Standardization of Care: Impact of an Enhanced Recovery Protocol on Length of Stay, Complications, and Direct Costs after Colorectal Surgery

Robert H Thiele, MD, Kathleen M Rea, MSN, APRN, Florence E Turrentine, PhD, RN, Charles M Friel, MD, FACS, Taryn E Hassinger, MD, Bernadette J Goudreau, BS, Bindu A Umapathi, MD, Irving L Kron, MD, FACS, Robert G Sawyer, MD, FACS, Traci L Hedrick, MD, FACS, Timothy L McMurry, PhD

BACKGROUND: Colorectal surgery is associated with considerable morbidity and prolonged length of stay (LOS). Recognizing the need for improvement, we implemented an enhanced recovery (ER) protocol for all patients undergoing elective colorectal surgery at an academic institution.

STUDY DESIGN: A multidisciplinary team implemented an ER protocol based on: preoperative counseling with active patient participation, carbohydrate loading, multimodal analgesia with avoidance of intravenous opioids, intraoperative goal-directed fluid resuscitation, immediate postoperative feeding, and ambulation. Discharge requirements remained identical throughout. A before and after study design was undertaken comparing patients before (August 2012 to February 2013) and after implementation of an ER protocol (August 2013 to February 2014). Risk stratification was performed using the NSQIP risk calculator to calculate the predicted LOS for each patient based on 23 variables.

RESULTS: One hundred and nine consecutive patients underwent surgery within the ER protocol compared with 98 consecutive historical controls (conventional). The risk-adjusted predicted LOS was similar for each group at 5.1 and 5.2 days. Substantial reductions were seen in LOS, morphine equivalents, intravenous fluids, return of bowel function, and overall complications with the ER group. There was a $7,129/patient reduction in direct cost, corresponding to a cost savings of $777,061 in the ER group. Patient satisfaction as measured by Press Ganey improved considerably during the study period.

CONCLUSIONS: Implementation of an ER protocol led to improved patient satisfaction and substantial reduction in LOS, complication rates, and costs for patients undergoing both open and laparoscopic colorectal surgery. These data demonstrate that small investments in the perioperative environment can lead to large returns. (J Am Coll Surg 2015;220:430–443. © 2015 by the American College of Surgeons)

A variety of management strategies and protocolized care pathways have been developed during the last several decades in an effort to reduce the time required to recover

from surgery. The "enhanced recovery" (ER) concept, first proposed by Kehlet,[1] is based on the belief that traditional perioperative management practices, such as fasting in the preoperative period, liberal fluid administration in the intraoperative period, and the use of nasogastric tubes and opioid-centric pain-management strategies in the postoperative period, deserve re-evaluation and modification in light of the best-available evidence-based medicine. More than 10 case-control studies including >3,000 subjects have demonstrated a 3-day reduction in length of stay (LOS) associated with the development of an ER program in a variety of surgical patient populations.[2-14] A meta-analysis of randomized controlled trials focused on ER

Abbreviations and Acronyms

ER = enhanced recovery
GDT = goal-directed therapy
LOS = length of stay
MBP = mechanical bowel preparation
PACU = postanesthesia care unit
PVI = Pleth Variability Index
SSI = surgical site infection

programs in colorectal surgical patients specifically found that LOS was reduced, on average, by 2.4 days.[15]

In colorectal surgery specifically, traditional fluid management strategies appear to be of particular importance.[16] Most notably the "goal-directed therapy" (GDT) concept, pioneered by Shoemaker and colleagues,[17] is based on the premise that maintaining oxygen delivery and use above a predetermined threshold can improve outcomes. Although not all studies have been positive,[18] in aggregate it appears that adherence to GDT protocols can reduce the morbidity associated with major surgery.[19-21] An extension of the GDT concept is the "fluid responsiveness" paradigm, which promotes the use of dynamic indicators of volume status to optimize preload.[22] A major advantage of the fluid responsiveness paradigm is its noninvasive nature. Traditional GDT algorithms relied on cardiac output measurements derived from a pulmonary artery catheter. Randomized controlled trials examining the use of the less invasive esophageal Doppler[23-29] and arterial waveform analyzers[30-35] have demonstrated mean reductions in LOS of 3.7 and 2.2 days, respectively.

Most recently, the anesthesiology community has developed the concept of the "perioperative surgical home" in which a physician team leader (anesthesiologist, surgeon, or hospitalist) known as a "perioperativist" oversees the entire patient experience. Essential components of the perioperative surgical home include standardized care, adoption of best practices, efficient delivery of health care, coordination among multiple members of the care team (physicians and nonphysicians), and active involvement of patients and their family members.[36] Critical to the perioperative surgical home model is reduced variability and conversion of what is traditionally a disjointed confluence of discrete health care interactions into a smooth, continuous experience.[37]

In an effort to improve clinical outcomes in patients undergoing colorectal surgery at the University of Virginia, we developed an institution-specific, colorectal ER pathway, which was implemented on August 1, 2013. Our colorectal ER pathway was created by amalgamating input from colorectal surgeons, postanesthesia care unit (PACU) and acute care nurses, as well as anesthesiologists and pain medicine physicians. To assess the efficacy of this quality initiative, we sought to compare the outcomes of patients before and after protocol implementation.

METHODS
Study design
Approval was sought but deemed unnecessary by the IRB at the University of Virginia for this quality-control initiative. We analyzed all consecutive patients undergoing elective major colorectal surgery by 2 board-certified colon and rectal surgeons before (August 1 2012 to March 1, 2013) and after (August 1, 2013 to March 1, 2014) the development of an ER program. To remove the confounding effects of protocol discussion and development on clinical practice, a 6-month period of time immediately before initiation of the protocol was omitted (March 1, 2013 to August 1, 2013) from analysis. The primary outcomes of interest included risk-adjusted LOS, using the American College of Surgeons NSQIP Surgical Risk Calculator to estimate expected length of stay. Secondary clinical variables included unadjusted LOS, numeric pain scores on a 1 to 10 scale, return of bowel function (defined as days to passage of flatus), intravenous fluids received (in milliliters), and morphine equivalents received throughout the hospital stay. Other secondary outcomes included readmission to any medical facility within 30 days, unplanned intubation, 30-day all cause mortality, superficial surgical site infection (SSI), deep SSI, organ space SSI, thromboembolic events, progressive renal insufficiency, acute renal failure, urinary tract infection, MI, postoperative bleeding, sepsis, pneumonia, unplanned return to operating room, and total complications. Additionally, patient satisfaction and financial data were compared.

Management strategies
Preprotocol management
Before initiation of the ER program, the colon and rectal patients were generally managed in the following manner. All patients received a mechanical bowel preparation (MBP) the night before surgery consisting of 4 L GoLytely, as well as erythromycin (1 g × 3), neomycin (1 g × 3), and metoclopramide (10 mg × 3). They were placed on a clear liquid diet the morning of the day before surgery and were made npo after midnight. The patients received preoperative education in the colorectal surgery clinic and were generally told that they would be in the hospital for 3 to 5 days for laparoscopic procedures and 5 to 7 days for open procedures. Nonopioid analgesic agents were not used preoperatively. Most patients undergoing open surgical procedures received low thoracic

Table 1.   Key Emergency Room Protocol Elements

Day before operation
Regular diet until 6 PM; bowel preparation (mechanical and oral antibiotics); chlorohexidine shower night before and morning of surgery
Day of operation, preoperative holding area
Identify enhanced recovery patients and initiate protocol; allow patients to have clears up until 2 hours before operation; Gatorade 20 oz, must be completed 2 hours before operation
Medications:
Alvimopan 12 mg po
Multimodal analgesia using
Celecoxib 200 mg po (not given to patient with coronary artery disease)
Gabapentin 600 mg po
Acetaminophen 975 mg po
Intraoperative
Duramorph (100 μg) spinal preinduction; no intraoperative opioids without attending approval
Induction: propofol, ketamine 0.5 mg/kg, magnesium 30 mg/kg (over 10 min), dexamethasone 4 mg
IV analgesia: lidocaine 40 μg/kg/min (continued into PACU), ketamine 0.6 mg/kg/h (10 μg/kg/min, stop approximately 45 minutes before waking in laparoscopic, drop to 5 μg/kg/min for open cases)
"Goal-directed" fluids guided by Pleth Variability Index; tidal volumes 6–8 mL/kg using 100% FiO_2
PACU
Clears in PACU unless aspiration risk; stand patients for weight; lactated Ringer's at 40 mL/h (unless patient aspiration risk and npo then 75 mL/h); continue lidocaine infusion
Postoperative care, surgical ward
Diet: Clears begins night of surgery, solid food postoperative day 1
Pain:
1 g IV acetaminophen 6 hours after initial dose and every 6 hours
Lidocaine infusion (0.5–1 mg/min) until postoperative day 2
Oxycodone 5 mg po q4h prn mild pain, 10 mg q4h prn moderate pain, oxycodone 15 mg po q4h prn severe pain
Celecoxib 100 mg po bid in patients without coronary artery disease
Activity: Ambulation begins night of surgery, head of bed at 30 degrees at all times
Medications:
Alvimopan 12 mg bid for 7 days
Magnesium oxide 400 mg po daily
Fluids:
LR at 40 mL/h for 24 h
Discharge
Medications: acetaminophen 1 g q8h for 1 week, oxycodone 5 mg q4h prn
Arrange for early follow-up in high-risk patients with surgeon or primary care; follow-up phone call within 48 hours of discharge

PACU, postanesthesia care unit.

epidurals using a combination of bupivacaine and hydromorphone, at the discretion of the anesthesiologist. Patients receiving laparoscopic procedures did not receive neuraxial analgesia. Intraoperative fluid administration was not standardized and was decided on by the anesthesiologist. Prophylactic antibiotics included predominately cefoxitin, and were administered within an hour of the skin incision. Postoperative fluids generally included an isotonic solution of normal saline or lactated Ringer's solution at 125 mL/hour until the patients tolerated a diet. Patients were given a clear liquid diet on the morning of the first postoperative day and were advanced as tolerated, although this was left to the discretion of the treating physician. Most patients were given patient-controlled analgesia with fentanyl, morphine sulfate, or hydromorphone. They were generally switched to oral opioids when they were able to tolerate a diet. If an epidural was in place, it was continued until patients were tolerating a regular diet and oral pain medication. Discharge criteria included ability to tolerate a regular diet, passage of flatus, and pain controlled on oral medications.

Postprotocol management

Key elements of our ER protocol are depicted in Table 1. During an 8-month period, a multidisciplinary team consisting of representatives from every unit along the care continuum met to discuss the perioperative protocol of colorectal surgical patients. We used this opportunity to standardize all care components from the first preoperative visit through convalescence. Key elements to our protocol include the following:

- The ER protocol is described to patients in the surgical clinic. Patients' role in their recovery is described in
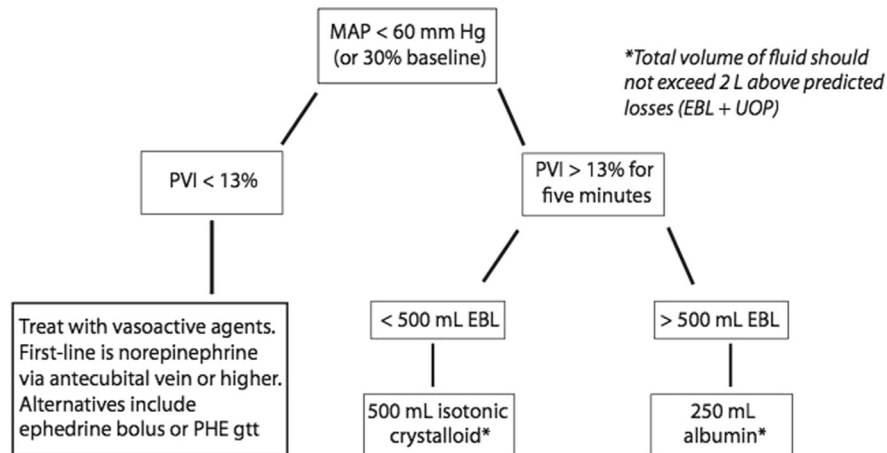
Figure 1. Intraoperative fluid management algorithm. EBL, estimated blood loss; gtt, drip; MAP, mean arterial pressure; PHE, phenylephrine; PVI, Pleth Variability Index; UOP, urine output.

detail. Patients are given a checklist of items to complete before and after their surgical procedure with the bedside nursing staff.

- Patients are told that the expected date of discharge is on the third postoperative day for both open and laparoscopic procedures.
- The ER protocol patients are flagged in the electronic medical record and on the operative schedule so that every provider is aware of this designation.
- The night before surgery, patients continued to receive an MBP consisting of 4 L GoLytely, as well as erythromycin (1 g × 3), neomycin (1 g × 3), and metoclopramide (10 mg × 3). Regular diet ceases at 6 PM, after which clear liquids can be consumed ad libidum until 2 hours before surgery.
- Patients were asked to take a chlorohexidine shower the evening before and the morning of surgery.
- On the day of surgery, patients consume 20 oz Gatorade Thirst Quencher G Series, 2 hours before induction.
- On admission to the surgical admissions suite, patients receive a multimodal analgesic combination, including 200 mg celecoxib, 600 mg gabapentin, and 975 mg oral acetaminophen.
- Alvimopan is administered preoperatively and twice daily for up to 7 days.
- Patients receive antibiotic prophylaxis with cefazolin and metronidazole within an hour of the incision.
- A morphine spinal (100 μg) is administered on entrance to the operating room.
- Patients receive 5,000 U unfractionated heparin immediately after placement of the spinal.
- N-Methyl-D-aspartate antagonists are used with induction (magnesium 30 mg/kg, ketamine 0.5 mg/kg) and

throughout the surgical procedure (ketamine 10 μg/kg/min). Magnesium and ketamine were selected because of the growing body of evidence suggesting that they decrease opioid need after surgery.[38-40]

- Intravenous lidocaine is infused during the surgical procedure (40 μg/kg/min) and for 48 hours after the procedure (1 mg/min).[41]
- Intraoperative fluid management was guided by a GDT algorithm using the Masimo Pleth Variability Index (PVI) to guide fluid responsiveness (see Fig. 1 for intraoperative fluid management algorithm).
- A separate clean fascial closure tray is used at the end of the case.
- Patients get out of bed in PACU to be weighed, and are out of bed and in a chair the night of surgery.
- Clear fluids are administered in PACU and on the night of surgery.
- Intravenous fluids are run at 40 mL/h on the night of surgery and discontinued at 8:00 AM on the first postoperative day. Little attention is paid to urine output or oliguria in the absence of abnormal vital signs. Strict parameters for fluid boluses the night of surgery are in place based on hypotension and tachycardia.
- A soft diet begins on the first postoperative day.
- Patients are placed on scheduled acetaminophen and celecoxib. The primary postoperative opioid analgesic agent is oral oxycodone (q4h as needed on the day of surgery, scheduled q4h starting at 6:00 AM on the first postoperative day for the open cases).
- Discharge criteria remained identical (tolerating a diet, passing flatus or >500 mL in presence of ileostomy, ambulatory, pain well controlled on oral analgesia.
- Patients are called within 72 hours after discharge by our colorectal nurse practitioner.

Table 2. Baseline Demographics for Patients before and after ER Protocol Implementation

Demographic characteristics	Before ER protocol (n = 98)	After ER protocol (n = 109)	p Value
Age, y, mean ± SD	58.0 ± 14.2	58.0 ± 15.2	1.0
Sex, male	48 (49)	48 (44)	0.49
Rectal surgery	39 (40)	40 (37)	0.67
Stoma created	36 (37)	43 (39)	0.77
Laparoscopic	31 (32)	43 (39)	0.25
BMI, kg/m^2, mean ± SD	28.3 ± 6.4	27.8 ± 8.1	0.85
Diabetes	12 (12)	20 (18)	0.25
Smoker	11 (11)	21 (19)	0.13
Dyspnea on exertion	12 (12)	11 (10)	0.66
Dependent functional status	6 (6)	6 (6)	1.0
Disseminated cancer	2 (2)	7 (6)	0.18
Steroids	12 (12)	12 (11)	0.83
ASA ≥3	63 (64)	54 (50)	0.04
Contaminated/dirty wound	27 (26)	27 (25)	0.87
Diagnosis			
Neoplasm	54 (55)	51 (47)	0.27
Diverticulitis	11 (11)	18 (17)	
Colonic fistula	5 (5)	4 (4)	
IBD	13 (13)	18 (17)	
Other	14 (14)	7 (6)	
NSQIP-predicted LOS, d, mean ± SD	5.2 ± 1.5	5.1 ± 1.9	0.68

Data are presented as n (%) unless noted otherwise.
ASA, American Society of Anesthesiologists; ER, enhanced recovery; IBD, inflammatory bowel disease; LOS, length of stay.

Protocol implementation

Extensive education of the staff, physicians, and residents was undertaken in the months before protocol implementation on August 1, 2013. Systems-level changes designed to facilitate compliance with the protocol included the creation of standard order sets for the preoperative clinic, PACU, and postoperative unit; printed checklists for providers were placed in the patients' bedside record and followed them from the clinic through discharge; wide distribution of the protocol to all providers in the continuum of care; anesthesia for ER-protocol patients was provided by a select group of 6 anesthesiologists and nurse anesthetists for the first 6 months of implementation; laminated sheets with printed protocol placed on each anesthesia cart; grouping of all ER-protocol patients on one postoperative unit; flagging of ER-protocol patients in the electronic medical record and on the operative schedule; and strict compliance data monitoring with active real-time feedback to providers.

Data collection

The University of Virginia is a participant of American College of Surgeons NSQIP and, as such, enters a multitude of perioperative variables into the NSQIP database on a prospective basis using a dedicated surgical clinical nurse reviewer. Our surgical clinical reviewers abstract all procedures included in the colectomy and proctectomy modules in the Targeted Procedure Program. The NSQIP definitions for all demographic and outcomes data were strictly adhered to during data collection in accordance with NSQIP participation (a full data dictionary can be found at http://site.acsnsqip.org/wp-content/uploads/2012/03/ACS-NSQIP-Participant-User-Data-File-User-Guide_06.pdf). Additional data points specific to the ER pathway that were not collected by NSQIP, including morphine equivalents, intravenous fluid amounts (mL), numeric pain scores (1 to 10), and compliance with protocol measures, were collected prospectively in a separate quality-improvement database. Press Ganey assesses patient satisfaction at our institution using a voluntary survey administered post discharge. The Press Ganey infoEDGE database was queried for all patients discharged during the 2 time periods. Means scores were given for each response and compared with facilities of similar size to obtain a percentile. Observed financial data are provided by our institution to the University HealthSystem Consortium clinical database. We can then compare our performance against risk-adjusted expected 30-day direct and total costs and the relative performance of peer institutions.

Statistical considerations

Chi-square and Student's t-test were used to compare categorical and continuous variables, respectively. Risk

Table 3. Compliance with Protocol Elements

Protocol elements	Before ER protocol (n = 98)	After ER protocol (n = 109)	p Value
Intraoperative morphine equivalents, mg, mean ± SD	21.7 ± 10.7	0.5 ± 1.1	0.0001
Total morphine equivalents, mg, mean ± SD	280.9 ± 395.7	63.7 ± 130.0	0.0001
Intraoperative net fluid balance, mL, mean ± SD	2,733 ± 1,464	848 ± 953	0.0001
Total net fluid balance, mL, mean ± SD	4,409 ± 5,496	−182 ± 3,933	0.0001
Gatorade, n (%)	—	90 (83)	NA
Ambulate DOS, n (%)	0	84 (77)	0.0001
Ambulate by POD 1, n (%)	79 (81)	96 (88)	0.178

DOS, day of surgery; ER, enhanced recovery; NA, not applicable; POD, postoperative day.

stratification was performed using the American College of Surgeons NSQIP risk calculator to calculate the predicted LOS for each patient based on 23 demographic- and procedure-related variables. To exclude the possibility of a long-term institutional trend, a time-series analysis was used to compare pre- and post-implementation LOS.

RESULTS

Demographics

Data from 98 consecutive patients in the conventional care pathway were compared with 109 consecutive patients post protocol implementation. Table 2 presents the number (or mean) and percent (or SD) for all patient characteristics included in the analysis. Patients were well matched, with the exception of American Society of Anesthesiologists score. Although there were a higher percentage of patients with American Society of Anesthesiologists scores ≥3 in the initial time period, the NSQIP-predicted LOS for each time period was identical.

Protocol compliance

Refer to Table 3 for compliance with protocol measures. Compliance was >75% for the following protocol elements: ingestion of Gatorade, ambulation the day of surgery, and ambulation on the first postoperative day.

Perioperative fluid management

The protocol was successful in reducing intraoperative and postoperative intravenous fluid administration. Intraoperative net fluid balance decreased from +2,733 ± 1,464 mL to +848 ± 953 mL (p < 0.0001), and net fluid balance during the course of hospitalization decreased from +4,409 ± 5,496 mL to −182 ± 3,933 mL (p < 0.0001). Of note, acute renal failure did not develop in any patients during either time period.

Analgesic use

The protocol was also successful in reducing the amount of opioids administered during the intraoperative and postoperative period by nearly 80%. Intraoperative

morphine equivalents decreased from 21.7 ± 10.7 mg to 0.5 ± 1.1 mg, and total hospital morphine equivalents decreased from 280.9 ± 395.7 mg to 63.7 ± 130.0 mg (p < 0.0001).

Pain scores

Numerical pain scores on day of surgery through the third postoperative day are demonstrated in Figures 2 and 3 for both open and laparoscopic cases, respectively. Pain scores were lower on the day of surgery for both open and laparoscopic cases in the ER pathway as compared with the traditional pathway (p < 0.001). However, for the open cases, ER patients had higher numerical pain scores on postoperative days 1, 2, and 3 than patients in the traditional care pathway (p < 0.01). Patients undergoing laparoscopic surgery had similar numerical pain scores in ER and traditional groups on postoperative days 1, 2, and 3.

Length of stay

Length of stay was reduced in all patients by 2.3 days (from 6.8 ± 4.7 [median 5] days to 4.6 ± 3.6 [median 3] days; p = 0.0002) as demonstrated in Table 4. Before implementation of the ER protocol, our actual LOS was a mean of 1.6 days longer than the NSQIP-predicted LOS. After ER-protocol implementation, the actual LOS was 0.6 days less than the predicted LOS. This corresponded to a 2.2-day reduction in adjusted LOS (p = 0.0001). A histogram demonstrating the difference between predicted and actual LOS for each time period is shown in Figure 4. For open surgical procedures, LOS was reduced from 7.5 ± 5.3 (median 6) days to 5.2 ± 4.4 (median 4) days (p = 0.007) and for laparoscopic procedures, LOS was reduced from 5.5 ± 2.6 (median 5) days to 3.8 ± 2.1 (median 3) days (p = 0.003). It should be noted that the mean LOS for the open cases in the ER protocol was nearly identical to the laparoscopic cases in the traditional care model. A time series displaying the change in LOS over time, relative to the medical center as a whole, is available in Figure 5.
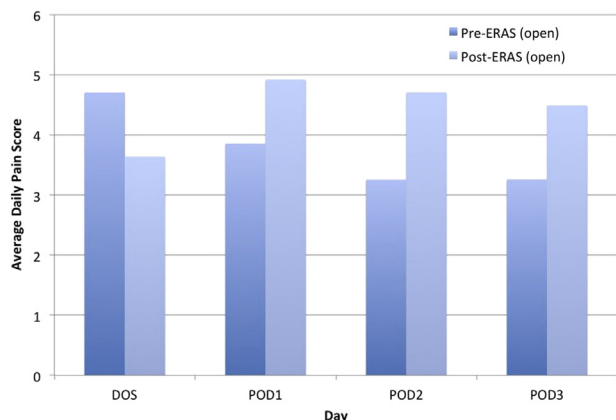
Figure 2. Numeric pain scores for patients undergoing open colorectal surgery on day of surgery (DOS) and postoperative days (POD) 1 to 3. ERAS, enhanced recovery after surgery.

Quality indicators

Despite leaving 2.2 days earlier, 30-day readmissions did not increase. There was a trend toward decreased readmissions from 17.3% to 9.2%, but this trend did not reach statistical significance (p = 0.10). The incidence of any surgical complication decreased from 30.1% to 14.7% (p = 0.007). For a list of all complications, refer to Table 4. Most improvement was seen in infectious complications; SSIs, including superficial, deep, and organ space SSIs, decreased from 20.4% to 7.3% (p = 0.008).

Bowel function

The time to first bowel movement was shorter in the ER group, at 1.9 ± 1.7 days vs 2.3 ± 1.6 days for patients in the traditional care pathway. There was a trend toward fewer patients with ileus in the ER pathway, at 16.5%
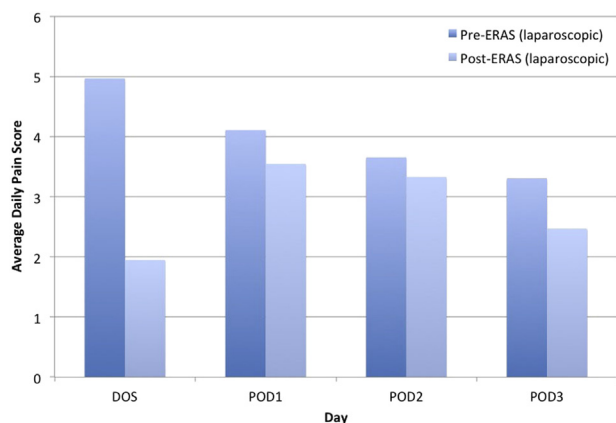

Figure 3. Numeric pain scores for patients undergoing laparoscopic colorectal surgery on day of surgery (DOS) and postoperative days (POD) 1 to 3. ERAS, enhanced recovery after surgery.

vs 27.6%, although this failed to reach statistical significance (p = 0.06).

Patient satisfaction

Forty-eight of 98 patients completed the voluntary Press Ganey survey before protocol implementation, and 47 of 109 patients completed the voluntary Press Ganey survey after protocol implementation. After implementation of the protocol, the overall survey score increased from the 26th to the 59th percentile. The "extent that patients felt ready for discharge" increased from the 41st to the 99th percentile. Satisfaction with pain control increased from the 43rd to the 98th percentile, and the likelihood that patients would recommend the hospital increased from 32nd to the 89th percentile. For a complete list of patient satisfaction scoring metrics, see Table 5.

Financial data

Mean total costs decreased from $25,344 to $18,777 (−$6,567) and mean direct costs decreased from $20,435 to $13,306 (−$7,129) equating to a cost savings of $777,061 in the ER group (p < 0.001). Indexing direct costs to University HealthSystem Consortium, direct costs decreased from $6,836 above expected in the traditional care pathway to $898 below expected with the ER pathway (p < 0.001). The 2.3-day reduction in LOS for the 109 patients on the ER protocol equated to a savings of 261 patient-bed days. Given that the University of Virginia institutional mean LOS is 5.5 days, this allowed the Medical Center to admit 47.5 additional patients during this time period as the direct result of the protocol.

DISCUSSION

Unique features of our enhanced recovery program

Our institutional data suggest that adoption of an ER program focused on maintenance of euvolemia and avoidance of a catabolic state preoperatively, minimal intraoperative opioid use, intraoperative goal-directed fluid therapy, and early mobilization can simultaneously reduce LOS, reduce the incidence of clinically relevant complications, decrease the cost of care, and increase patient satisfaction. Our outcomes are similar to those reported in other case-control studies of ER programs,[2-14] however, our ER program has some unique features.

Bowel preparation

During the past decade, the use of an MBP has been the focus of much debate. In 1974, Washington and colleagues[42] were among the first to demonstrate a

Table 4. Clinical Outcomes before and after ER Protocol Implementation

Outcomes	Before ER protocol (n = 98)	After ER protocol (n = 109)	p Value
Length of stay, d, mean ± SD (median)	6.8 ± 4.7 (5)	4.6 ± 3.6 (3)	0.0002
Open	7.5 ± 5.3 (6)	5.2 ± 4.4 (4)	0.007
Laparoscopic	5.5 ± 2.6 (5)	3.8 ± 2.1 (3)	0.003
Readmission	17 (17)	10 (9)	0.1
Ileus	27 (28)	18 (17)	0.06
Unplanned intubation	2 (2)	1 (1)	0.60
Death	0	0	1.0
Superficial/deep SSI	10 (10)	4 (4)	0.09
Organ space SSI	10 (10)	4 (4)	0.09
Any SSI	20 (20)	8 (7)	0.008
Thromboembolic event	4 (4)	3 (3)	0.71
Progressive renal insufficiency	0	0	1.0
Acute renal failure	0	0	1.0
Urinary tract infection	3 (3)	1 (1)	0.35
Myocardial infarction	1 (1)	1 (1)	1.0
Postoperative bleeding	12 (12)	6 (6)	0.13
Sepsis	1 (1)	2 (2)	1.0
Pneumonia	1 (1)	3 (3)	0.62
Unplanned return to OR	7 (7)	5 (5)	0.56
Any complication	30 (30)	16 (15)	0.007
Mean 30-d direct cost, mean ± SD	20,435 ± 12,857	13,306 ± 9,263	0.001

Data are presented as n (%) unless noted otherwise.
ER, enhanced recovery; OR, operating room; SSI, surgical site infection.

substantial reduction in SSIs with oral antibiotics in patients undergoing elective intestinal surgery. The Nichols-Condon bowel preparation (using neomycin and erythromycin, in addition to vigorous mechanical cleansing) was published in 1977, demonstrating a reduction in SSI from 43% to 9% and became the standard bowel preparation for the next 2 decades.[43] More recently, however, the use of the MBP has been questioned, with several clinical trials that randomized patients to either an MBP or no preparation at all. On a meta-analysis, the use of the MBP did not seem to improve patient outcomes, specifically focused on SSI.[44] Based on these studies, and the unpleasant nature of the MBP itself, many surgeons have omitted MBP as a part of their clinical pathways.[45-48]

However, it must be noted that the majority of these recent trials included MBP without the addition of oral antibiotics. Therefore, although MBP alone might not impact SSI, the combination of an MBP and nonabsorbable antibiotics remains poorly studied. In a 2009 Cochrane review, Nelson and colleagues[49] concluded that oral antibiotics did successfully reduce the rate of SSI. In this article, the authors correctly observe that most studies included oral antibiotics used in conjunction with an MBP. Therefore, the efficacy of oral antibiotics without an MBP is unknown. Although not conclusive, these data seem to support the use of oral antibiotics in the context of a complete MBP. This concept is also supported by the report from the Michigan Surgical Quality Collaborative Colectomy Best Practices Project, which noted an SSI rate of 5% in patients receiving a combination of oral antibiotics and an MBP compared with 9.7% in patients who did not.[50] The Michigan collaborative concluded that best practices supported the use of an MBP with oral antibiotics and strongly advocated for this standard.[50]

Based on these data, we elected to maintain an MBP using GoLytely and oral antibiotics with the following caveats: patients are still allowed to consume clear liquids after midnight, they are encouraged to consume 20 oz Gatorade 2 hours before induction, and intravascular volume status is measured intraoperatively using PVI. Our expectation was that if patients were allowed to take clear fluids immediately before their operation, they would autoregulate their intravascular volume status and, if not, hypovolemia would be detected using PVI. Our results seem to demonstrate that use of an MBP is not detrimental to an ER program.
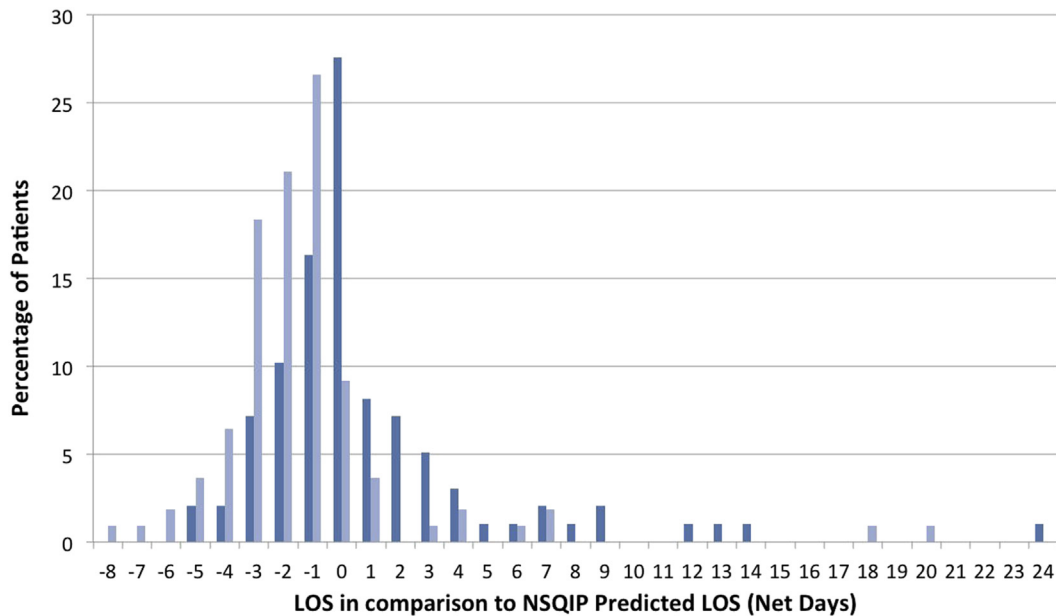
Figure 4. Histogram of adjusted length of stay (LOS) demonstrating a shift of the curve to the left during the enhanced recovery protocol with fewer outliers. Dark blue bar, pre—enhanced recovery after surgery (ERAS); light blue bar, post-ERAS.

Pleth Variability Index—guided fluid management

Despite the fact that multiple randomized controlled trials have suggested that intraoperative use of relatively noninvasive monitors can reduce LOS in surgical patients,[23-25] only a few published ER programs have used advanced hemodynamic monitoring as part of their fluid-management strategy. Miller and colleagues[51] used either esophageal Doppler or the LiDCO rapid device as part of an "intraoperative goal-directed fluid therapy strategy," but the authors did not explicitly specify how these devices were used.[51] Whether or not advanced hemodynamic monitoring is superior to a simple "restrictive" or "zero balance" approach is a matter of debate.[52,53]

Our intraoperative fluid management algorithm (see Fig. 1) was based on the concept of fluid responsiveness.[54] Knowing that excessive intravenous fluid can be harmful,[16] we only administered intravenous fluids when our patients were hypotensive, and we believed that they would be fluid responsive based on advanced hemodynamic monitoring. We selected the PVI device because of its simplicity and affordability relative to other advanced hemodynamic monitors. Notably, the PVI device does not attempt to measure cardiac output or stroke volume. With the possible exception of esophageal Doppler, it does not appear that minimally invasive advanced hemodynamic monitors accurately measure cardiac output or stroke volume when compared with clinical or reference standards.[55] More importantly, multiple

studies have confirmed that PVI can predict the cardiovascular response to fluid administration in mechanically ventilated patients.[56-59] Despite some negative data about the use of GDT in the context of ER protocols,[52,53] we believed that use of a fluid responsiveness monitor would allow us to safely practice a relatively restrictive fluid-management strategy, and not miss the occasional patient who might arrive to the operating room under-resuscitated. In addition, our a purely restrictive fluid or net-zero balance management strategy represented a major paradigm shift at our institution, and a continuous measure of fluid responsiveness helped reinforce the reality that a nonfasted patient encouraged to take clear liquids and carbohydrate-containing solutions does not necessarily arrive to the operating room hypovolemic. These factors, combined with the completely noninvasive nature and relatively low cost of the PVI, guided our decision to use the device.

N-methyl-D-aspartate antagonist use

Opioid use is associated with a variety of potentially adverse effects, and major components of ER protocols are achieving adequate pain control (ie, allowing for mobility) and minimizing opioid use. Particularly relevant for colorectal surgical patients are the effects of opioids on the incidence of postoperative nausea and vomiting,[60-64] as well as on the development of an ileus.[65,66] In an effort to minimize perioperative opioid
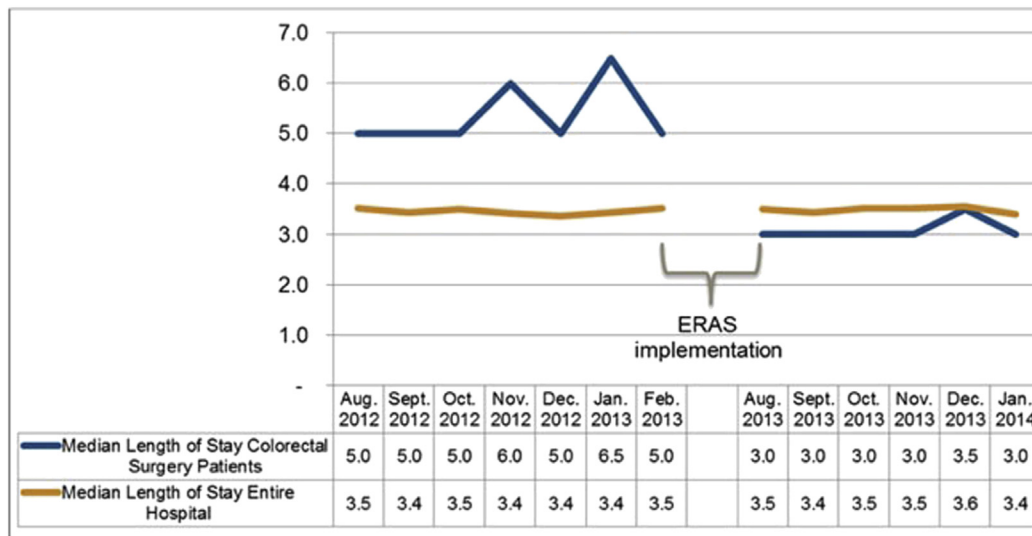
Figure 5. Length of stay (LOS) for colorectal surgery patients relative to the medical center as a whole. ERAS, enhanced recovery after surgery.

needs, we used a preservative-free morphine spinal, acetaminophen, celecoxib, gabapentin, a combination of N-methyl-D-aspartate antagonists (magnesium and ketamine), and an intra- and postoperative lidocaine infusion. Our ER protocol is the first published protocol to formally include N-methyl-D-aspartate antagonists, despite the growing body of literature suggesting that they can lower pain scores and reduce opioid needs after surgery.[38-40] N-methyl-D-aspartate antagonists are particularly attractive because of their potential to blunt opioid-induced hyperalgesia.[67,68] Because of the multimodal nature of our analgesic regimen, it is impossible to quantify the individual contribution of each nonopioid analgesic agent to our observed benefit.

Pain, opioid requirements, and patient satisfaction

Although the laparoscopic patients reported lower pain scores on every day, the patients undergoing open surgical procedures reported higher pain scores on every day besides the day of surgery, compared with the pre-ER cohort. We assume this is because the spinal lasts approximately 18 hours or less, although another explanation might be the increased ambulation associated with the ER program. Interestingly, despite this, as well as the drastic reduction in perioperative opioid use (78% reduction), patient satisfaction with pain control increased from the 43rd to the 98th percentile. The reasons for this are complex. However, one possibility is that patient satisfaction with pain control might be more closely correlated with their perception that caregivers (in particular, nurses) care about their pain rather than actual pain scores.[69]

Of note, patient satisfaction with nurse responsiveness to requests increased from the 12th to the 73rd percentile, nurse friendliness increased from the 18th to the 93rd percentile, and overall nursing care increased from the 14th to the 47th percentile after initiation of the protocol. It might also be due to the extensive patient education about the detrimental effects of opioids on their recovery and our emphasis on extensive ambulation in the postoperative period.

Complications and quality

Perioperative complications are a main driver of LOS.[70,71] Retrospective data from NSQIP suggest that long-term survival and quality of life are also linked to the occurrence of perioperative complications.[72] Therefore, although the exact reasons for our observed reduction in LOS are not known, our observed reduction in any NSQIP complication (decreased from 31% to 14%) might have played a major role in this. Our data are similar to Miller and colleagues'[51] experience at Duke University, where urinary tract infections were reduced from 24% to 13% and there was a trend toward decreased SSIs (from 37% to 28%).

Financial impact

Mean direct costs decreased by $7,129 per patient, or the equivalent of $3,100 per hospital day saved. This is higher than that reported by other groups. The Mayo Clinic estimated savings of $1,039 per patient after implementation of ER in patients undergoing minimally invasive colorectal surgery.[73] Roulin and colleagues[74] realized a 3-day

Table 5. Patient Satisfaction Scores as Measured by Press Ganey before and after ER Protocol Implementation

Question	Before ER protocol, mean	After ER protocol, mean	Before ER protocol, percentile	After ER protocol, percentile
n	48	47		
Overall survey score	84.6	86.9	26	59
Nurses overall	86.6	89.8	14	47
Friendliness/courtesy of the nurses	91	95.1	18	93
Nurses' attitude toward requests	87	91.5	12	73
Nurses kept you informed	86.2	89.9	27	77
Physician overall	90.9	91.3	97	97
Discharge overall	82.5	87.6	19	91
Extent ready for discharge	86.2	92.6	41	99
Instructions care at home	85.6	91	26	97
Personal issues overall	84.9	89.1	29	89
How well your pain was controlled	86.7	91	43	98
Staff addressed emotional needs	83.9	90.2	23	98
Response concerns/complaints	84.6	88.9	39	92
Included in decision making	85.6	90.2	49	97
Overall assessment section overall	88.1	92.2	29	81
Likelihood recommending hospital	87.5	92.9	32	89
Overall rating of care given	87.2	92.9	17	85

ER, enhanced recovery.

reduction in median LOS and a $2,084 per patient reduction in hospital costs after initiation of an ER program in Switzerland. Miller and colleagues[51] observed an unadjusted cost savings of $2,030 per patient and an adjusted cost savings of $1,854 per patient, although this did not reach statistical significance. Our program might have resulted in increased cost savings because we were able to significantly reduce overall complications (55% reduction) in addition to LOS.

Not included in this financial analysis is the impact of reduced LOS on throughput. By saving 261 patient-days during the course of 6 months, we were able to free up space in the medical center for an additional 47 admissions. Many medical centers like ours operate at or near capacity almost continuously. Therefore, the major financial impact is not in the reduced cost associated with shortening LOS (as most hospital costs accrue early in admission[75]), but the increased revenue that accompanies the capacity for additional hospital admissions.

Limitations
Our study has several limitations. This was a single institution in a small service with 2 surgeons. As such, it was relatively straightforward to standardize care. Larger institutions with additional surgeons and different practice patterns might face more difficulty with standardization. In addition, we are limited by the before and after study design. However, it is our belief that successful implementation of an ER pathway requires such climate change within an institution that it would be nearly impossible to randomize individual patients within the same institution and experience the same results.

CONCLUSIONS
Using a multidisciplinary approach, we successfully implemented an ER pathway that led to substantial reductions in LOS, complications, and costs, while improving patient satisfaction. These data demonstrate that small investments in the perioperative environment can lead to large returns.

Author Contributions
Study conception and design: Thiele, Friel, Kron, Sawyer, Hedrick, McMurry

Acquisition of data: Rea, Turrentine, Hassinger, Goudreu, Umapathi, Hedrick

Analysis and interpretation of data: Thiele, Hedrick, McMurry

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Discussion

CrossMark

DR ROBERT R CIMA (Rochester, MN): Enhanced recovery after surgery (ERAS) is really a minimalist sort of principle. As you said, it's multidisciplinary and across time periods. I was interested to see that in your protocol, there are multiple steps that go beyond this normal ERAS principle, such as the use of continuous IV infusion for pain medicines, nonopioid, but still lidocaine and ketamine, as well as the implementation and use of alvimopan, which is controversial in this setting because it stacks the deck because it adds another layer of complexity into your analysis. So are you really stacking the deck? Is this truly following the basic principles of ERAS?

You provide aggregate compliance data, basically more end result data in the sense of your work on fluids and reducing the amount of fluids, reducing the morphine equivalent. Did you track compliance with the individual steps? Was there a break point at which that was important? Were all the steps important? Are there individual steps that are more important than others? Can you discuss that? As you mentioned in your last few slides, implementing change is significant. This is a cross-disciplinary change. Did you have dedicated teams initially, or do you maintain dedicated teams, or does any anesthesiologist who is assigned to your room come in and follow this? How do you track that type of thing? Similarly, in nursing care and the involvement of residents, how strictly are those rules followed? How do you sustain that? Last, you went over the lessons learned, but this is a process change. Can it be expanded throughout your institution to other projects? What would you give as important lessons learned?

DR EUGENE FOLEY (Madison, WI): There is growing literature suggesting that in a variety of clinical settings, the use of multidisciplinary, standardized patient care protocols can improve quality of care, as measured by increased efficiency and decreased complications. The exact mechanism behind this phenomenon is probably multifactorial, but there is something about variation in patient care or processes of care that has been repeatedly shown to increase cost and lead to poorer outcomes.

Dr Hedrick and her colleagues have effectively taken this strategy to the postoperative care of their colorectal surgery patients and demonstrated impressive reductions in length of stay and postoperative complications. I have several questions for the authors.

1. All of us who take care of gastrointestinal surgery patients recognize that some patients simply don't tolerate early refeeding well. Do your data help us identify the characteristics of such patients? If so, should we exclude them from such a protocol?

2. You point out that several of the elements in your ERAS protocol are different than those of other ERAS protocols, which have shown similar results, such as the use of a bowel preparation and the single-shot spinal. Do you have any sense about which of the elements of your protocol are the most important: decreased narcotic use, fluid therapy, or simply the change in patient and provider expectations?

3. Finally, I can't help but notice that the surgical site infection (SSI) rate in your protocol group was less than half that in the control group. We know that SSI rate is a major contributor to increased length of stay and cost after colorectal surgery. Did the ERAS protocol directly affect your SSI rates? If not, is it possible that some of the improvements in length of stay and cost were due to SSI reduction, not the ERAS protocol itself?

DR RICHARD LYNN (Palm Beach, FL): I initially wanted to discuss this paper because I did not see in the abstract any mention of Entereg (Cubist Pharmaceuticals) or alvimopan, but obviously you put that on your list of things that you do, but really didn't mention anything else about it. I have no disclosures about any financial interests in the drug or the company, but I must say