0.*
    a. (stepper with hours and minutes from 0 to 12 hours – 1 hour steps and 15 minute steps)

8. How many laps of the ward hallway did you walk yesterday after your surgery? *One lap is considered the full length of the ward hallway from one end to the other. If you only walked from your room to one end of the hallway and back it is considered a half-lap. If you didn't walk in the hallway at all your answer should be 0.*
    a. (stepper with number of laps 0 to 10 – 1/2 lap steps)

9. Did you do your breathing exercises yesterday after your surgery?
    a. YES/NO

<u>Questionnaire 3 – given on POD 2</u>
<u>Survey about POD 1</u>
19 Questions Total

1. What is the highest level of nausea that you experienced yesterday?
    a. (Visual Analogue Scale of Nausea - 0 to 10).

2. What is the highest level of pain in your incision (surgical cut) that you experienced yesterday when moving around? *If you weren't able to move around yesterday, report the highest level of pain while in bed.*
    a. (Visual Analogue Scale of Pain - 0 to 10).

3. Was your pain well controlled with only the pills you were taking yesterday? *If you still had an epidural catheter or PCA pump (you press a button to receive pain medication) working yesterday night, your answer should be NO.*
    a. YES/NO

4. Was the tube in your bladder removed yesterday so that you can urinate on your own?
    a. YES/NO/I did not have a tube in my bladder

5. How much liquid (i.e. water, juice) did you drink yesterday? *One full red cup contains 400 ml of liquid.*
    a. (stepper from 0 to 10 cups (0 ml to 4000+ mL); 1 cup = 400 mL – half a cup (200mL) steps)

6. How many cans of nutritional drink (i.e. Ensure, Boost) did you have yesterday?
    a. multiple choice (0 to 3 or more) cans of nutritional drink.

7. Did you have at least one meal (i.e. lunch, dinner) with solid food yesterday?
    a. YES/NO

8. Did you chew gum yesterday?
    a. YES/NO

9. Did you start taking laxatives yesterday (i.e. milk of Magnesia)?
    a. YES/NO

10. Were you able to get in and out of bed on your own, without assistance yesterday?
    a. YES/NO

11. Were you able to go the bathroom on your own, without assistance yesterday?
    a. YES/NO

12. How much time did you spend sitting in a chair yesterday? *If you didn't sit in the chair at all your answer should be 0.*
    a. (stepper with hours and minutes from 0 to 12 hours – 1 hour steps and 15 minute steps)

13. How many laps of the ward hallway did you walk yesterday after your surgery? *One lap is considered the full length of the ward hallway from one end to the other. If you only walked from your room to one end of the hallway and back it is considered a half-lap. If you didn't walk in the hallway at all your answer should be 0.*
    a. (stepper with number of laps 0 to 10 – 1/2 lap steps)

14. Did you do your breathing exercises yesterday?
    a. YES/NO

15. Did you pass gas yesterday?
    a. YES/NO

16. Did you pass stool yesterday?
    a. YES/NO

17. Did they give you intravenous fluids through the drip in your arm yesterday? *If you received a bag of fluid similar to the one in the picture yesterday, your answer should be YES.*
    a. YES/NO

18. In relation to your surgery, did you feel sufficiently recovered to leave the hospital yesterday?
    a. YES/NO

19. Is your hospital discharge planned for today?
    a. YES/NO

Questionnaire 4 – given on POD 3
Survey about POD 2
18 Questions Total

1. What is the highest level of nausea that you experienced yesterday?
    a. (Visual Analogue Scale of Nausea - 0 to 10).

2. What is the highest level of pain in incision (surgical cut) that you experienced yesterday when moving around? *If you weren't able to move around yesterday, report the highest level of pain while in bed.*
    a. (Visual Analogue Scale of Pain - 0 to 10).

3. Was your pain well controlled with only the pills you were taking yesterday? *If you still had an epidural catheter or PCA pump (you press a button to receive pain medication) working yesterday night, your answer should be NO.*
    a. YES/NO

4. How much liquid (i.e. water, juice) did you drink yesterday? *One full red cup contains 400 ml of liquid.*
    a. (stepper from 0 to 10 cups (0 ml to 4000+ mL); 1 cup = 400 mL – half a cup (200mL) steps)

5. How many cans of nutritional drink (i.e. Ensure, Boost) did you have yesterday?
    a. multiple choice (0, 1, 2, 3 or more) cans of nutritional drink

6. Did you have at least one meal (i.e. lunch, dinner) with solid food yesterday?
    a. YES/NO

7. Did you chew gum yesterday?
    a. YES/NO

8. Did you take laxatives (i.e. Milk of Magnesia) yesterday?
    a. YES/NO

9. Were you able to get in and out of bed on your own, without assistance yesterday?

a. YES/NO

10. Were you able to go the bathroom on your own, without assistance yesterday?
    a. YES/NO

11. How much time did you spend sitting in a chair yesterday? *If you didn't sit in the chair at all your answer should be 0.*
    a. (stepper with hours and minutes from 0 to 12 hours – 1 hour steps and 15 minute steps)

12. How many laps of the ward hallway did you walk yesterday after your surgery? *One lap is considered the full length of the ward hallway from one end to the other. If you only walked from your room to one end of the hallway and back it is considered a half-lap. If you didn't walk in the hallway at all your answer should be 0.*
    a. (stepper with number of laps 0 to 10 – 1/2 lap steps)

13. Did you do your breathing exercises yesterday?
    a. YES/NO

14. Did you pass gas yesterday?
    a. YES/NO

15. Did you pass stool yesterday?
    a. YES/NO

16. Did they give you intravenous fluids through the drip in your arm yesterday? *If you received a bag of fluid similar to the one in the picture yesterday, your answer should be YES.*
    a. YES/NO

17. In relation to your surgery, did you feel sufficiently recovered to leave the hospital yesterday?
    a. YES/NO

18. Is your hospital discharge planned for today?
    a. YES/NO

Questionnaire 5 – given on POD 4
Survey about POD 3
18 Questions Total

1. What is the highest level of nausea that you experienced yesterday?
    a. (Visual Analogue Scale of Nausea - 0 to 10).

2. What is the highest level of pain in incision (surgical cut) that you experienced yesterday when moving around? *If you weren't able to move around yesterday, report the highest level of pain while in bed.*
    a. (Visual Analogue Scale of Pain - 0 to 10).

3. Was your pain well controlled with only the pills you were taking yesterday? *If you still had an epidural catheter or PCA pump (you press a button to receive pain medication) working yesterday night, answer NO.*
    a. YES/NO

4. How much liquid (i.e. water, juice) did you drink yesterday? *One full red cup contains 400 ml of liquid.*
    a. (stepper from 0 to 10 cups (0 ml to 4000+ mL); 1 cup = 400 mL – half a cup (200mL) steps)

5. How many cans of nutritional drink (i.e. Ensure, Boost) did you have yesterday?
    a. multiple choice (0, 1, 2, 3 or more) cans of nutritional drink

6. Did you have solid food yesterday?
    a. YES/NO

7. Did you chew gum yesterday?
    a. YES/NO

8. Did you take laxatives yesterday (i.e. milk of Magnesia)?
    a. YES/NO

9. Were you able to get in and out of bed on your own, without assistance yesterday?
    a. YES/NO

10. Were you able to go the bathroom on your own, without assistance yesterday?
    a. YES/NO

11. How much time did you spend sitting in a chair yesterday? *If you didn't sit in the chair at all your answer should be 0.*
    a. (stepper with hours and minutes from 0 to 12 hours – 1 hour steps and 15 minute steps)

12. How many laps of the ward hallway did you walk yesterday after your surgery? *One lap is considered the full length of the ward hallway from one end to the other. If you only walked from your room to one end of the hallway and back it is considered a half-lap. If you didn't walk in the hallway at all your answer should be 0.*
    a. (stepper with number of laps 0 to 10 – 1/2 lap steps)

13. Did you do your breathing exercises yesterday?
    a. YES/NO

14. Did you pass gas yesterday?
    a. YES/NO

15. Did you pass stool yesterday?
    a. YES/NO

16. Did they give you intravenous fluids through the drip in your arm yesterday? *If you received a bag of fluid similar to the one in the picture yesterday, your answer should be YES.*
    a. YES/NO

17. In relation to your surgery, did you feel sufficiently recovered to leave the hospital yesterday?
    a. YES/NO

18. Is your hospital discharge planned for today?
    a. YES/NO

Feedback questionnaire – given on POD 3 or at time of discharge

17 Questions Total

System Usability Scale questionnaire

1. I think that I would like to use this system frequently

    a. Likert scale 1-5. (1= I strongly disagree, 5= I strongly agree)

2. I found the system unnecessarily complex

    a. Likert scale 1-5. (1= I strongly disagree, 5= I strongly agree)

3. I thought the system was easy to use
    a. Likert scale 1-5. (1= I strongly disagree, 5= I strongly agree)
4. I think that I would need the support of a technical person to be able to use this system
    a. Likert scale 1-5. (1= I strongly disagree, 5= I strongly agree)
5. I found the various functions in this system were well integrated
    a. Likert scale 1-5. (1= I strongly disagree, 5= I strongly agree)
6. I thought there was too much inconsistency in this system
    a. Likert scale 1-5. (1= I strongly disagree, 5= I strongly agree)
7. I would imagine that most people would learn to use this system very quickly
    a. Likert scale 1-5. (1= I strongly disagree, 5= I strongly agree)
8. I found the system very cumbersome to use
    a. Likert scale 1-5. (1= I strongly disagree, 5= I strongly agree)
9. I felt very confident using the system
    a. Likert scale 1-5. (1= I strongly disagree, 5= I strongly agree)
10. I needed to learn a lot of things before I could get going with this system
    a. Likert scale 1-5. (1= I strongly disagree, 5= I strongly agree)

<u>Patient satisfaction questionnaire</u>

11. Considering the education material and information I received, I felt very informed about what to do during my recovery after surgery
    a. Likert scale 1-5. (1= I strongly disagree, 5= I strongly agree)
12. This app was very helpful to understand and achieve my recovery goals.
    a. Likert scale 1-5. (1= I strongly disagree, 5= I strongly agree)
13. This app increased my motivation to recover after surgery.
    a. Likert scale 1-5. (1= I strongly disagree, 5= I strongly agree)
14. The information contained in this app was consistent to what my nurse and surgeon told me.
    a. Likert scale 1-5. (1= I strongly disagree, 5= I strongly agree)
15. NET Promoter Score. How likely is it that you would recommend this app to another patient?
    a. Scale 1-10. (1= Not likely at all, 10= Extremely likely)

16. What did you like about this app?
    a. Free text
17. How would you improve this app?
    a. Free text