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Enhanced Recovery After Surgery Program Implementation in 2 Surgical Populations in an Integrated Health Care Delivery System

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Abstract

IMPORTANCE—Novel approaches to perioperative surgical care focus on optimizing nutrition, mobility, and pain management to minimize adverse events after surgical procedures.

OBJECTIVE—To evaluate the outcomes of an enhanced recovery after surgery (ERAS) program among 2 target populations: patients undergoing elective colorectal resection and patients undergoing emergency hip fracture repair.

DESIGN, SETTING, AND PARTICIPANTS—A pre-post difference-in-differences study before and after ERAS implementation in the target populations compared with contemporaneous surgical comparator groups (patients undergoing elective gastrointestinal surgery and emergency orthopedic surgery). Implementation began in February and March 2014 and concluded by the end of 2014 at 20 medical centers within the Kaiser Permanente Northern California integrated health care delivery system.

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EXPOSURES—A multifaceted ERAS program designed with a particular focus on perioperative pain management, mobility, nutrition, and patient engagement.

MAIN OUTCOMES AND MEASURES—The primary outcome was hospital length of stay. Secondary outcomes included hospital mortality, home discharge, 30-day readmission rates, and complication rates.

RESULTS—The study included a total of 3768 patients undergoing elective colorectal resection (mean [SD] age, 62.7 [14.1] years; 1812 [48.1%] male) and 5002 patients undergoing emergency hip fracture repair (mean [SD] age, 79.5 [11.8] years; 1586 [31.7%] male). Comparator surgical patients included 5556 patients undergoing elective gastrointestinal surgery and 1523 patients undergoing emergency orthopedic surgery. Most process metrics had significantly greater changes in the ERAS target populations after implementation compared with comparator surgical populations, including those for ambulation, nutrition, and opioid use. Hospital length of stay and postoperative complication rates were also significantly lower among ERAS target populations after implementation. The rate ratios for postoperative complications were 0.68 (95% CI, 0.46–0.99; $P = .04$) for patients undergoing colorectal resection and 0.67 (95% CI, 0.45–0.99, $P = .05$) for patients with hip fracture. Among patients undergoing colorectal resection, ERAS implementation was associated with decreased rates of hospital mortality (0.17; 95% CI, 0.03–0.86; $P = .03$), whereas among patients with hip fracture, implementation was associated with increased rates of home discharge (1.24; 95% CI, 1.06–1.44; $P = .007$).

CONCLUSIONS AND RELEVANCE—Multicenter implementation of an ERAS program among patients undergoing elective colorectal resection and patients undergoing emergency hip fracture repair successfully altered processes of care and was associated with significant absolute and relative decreases in hospital length of stay and postoperative complication rates. Rapid, large-scale implementation of a multidisciplinary ERAS program is feasible and effective in improving surgical outcomes.

To *Err Is Human*, the landmark Institute of Medicine report¹ published in 1999, detailed the substantial toll that medical errors exact on patients, practitioners, and the health care system and elevated patient safety to a national priority. Ensuring patient safety has been particularly relevant in US surgical care, where more than 50 million in-patient procedures are performed annually² and where perioperative complications are common and costly.^{3–11}

To reduce complications and improve outcomes after surgery, bundled surgical care approaches have been proposed that aim to reduce the stress of surgery and maximize the potential for recovery.^{12–17} Enhanced recovery after surgery (ERAS) programs focus on several core elements, including optimizing pain control, nutrition and fluid management, and mobility, among others.^{13,17} Although prior studies^{14,18} have reported improved processes and outcomes after ERAS implementation, many have been limited by modest sample sizes and relatively few implementation target populations or sites.^{11–15,18–21}

In this study, we assessed the concurrent implementation of an ERAS program among patients undergoing elective colorectal resection and patients undergoing emergency hip fracture surgery within the Kaiser Permanente Northern California (KPNC) integrated health care delivery system. We sought to evaluate how care and patient outcomes changed as a result of program implementation by comparing process and outcome measures in the ERAS

target populations with those in similar surgical populations that received usual care before and after implementation.

Methods

This study was approved by the KPNC Institutional Review Board with a waiver of informed consent.

The KPNC ERAS Program

Program Design—In 2014, KPNC implemented an ERAS program across 20 hospitals in Northern California that targeted 2 surgical populations: patients undergoing elective colorectal resection and patients undergoing emergency hip fracture repair. Program design and implementation were led by a regional team composed of multidisciplinary subject matter experts, including clinicians, performance improvement staff, and patient engagement teams. The KPNC ERAS program aimed to standardize surgical care (Table 3) with a specific focus on 4 core perioperative elements: (1) pain management, (2) mobility, (3) nutrition, and (4) patient engagement. Pain management focused on opioid-sparing interventions through the use of multimodal analgesia, which included preoperative and postoperative intravenous acetaminophen, nonsteroidal anti-inflammatory medication, and perioperative intravenous lidocaine (colorectal) or peripheral nerve blocks (hip fracture). For mobility, ambulatory patients were encouraged to begin ambulation within 12 hours of surgery completion and maintain a daily goal of walking at least 21 ft in the first 3 postsurgical days. Nutrition was enhanced by reducing prolonged perioperative surgical fasting through the use of a preoperative high-carbohydrate beverage within 2 to 4 hours and/or solids within 8 to 12 hours before surgery. Postoperative nutrition was provided within 12 hours after surgery. To improve patient engagement in care, an infographic-based calendar was distributed to patients detailing expected care processes starting from the night before surgery through hospital discharge; an informational video series was also designed to improve patient education.

Program Implementation—The ERAS program was implemented in a staggered, nonrandomized fashion across 20 medical centers throughout 2014 (eTable 1 and eTable 2 in the Supplement). Two pilot sites were chosen based on leadership interest, performance improvement expertise, and clinician engagement. Pilot site implementation was undertaken in February and March 2014, followed by secondary site implementation at an additional 6 centers between April and May 2014. In June 2014, a regional ERAS summit, including more than 400 regional and medical center staff members, detailed the full implementation elements and time line, the data analytic strategy and performance dashboards, and the patient education materials. All remaining medical centers implemented the ERAS program in both target populations by the end of 2014. To support implementation, new electronic tools were created, including (1) 13 electronic medical record order sets to facilitate standardized practice and (2) performance dashboards to facilitate low-latency case review at the patient, pathway, medical center, and regional levels.

Study Design

We used a pre-post difference-in-differences study design to compare changes in practices and outcomes between target and comparator groups after implementation of the ERAS program. Starting with the ERAS implementation month, standardized as time zero for each medical center and pathway, we collected practice and outcomes data from the preceding (pre) 12 months and subsequent (post) 12 months (eFigure in the Supplement).

ERAS Target and Comparator Groups—We identified ERAS target patients based on *International Classification of Diseases, Ninth Revision, Clinical Modification (ICD-9-CM)* hospital and diagnosis procedure codes (eTable 3 in the Supplement). We identified inpatient comparator groups undergoing similar surgical procedures within their first 3 days of hospital admission using *ICD-9-CM* procedure codes and Clinical Classification Software procedure level 2 categories (eTable 4 in the Supplement). For patients undergoing elective colorectal resection, comparator patients included those not admitted through the emergency department who also underwent gastrointestinal surgery. For patients undergoing emergency hip fracture repair, comparator patients included those admitted through the emergency department who underwent orthopedic surgery.

Hospitalization Data—We linked ERAS target and comparator patients with existing hospitalization data to include validated risk scores quantifying acute severity of illness at hospital admission (Laboratory and Acute Physiology Score, version 2) and comorbid disease burden (Comorbidity Point Score, version 2).^{22–24} We also identified patients admitted directly to the intensive care unit because patients requiring critical care have higher rates of adverse outcomes. We determined hospital death, length of stay, discharge disposition, and 30-day readmission based on previously described methods.^{22–26}

Process of Care Metrics—We selected 3 process of care metrics within each ERAS perioperative care element, excluding patient engagement, in our analysis. For mobility, we evaluated (1) ambulation within 12 hours of surgery (early ambulation), (2) ambulation of 21 ft or more in the first 3 postoperative days (sustained ambulation), and (3) the elapsed time from surgery to first ambulation (time to ambulation). For nutrition, we evaluated (1) the provision of solids and/or liquids in the preoperative period (no prolonged fast), (2) the provision of postoperative oral nutrition within 12 hours of surgery (early nutrition), and (3) the elapsed hours from surgery to first nutrition (time to nutrition). For pain management and sedation, we evaluated (1) the use of any benzodiazepines in the first 3 postoperative days (benzodiazepine use), (2) the total intravenous morphine-equivalent dosage of opioid medication administered from hospitalization through the third postoperative day (opioid use), and (3) the proportion of time in which patients rated their current pain as acceptable (acceptable pain scores). We quantified these metrics based on medication administration records, preoperative checklists, and/or nursing shift assessments recorded in the electronic medical record.

Outcome Metrics—Our primary outcome metric was hospital length of stay. Our secondary outcomes included hospital mortality, discharge to home, and 30-day readmission. We evaluated surgical complication data, available for a subsample of patients

(eTable 5 in the Supplement), based on data abstracted manually according to National Surgical Quality Improvement Program (NSQIP) guidelines and procedures.³ We quantified surgical complications based on NSQIP categories. The NSQIP data abstraction was regionalized in January 2014 along with a decision to standardize the NSQIP participation model to multispecialty or target the model for all medical centers, preferentially targeting patients undergoing colorectal and hip fracture surgery. In a post hoc analysis, we evaluated major complication rates, which included septicshock, myocardial infarction, stroke, cardiac arrest, progressive kidney injury or renal failure, respiratory failure requiring mechanical ventilation, and venous thromboembolic disease.

Statistical Analysis

Data are presented as mean (SD), median (interquartile range), and number (percentage). Unadjusted comparisons between groups are based on unpaired, 2-tailed *t* tests, Wilcoxon rank sum tests, or χ^2 tests.

Process Measure Rate Ratios—To evaluate the comparative effect of implementation on process metrics after ERAS care vs usual care, we used generalized linear models to estimate the rate ratios for each metric, including a preperiod vs postperiod indicator flag, an ERAS vs comparator group indicator flag, and the interaction between the period and ERAS indicators. We reported rate ratios based on the interaction term indicating the postimplementation period among the ERAS-targeted group. For binary values, we used a Poisson distribution with a log-link function, whereas for continuous values, we used a gaussian distribution with a log-link function, both with robust SEs. We used the same models in an interrupted time-series approach to evaluate the monthly rates of process metric change between ERAS and comparator groups.

Outcome Measure Rate Ratios—To estimate rate ratios for the outcome metrics, we used generalized linear models while also including age, severity of illness at admission metrics (Laboratory and Acute Physiology Score, version 2, and Comorbidity Point Score, version 2), and direct admission to the intensive care unit as fixed effects and facility as a random effect. We considered 2-sided *P* .05 to be statistically significant. All analyses were performed in STATA/SE, version 14.1 (StataCorp).

Results

ERAS Cohorts

The study included a total of 3768 patients undergoing elective colorectal resection (mean [SD] age, 62.7 [14.1] years; 1812 [48.1%] male) and 5002 patients undergoing emergency hip fracture repair (mean [SD] age, 79.5 [11.8] years; 1586 [31.7%] male) (Table 2). Mean severity of illness and comorbid disease burden was higher among patients undergoing emergency hip fracture repair than among those undergoing elective colorectal resection.

ERAS Process and Outcome Metrics

Most process metrics among ERAS patients demonstrated significant changes between the preimplementation and post-implementation phases (Table 3). The rate of early ambulation

increased from 22.3% to 56.5% ($P < .001$) among patients undergoing elective colorectal resection and from 2.8% to 21.2% ($P < .001$) among patients undergoing hip fracture repair. Similarly, the use of early nutrition increased from 13.0% to 39.2% in patients undergoing elective colorectal resection and from 45.6% to 57.1% in patients undergoing hip fracture repair ($P < .001$). The total dose of morphine equivalents also decreased significantly in both groups (52.4 vs 30.6 mg in the colorectal resection group and 38.9 vs 27.0 mg in the hip fracture group; $P < .001$). Hospital length of stay decreased significantly in both ERAS groups (5.1 to 4.2 days in the colorectal resection group and 3.6 to 3.2 days in the hip fracture group; $P < .001$), whereas postoperative complication rates decreased from 18.1% to 14.7% ($P = .02$) in patients undergoing elective colorectal resection and from 30.8% to 24.9% ($P = .003$) in patients undergoing hip fracture repair.

Comparator Groups

We identified 5556 patients for the colorectal resection comparator group and 1523 patients for the hip fracture repair comparator group (eTable 6 in the Supplement). Among the comparator group patients, many process metrics also changed significantly between the preimplementation and postimplementation phases, albeit more modestly (eTable 7 in the Supplement). The Figure shows the comparative attainment of process metrics between the ERAS target populations and their comparators and several patterns indicated by estimates from interrupted time-series analyses (eTable 8 in the Supplement), including similar changes over time (eg, benzodiazepine use in both groups), frameshifts after ERAS implementation that resulted in similar levels of attainment (eg, early ambulation in both groups), and frameshifts after implementation that resulted in differing levels of metric attainment (eg, early nutrition and no prolonged fasting among patients undergoing colorectal resection).

Rate Ratios

We found favorable rate ratios in most process metrics among ERAS target populations compared with their respective comparator groups (eTable 9 in the Supplement). For example, ERAS implementation was associated with a significantly increased relative rate of early ambulation in patients undergoing colorectal resection (1.99; 95% CI, 1.80–2.21; $P < .001$) and hip fracture repair (4.44; 95% CI, 3.19–6.21; $P < .001$). Similarly, ERAS implementation was associated with a decreased relative rate of opioid use among patients undergoing colorectal resection (0.79; 95% CI, 0.71–0.89; $P < .001$) and patients undergoing hip fracture repair (0.73; 95% CI, 0.63–0.85; $P < .001$). There were no relative changes in the rate of benzodiazepine use in patients undergoing colorectal resection (1.11; 95% CI, 0.88–1.41; $P = .35$) or hip fracture repair (0.85; 95% CI, 0.62–1.17; $P = .33$).

In patients undergoing colorectal resection and hip fracture repair, ERAS implementation was associated with favorable reductions in hospital length of stay and postoperative complication rates (Table 4 and eTable 10 in the Supplement). Among patients undergoing colorectal resection, ERAS implementation was associated with decreased rates of hospital mortality (0.17; 95% CI, 0.03–0.86; $P = .03$) and major complications (0.28; 95% CI, 0.12–0.68; $P = .005$). Among patients undergoing hip fracture repair, implementation was associated with an increased rate of discharge to home (1.24; 95% CI, 1.06–1.44; $P = .007$).

In neither patients undergoing colorectal resection (0.94; 95% CI, 0.74–1.20; $P = .65$) nor patients undergoing hip fracture repair (0.96; 95% CI, 0.74–1.16; $P = .78$) was ERAS implementation associated with relative differences in the rate of 30-day readmission.

Discussion

System-level implementation of an ERAS program resulted in significant practice changes across a heterogeneous set of patients, clinicians, and hospitals. Compared with other surgical populations treated at the same hospitals over identical periods, ERAS-driven practice changes were associated with significantly decreased hospital length of stay and rates of postoperative complications. In patients undergoing elective colorectal resection, program implementation was associated with decreased surgical mortality and major complications. In patients undergoing emergency hip fracture repair, implementation was associated with improved rates of discharge to home.

Most prior studies^{12,14–18,27} that evaluated ERAS implementation have included patients undergoing colorectal surgery. A Cochrane systematic review¹² of ERAS in 2011 identified 4 randomized clinical trials including a total of 237 patients who met the review criteria. Similar to our results, length of stay and overall complication rates decreased with ERAS implementation without significant differences in readmission rates. A more recent meta-analysis by Greco et al¹⁴ identified 16 trials that enrolled a total of 2376 patients and reported a significant reduction in length of stay and nonsurgical complication rates without an accompanying difference in readmission rates. Although these prior studies^{12,14–18,27} are broadly consistent with our findings, we also identified a significant reduction in hospital mortality after ERAS implementation in our population undergoing elective colorectal resection.

Considerably fewer studies have robustly evaluated ERAS implementation outside colorectal surgery. A meta-analysis²⁸ of ERAS programs in several surgical domains that included 38 trials and 5099 patients found significant reductions in length of stay and 30-day complication rates, without significant differences in mortality or readmission. Of these trials, only 3 included patients undergoing lower extremity joint replacement. Macfie et al²⁹ evaluated 232 patients with femoral neck fractures and found that an ERAS program reduced postoperative complications without significant differences in mortality or length of stay. With a pre-post study design, Pedersen et al³⁰ reported significant reductions in inpatient complication rates with a significant reduction in hospital mortality among community-dwelling patients. We identified a similar reduction in complication rates along with a modest reduction in length of stay.

Strengths and Limitations

This study has several strengths compared with prior studies. First, we evaluated 2 heterogeneous surgical populations to assess for similar and differential effects of implementation. Patients undergoing colorectal resection were younger and healthier than patients undergoing hip fracture repair; they also underwent elective procedures. Before implementation, their care processes differed as well. For example, the rates of early ambulation were much higher among the patients undergoing colorectal resection, whereas

the rates of postoperative nutrition were much higher among patients undergoing hip fracture repair. Despite these substantial differences in baseline patient and care characteristics, the effect of program implementation on complications was a similar one-third relative decrease in complication rates; length of stay also decreased in both groups. Most prior studies^{12–15,18–21} have been limited to more homogeneous target populations. This study demonstrates the effectiveness of a systems-level approach to ERAS program implementation even across widely divergent target populations.

Second, we included contemporaneous comparator patients to isolate the effect of program implementation rather than effects that arise from secular change in surgical practice. Despite the fact that comparator patients were treated by the same surgical teams and experienced some modest changes in process metrics, their outcomes were largely unchanged before and after implementation, strengthening the assertion that the changes in outcomes in the target populations resulted from the implementation of the ERAS program itself. Most prior multicenter studies^{14,18} have not used contemporaneous comparator groups, limiting their study conclusions because of inherent limitations of standard pre-post study designs.

Third, prior studies^{12,20} have had limited ability to evaluate program implementation at scale in real-world settings. During a 2-year period, we were able to evaluate care patterns in more than 15 000 surgical patients. Program implementation affected the practice of thousands of clinicians and occurred in a diverse set of hospitals that differ significantly in size, patient case mix, teaching status, geographic location, and on-site specialty service availability, strengthening the generalizability of our findings. Our study was aided by evaluating electronic medical record–based metrics that were already used by clinicians, allowing us to precisely quantify a large panel of performance measures populated during routine care delivery. Thus, we were able to demonstrate the feasibility of large-scale ERAS program implementation during a relatively short interval.

The study also has important limitations. First, the evaluation was not a randomized clinical trial, and the program rollout was not randomized by site. Thus, the results may be affected by residual confounding and baseline differences in intervention and usual care patients. Our comparator groups also underwent different surgical procedures than the target populations, limiting our ability to directly compare 2 identical groups. Second, we did not have standardized and validated complications data on all patients; there was also an imbalance in the acquisition of these data over time and between the target and comparator groups. Because of the size and speed of the implementation effort, program resources were not available to perform data abstraction for every surgical patient. Third, as a highly integrated health care delivery system, the KPNC may differ from other health care systems in the United States. Thus, implementation and results may vary depending on the particular model of surgical practice and performance improvement method. Fourth, our study evaluated short-term outcomes; future studies are necessary to evaluate the effect of enhanced recovery on longer-term outcomes, especially functional and cognitive ability after surgery.

Conclusions

Implementation of the ERAS program successfully altered the process-of-care metrics for patients undergoing emergency hip fracture repair and patients undergoing elective colorectal resection across 20 hospitals. In this study of more than 15 000 surgical patients, program implementation was associated with significant absolute and relative improvements in hospital length of stay and surgical complication rates.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

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Key Points

Question

What is the influence of implementation of an enhanced recovery after surgery program on outcomes among patients undergoing elective colorectal resection and emergency hip fracture repair?

Findings

In this pre-post difference-in-differences study of 15 849 surgical patients at 20 medical centers in Northern California, implementation of a multifaceted enhanced recovery program was associated with a one-third reduction in postoperative complication rates in the target population relative to comparator surgical populations. The program was also associated with decreased hospital mortality among patients undergoing colorectal resection and increased rates of discharge to home among patients undergoing hip fracture repair.

Meaning

Large-scale implementation of an enhanced recovery after surgery program significantly improved many processes and outcomes of surgical care in 2 distinct populations.

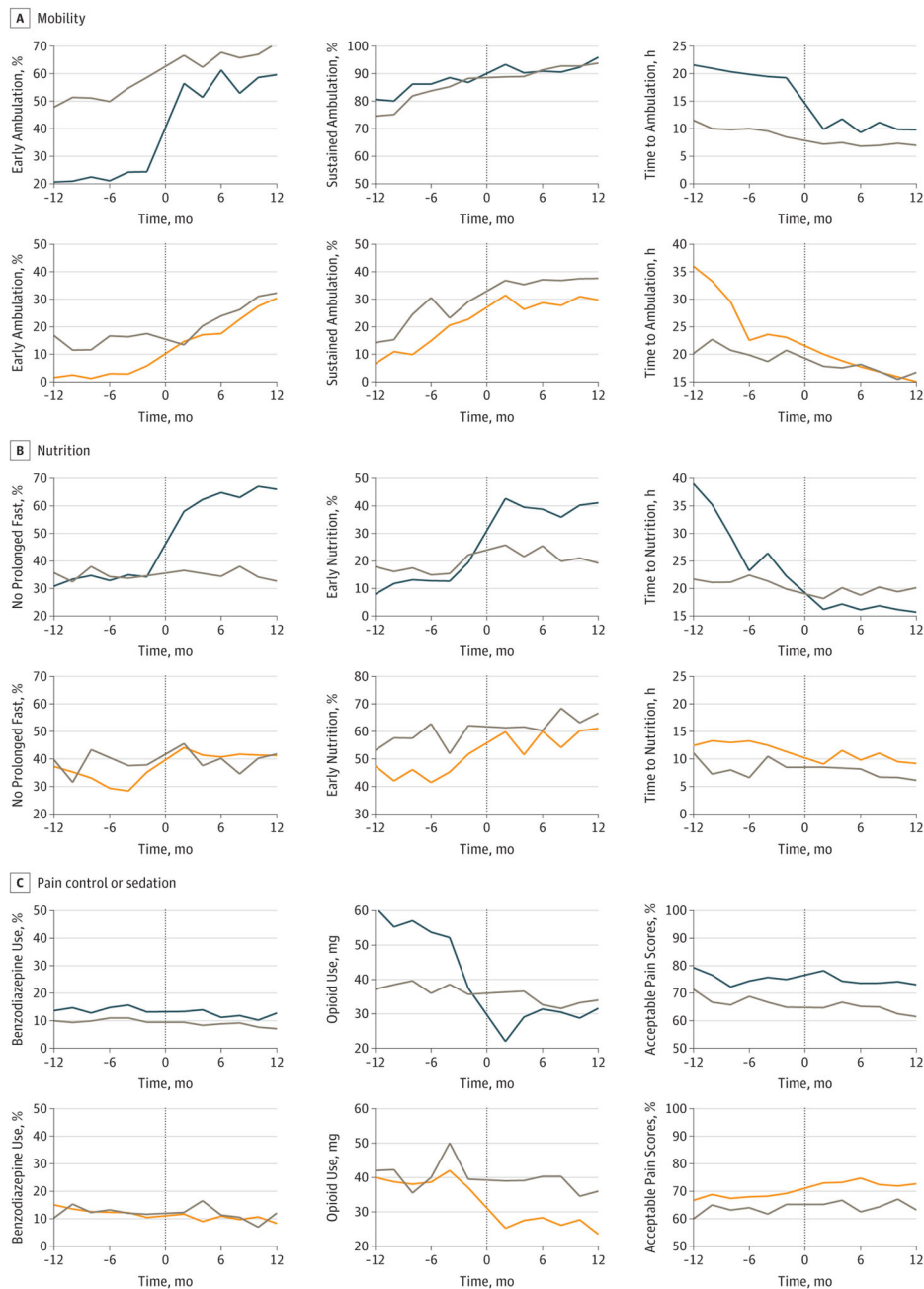


Figure. Bimonthly Process Metric Attainment Before and After Enhanced Recovery After Surgery (ERAS) Program Implementation

Data are standardized to the month of implementation in each facility for mobility (A), nutrition (B), and pain control or sedation (C). Each point represents mean values during a 2-month period; data from the implementation month (month zero) are not included. Top rows represent ERAS colorectal resection (blue lines) and comparator (gray lines) groups; bottom rows represent ERAS hip fracture repair (orange lines) and comparator (gray lines)

groups. The y-axes vary for each plot to improve clarity; percentage changes include a 50% interval, whereas changes in hours include a 25-hour interval.

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Table 1

Care Processes Included in the Kaiser Permanente Northern California Enhanced Recovery After Surgery Program

Care Process	Description
Preoperative	
Patient education	Verbal counseling and written brochures provided preoperatively
No prolonged fasting	Clear liquids allowed up to 2 h and solids up to 8 h before surgery
Carbohydrate loading	Carbohydrate-rich drink or apple juice 2 to 4 h preoperatively
Decreased sedative medications	Recommended premedication limited to 2 mg of midazolam
Regional anesthesia	Peripheral nerve blocks in emergency department (hip fracture)
Intraoperative	
Antimicrobial prophylaxis	Chlorhexidine skin preparation and antibiotics within 1 h before incision
Postoperative nausea and vomiting prophylaxis	Multimodal prophylaxis based on risk
Multimodal analgesia	Gabapentin, acetaminophen, intravenous lidocaine infusion, nerve blocks, or thoracic epidural
Standard anesthetic protocol	Hip fracture: neuraxial anesthesia preferred Colorectal: thoracic epidural, nerve block, or intravenous lidocaine infusion
Minimally invasive surgery	Laparoscopic approach preferred (colorectal)
Avoidance of drains and tubes	Routine nasogastric tubes and drains discouraged
Perioperative fluid management	Restrictive or goal-directed fluid replacement
Prevention of hypothermia	Active warming devices
Postoperative	
Multimodal analgesia	Scheduled acetaminophen and ketorolac, intravenous lidocaine infusion (colorectal), or regional anesthesia
Early oral nutrition	Full liquid or regular diet within 12 h after surgery
Early and sustained ambulation	Ambulation accomplished within 12 h after surgery and twice daily thereafter
Early urinary catheter removal	Removal of urinary catheter within 24 h after surgery
Deep vein thrombosis prevention	Sequential compression devices unless ambulating
Restoration of gut function	Chewing gum (colorectal)

Table 2
 Baseline Characteristics of Patients in the 1-Year Periods Before (Pre) and After (Post) the Enhanced Recovery After Surgery Implementation Across 20 Medical Centers in Kaiser Permanente Northern California

Characteristic	Elective Colorectal Resection		Emergency Hip Fracture Repair		P Value ^a
	Pre (n = 1890)	Post (n = 1878)	Pre (n = 2488)	Post (n = 2514)	
Age, mean (SD), y	63.2 (14.2)	62.1 (14.0)	79.3 (11.9)	79.7 (11.7)	.23
COPS2, mean (SD)	27.5 (30.8)	27.9 (30.1)	43.9 (40.7)	43.5 (40.0)	.72
LAPS2, mean (SD)	20.2 (13.0)	19.7 (12.4)	57.0 (29.5)	58.0 (30.2)	.21
Direct ICU admission, No. (%)	5 (0.3)	6 (0.3)	16 (0.6)	19 (0.8)	.63
Elapsed time between admission and surgery, median (IQR), h	2.2 (1.8–2.9)	2.2 (1.7–2.9)	15.9 (6.1–23.6)	15.7 (6.3–23.0)	.52
Duration of surgery, median (IQR), h	2.6 (1.9–3.6)	2.7 (2.0–3.9)	1.0 (0.7–1.4)	1.0 (0.7–1.4)	.53

Abbreviations: COPS2, Comorbidity Point Score, version 2; ICU, intensive care unit; IQR, interquartile range; LAPS2, Laboratory and Acute Physiology Score, version 2.

^a P values for pre-post comparisons are based on 2-tailed, unpaired t test; χ^2 test; or Wilcoxon rank sum test.

Table 3

Process and Outcome Metrics Before (Pre) and After (Post) Enhanced Recovery After Surgery Implementation for the Colorectal Resection and Hip Fracture Repair Cohorts

Metric	No. of Patients	Patients ^a		P Value ^b
		Pre	Post	
Colorectal Resection Cohort				
Mobility				
Early ambulation	3687	415 (22.3)	1032 (56.5)	<.001
Sustained ambulation	3685	1603 (86.2)	1735 (95.0)	<.001
Time to first ambulation, median (IQR), h	3717	20.3 (13.5–26.1)	10.3 (6.7–18.6)	<.001
Nutrition				
No prolonged fast	3767	69 (3.7)	247 (13.2)	<.001
Early nutrition	3767	245 (13.0)	736 (39.2)	<.001
Time to first nutrition, median (IQR), h	3680	27.0 (18.4–54.1)	16.4 (7.0–23.2)	<.001
Analgesia and sedation				
Any benzodiazepine use	3767	267 (14.1)	233 (12.4)	.12
Morphine equivalents, median (IQR), mg	3604	52.4 (23.0–102.0)	30.6 (13.9–65.5)	<.001
Mean acceptable pain scores, median (IQR), %	3761	75.9 (60.0–88.7)	73.8 (59.3–88.4)	.14
Outcome metrics				
Hospital length of stay, median (IQR), d	3768	5.1 (3.4–7.1)	4.2 (3.1–6.2)	<.001
Hospital mortality	3768	16 (0.9)	6 (0.3)	.03
Discharge to home	3768	1808 (95.7)	1816 (96.7)	.10
30-d Readmission	3768	348 (18.6)	364 (19.4)	.50
Postoperative complications	2406	184 (18.1)	204 (14.7)	.02
Major complications	2406	42 (4.1)	39 (2.8)	.08
Hip Fracture Repair Cohort				
Process metrics				
Mobility				
Early ambulation	4619	66 (2.8)	481 (21.2)	<.001
Sustained ambulation	4616	356 (15.2)	719 (31.7)	<.001
Time to first ambulation, median (IQR), h	3189	25.3 (18.1–46.4)	17.3 (11.6–25.5)	<.001
Nutrition				
No prolonged fast	5002	32 (1.3)	122 (4.9)	<.001
Early nutrition	5002	1134 (45.6)	1436 (57.1)	<.001
Time to first nutrition, median (IQR), h	4915	12.6 (6.5–17.5)	10.3 (4.9–15.7)	<.001
Analgesia and sedation				
Any benzodiazepine use	5002	316 (12.7)	251 (10.0)	.002
Morphine equivalents, median (IQR), mg	4887	38.9 (22.0–66.5)	27.0 (13.5–48.3)	<.001
Mean acceptable pain scores, median (IQR), %	4988	68.2 (54.3–82.1)	72.7 (57.1–85.7)	<.001

Metric	No. of Patients	Patients ^a		P Value ^b
		Pre	Post	
Outcome metrics				
Hospital length of stay, median (IQR), d	5002	3.6 (2.8–4.8)	3.2 (2.6–4.7)	<.001
Hospital mortality	5002	35 (1.4)	42 (1.7)	.45
Discharge to home	5002	541 (21.7)	676 (26.9)	<.001
30-d Readmission	5002	299 (12.2)	342 (13.8)	.09
Postoperative complications	2287	240 (30.8)	375 (24.9)	.003
Major complications	2287	25 (3.2)	56 (3.7)	.53

Abbreviation: IQR, interquartile range.

^aData are presented as number (percentage) of patients unless otherwise indicated. Not all data were available for all patients, so the total denominator differs based on the specific metric.

^bP values are based on χ^2 or Wilcoxon rank sum tests.

Table 4

Difference-in-Differences Risk Ratios for ERAS Patient Outcome Metrics After Program Implementation Among Colorectal Resection and Hip Fracture Repair Cohorts^a

Metric	Difference-in-Differences Estimates, Rate Ratio (95% CI)			
	Colorectal Resection vs Comparator	P Value	Hip Fracture vs Comparator	P Value
Hospital length of stay, d	0.92 (0.86–0.99)	.03	0.83 (0.77–0.91)	<.001
Hospital mortality	0.17 (0.03–0.86)	.03	1.12 (0.37–3.41)	.84
Discharge to home	1.01 (0.99–1.02)	.13	1.24 (1.06–1.44)	.007
30-d Readmission	0.94 (0.74–1.20)	.65	0.96 (0.74–1.26)	.78
Postoperative complications	0.68 (0.46–0.99)	.04	0.67 (0.45–0.99)	.05
Major complications	0.28 (0.12–0.68)	.005	0.53 (0.15–1.84)	.32

Abbreviation: ERAS, Enhanced Recovery After Surgery.

^aA difference-in-differences risk ratio of 0.67 (postoperative complications; hip fracture) can be interpreted as a 33% lower rate of postoperative complications among patients undergoing hip fracture repair after ERAS program implementation compared with before ERAS implementation relative the orthopedics comparator cohort during the same intervals.