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Abstract

Background: Exposure to opioids after surgery is the first point of contact for some people who develop chronic opioid use disorder. Hence, effective postoperative pain management, with less reliance on opioids, is critical. The Perioperative Opioid Quality Improvement (POQI) program developed and implemented 1) a digital health platform leveraging patient-reported risk factors from surveys and 2) a post-surgical pain risk stratification algorithm to personalize perioperative care planning through the integration of several commercially available digital health solutions into one combined POQI platform. As a result of the COVID-19 pandemic, the POQI platform development was reduced in scope.

Objective: This was a pilot study to assess the screening performance of the risk algorithm, quantify the utilization of the POQI platform, and evaluate clinicians' and patients' perceptions of utility and benefit.

Methods: An initial prototype of the POQI platform was implemented in a quality improvement initiative at a Canadian tertiary care centre and evaluated between Jan-Sep/2022. After surgical booking, a preliminary risk stratification algorithm was applied to responses to a health history questionnaire. The resulting estimated risk guided assigning the patient to a care pathway based on low- or high-risk for persistent pain and opioid use. Demographic, procedural, and medication administration data were extracted retrospectively from the electronic medical record. Postoperative inpatient opioid usage >90 morphine milligram equivalents per day was used as the outcome to assess algorithm performance. Data were summarized and compared between low- and high-risk groups. Classification data was assessed by a confusion matrix. POQI utilization was assessed by completed surveys on postoperative days 7, 14, 30, 60, 90 and 120. Semi-structured interviews were conducted with patients and clinicians to obtain qualitative feedback on the platform.

Results: Two hundred and seventy-six eligible patients were admitted for colorectal procedures. The risk algorithm stratified 203/276 (74%) as low-risk and 73/276 (26%) as high-risk. Among the 214/276 patients with available data, high-risk patients were younger than low-risk patients (median age 53 vs. 59 years, median difference [MD] 5 years, 95%CI 1-9, p=0.021), more often female (61.6% vs. 38.4%, odds ratio 2.5, 95%CI 1.4-4.5, p=0.002), and reported lower baseline (preoperative) quality of recovery scores (median 122 vs. 131, MD 12, 95%CI 2-23, p=0.016). The pilot risk stratification algorithm was reasonably specific (true negative rate 72%) but not sensitive (true positive rate 32%). A minority of patients (85/214; 40%) completed any postoperative quality of recovery questionnaires; 14/214 (7%) did so beyond 60 days post-surgery; and 49/214 completed post-discharge medication surveys. Interviewed participants welcomed the initiative but noted usability issues and poor platform education.

Conclusions: An initial prototype of the POQI platform was deployed operationally; the pilot risk algorithm had reasonable specificity but poor sensitivity. Attrition was high, with a significant loss to follow-up in post-discharge survey completion. Shortcomings in the design and implementation of the platform were expressed in qualitative feedback from clinicians and patients, yet they appreciated the potential impact of pre-emptively addressing opioid exposure. Thus, an iterative platform re-design with additional available features and re-evaluation should be undertaken before broader implementation.

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Background: Exposure to opioids after surgery is the first point of contact for some people who develop chronic opioid use disorder. Hence, effective postoperative pain management, with less reliance on opioids, is critical. The Perioperative Opioid Quality Improvement (POQI) program developed and implemented 1) a digital health platform leveraging patient-reported risk factors from surveys and 2) a post-surgical pain risk stratification algorithm to personalize perioperative care planning through the integration of several commercially available digital health solutions into one combined POQI platform. As a result of the COVID-19 pandemic, the POQI platform development was reduced in scope.

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Keywords: patient-oriented research; patient-reported outcome measures; risk prediction; pain; individualized risk; surgery; anesthesia; opioid analgesia; short-term opioid use; care planning; digital health platforms

Introduction

The ongoing opioid overdose epidemic has contributed to unprecedented and unnecessary deaths, with an estimated 100,306 deaths from prescription and illegal opioids in the US in the twelve months before April 2021 [1] and 5,360 deaths in Canada in the first nine months of 2022 [2]. For many patients with an opioid use disorder, the perioperative period represents the source of initial exposure (>6% compared to 0.4% in a control cohort without surgery in the US) [3]. Hence, effective postoperative pain management, with less reliance on the prescription of opioids, could be a valuable mechanism to reduce the development of subsequent opioid use disorder. Post-surgical opioids are most frequently prescribed by the surgeon and followed up by the patient's primary care physician [4]. Anesthesiologists are uniquely positioned to manage acute postoperative pain effectively with multi-modal analgesia to decrease perioperative opioid exposure and prevent subsequent persistent opioid use [3].

Perioperative healthcare is being optimized through enhanced recovery after surgery (ERAS) pathways [4–6], multi-modal analgesic plans [5,7,8], and regional anesthesia techniques [9]. Further opportunities to improve post-surgical pain trajectories are offered by pre-habilitation programs [10–12], our developing understanding of the risks of persistent post-surgical pain [13–17], and the feasibility of accessing and analyzing large volumes of data. A critical step is identifying patients at high risk of significant post-surgical pain and long-term opioid use.

The Perioperative Opioid Quality Improvement (POQI) program was designed to address the ongoing opioid use epidemic in British Columbia, which continues to be one of our province's most pressing public health concerns. Recent studies have highlighted the scale of the local opioid problem and highlighted the case for addressing opioid risk during routine clinical care, including surgery: 12% of our population received an opioid prescription in 2017, with the number receiving a high dose (>90 MME/day) increasing during 2013-2017 [18]; opioid overdose patients have often had previous clinical encounters for pain (50%) and surgery (5%) [19].

The POQI program was funded in 2019 by DIGITAL, Canada’s Global Innovation Cluster for digital technologies, as a consortium between digital health companies, healthcare organizations, and university partners. It aimed to develop and implement a post-surgical pain risk stratification algorithm by integrating several commercially available digital health solutions into one combined POQI digital health platform for pre-habilitation and post-surgical care planning. The COVID-19 pandemic impacted the ability to engage clinicians and patients in co-design and iteratively test the solution. Hence, the project faced significant delays, and the scope of the POQI platform development was reduced. Specifically, planned features for two-way communication and personalization of educational information for patients were not included in the prototype tested in this study.

The specific objectives of the pilot deployment of the POQI platform were to assess a) the screening performance of the risk stratification algorithm to facilitate subsequent risk score optimization and b) the utilization, utility, and perceived benefit of the POQI platform among end-users (clinicians and patients).

Methods

Study Design and Approval

The study involved the design, implementation, and pilot evaluation of the POQI digital health platform at Providence Health Care's St. Paul's Hospital (St. Paul's) in Vancouver, BC, Canada. The target users were clinicians and patients. The patient population for pilot testing had undergone a designated set of colorectal surgeries, selected because this surgical clinic was an early adopter of an electronic health history questionnaire upon which the platform expanded. As a result of this initiative, the Department of Anesthesiology and Pain Medicine at Providence Health Care (PHC) established a new Transitional Pain Clinic for patients at risk of persistent postoperative pain or opioid use after surgery. It held weekly clinics during the study period and continued to serve St. Paul's patients after the study concluded.
The POQI platform incorporated an algorithm [20] that classified patients as low-risk or high-risk for persistent post-surgical pain and long-term opioid use. Clinicians used this classification to assign patients to low-risk or high-risk pathways for personalized pre-habilitation, patient education, and care planning. Specifically, patients were told that there were resources that they could use to learn about pain and non-pharmacologic strategies for pain and that they could keep track of their medication use and pain scores over time in the system. The performance of this risk stratification was evaluated based on observed postoperative inpatient opioid usage. The clinical and patient user experiences were evaluated using mixed methods.

The University of British Columbia – Providence Health Care Research Ethics Board determined this work to be quality improvement (reviewed 13 October 2020), for which they do not require ethical review under Article 2.5 of the Canadian Tri-Council Policy Statement. Hence, this project was run as a quality improvement pilot project governed by a Privacy Impact Assessment and Security Threat and Risk Assessment. This manuscript adheres to the SQUIRE 2.0 (Standards for QUality Improvement Reporting Excellence) reporting guidelines [21].

The POQI digital health platform

Development of the POQI platform combined existing technology from three industry partners: a preoperative survey and postoperative care platform for low-risk patients (POQI-L), supplied by Thrive Health (Vancouver, BC, Canada); a postoperative care platform for high-risk patients (POQI-H), supplied by Careteam Technologies (Vancouver, BC, Canada); and a data broker, supplied by Excelar Technologies (Vancouver, BC, Canada, also incorporating Xerus Medical from 2021) (**Figure 1**). Additional components were identified and developed based on the needs of the clinical implementation partners (the anesthesiologists and perioperative care team at St. Paul's). The platform's original scope of development work was scaled back due to resource and time constraints during the COVID-19 pandemic. The resultant POQI platform used in this study should be considered an initial prototype. Original development plans included: a) additional iterations of user testing and design refinement; b) additional features, such as two-way communication between patients and clinicians; and c) personalization of educational materials to meet patients' needs optimally.

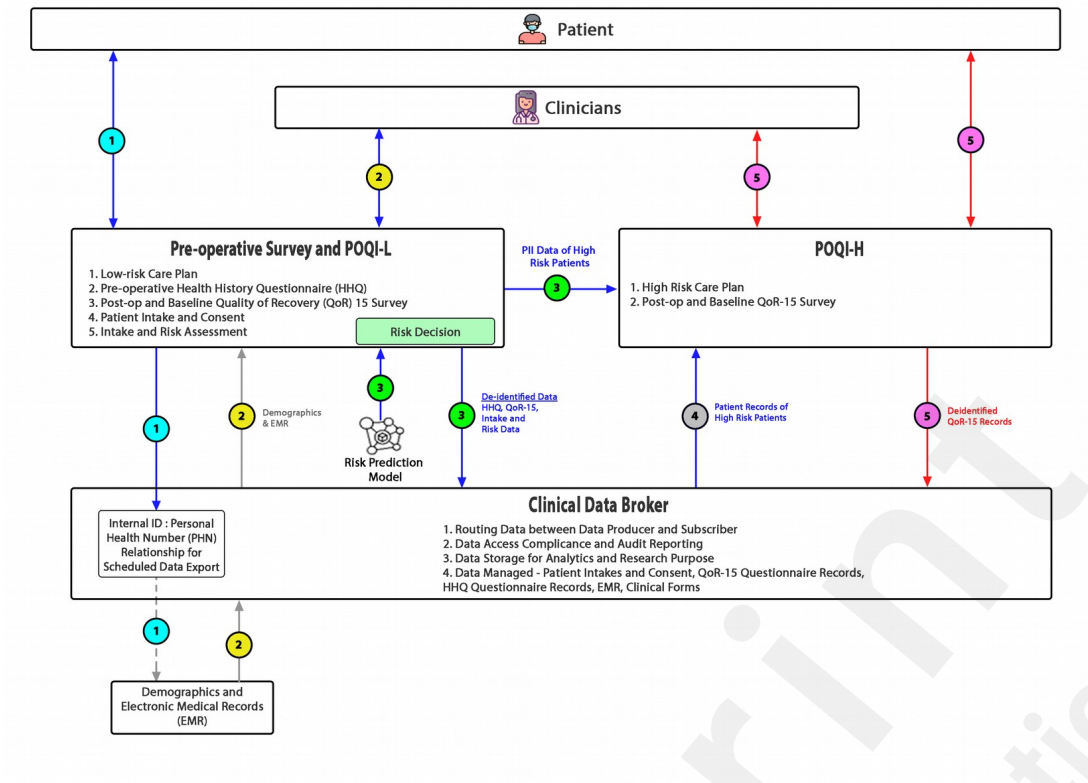

Figure 1: Workflow in the postoperative quality improvement (POQI) platform showing the integration of clinical and patient-reported data from patient-facing components and the electronic medical record (EMR) integrated by a data broker; PII – personally identifiable information; PHN, personal health number; POQI-L, POQI platform for low-risk patients; POQI-H, POQI platform for high-risk patients; QoR, quality of recovery.

The prototype POQI platform allowed for the collection of patient-specific data, including a pre-surgical health history questionnaire (HHQ, questions selected as risk factors for modelling are in **Multimedia Appendix 1**) and patient-reported outcome measures (PROMs) at baseline. Data were also collected postoperatively using quality of recovery 15 questionnaires (QoR-15) [22] and additional PROM surveys to collect self-reported medication usage and pain (scores). The platform was linked to an automated export from the Cerner electronic medical record (EMR) system (Cerner Corp., North Kansas City, MO), which allowed for collecting surgery details and oral and intravenous (IV) opioid utilization data from inpatient medication administration records.

Initial HHQ data were used to stratify patients for risk of persistent post-surgical pain and opioid use, using a previously developed risk score, which was based on data collected from 122 colorectal surgery patients; 22 (18%) had a high postoperative opioid utilization, which was strongly associated with a history of chronic pain, substance use disorder, and open surgery [20]. Patients were categorized into high-risk and low-risk using a points-based prediction model that considered 11 risk factors with different weights [20]: substance use disorder (weight=5); current prescription of opioid (5), benzodiazepine (4), or antidepressant (4); recreational drug use (4); history of chronic pain (4), anxiety or panic attacks (2), depression (2), or poorly controlled pain after surgery (2); female sex (2); age <40 years (1) (see relevant HHQ questions in **Multimedia Appendix 1**). The algorithm flagged a patient as high-risk if the risk score was >7/35, after which a clinician manually onboarded the patient to the POQI-H platform or confirmed that they should remain on the POQI-L platform.

The clinician could override the algorithm's proposed risk label if they deemed it clinically appropriate. Additionally, clinicians could use their clinical judgment to manually onboard patients directly to POQI-H after St. Paul's Transitional Pain Clinic consult, even when no electronic HHQ data were available.

High-risk patients were given a care plan that provided them with education about pain and opioid management and prompted them to record their medication use and pain scores (see Study Design and Approval section above for details). Some high-risk patients were also seen preoperatively by St. Paul's Transitional Pain Clinic for pre-habilitation, education and pain management planning when the responsible clinician deemed it appropriate. Postoperatively, high-risk patients were flagged by St. Paul's Transitional Pain Clinic providers for closer follow-up by the Acute Pain Service in the hospital.

Regardless of risk categorization, patients who used a significant quantity of opioids postoperatively (>90 morphine milligram equivalents [MME]) were also followed by St. Paul's Transitional Pain Service for optimization of their post-discharge pain management and opioid weaning; 90 MME was chosen as the threshold for referral as it is recommended in the 2017 Canadian Guideline for Opioids for Chronic Non-Cancer Pain that patients using more than 90 MME per day be weaned to the lowest effective dose, potentially including discontinuation [23].

Participants and recruitment

Pilot use of the POQI platform was initiated at St. Paul's in Dec-2021 and formally adopted on 01-Jan-2022. The target population for pilot testing included patients undergoing a designated set of colorectal surgeries during the active enrollment period (**Multimedia Appendix 2**), excluding screening and minimally invasive diagnostic procedures like endoscopies. Patients who had surgery not included in the designated set or had undergone procedures with a surgical time under 20 minutes were excluded. Patients who had surgery before 01-Jan-2022 were also excluded, as the complete POQI platform implementation was not available for clinical use until then. Only the surgical encounter closest to the most recently recorded HHQ was considered when patients had multiple procedures. Eligible patients were enrolled for the pilot through routine clinical care by the medical office assistant in surgical clinics (**Figure 2**). Postoperative data collection continued for up to 120 days after surgery, with surveys potentially completed on postoperative days 7, 14, 30, 60, 90, and 120.

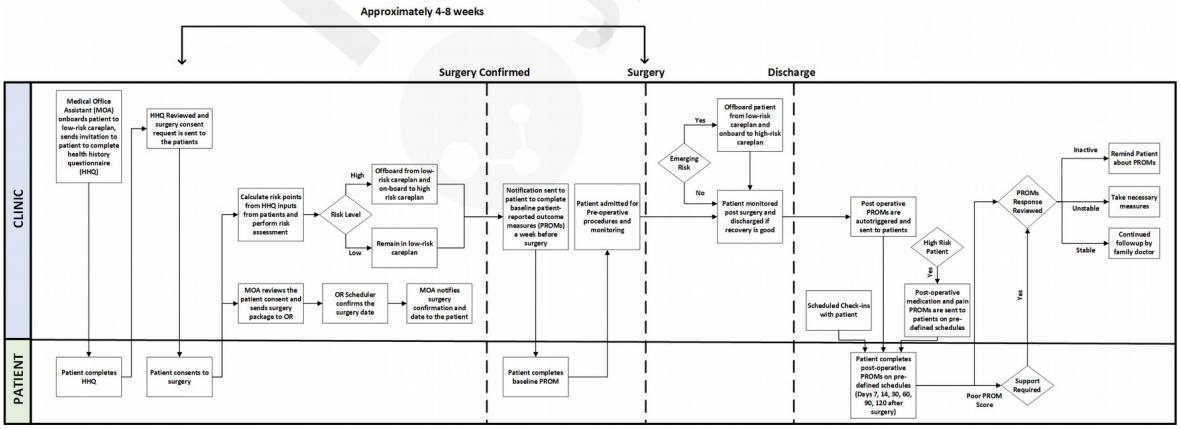

Figure 2: Clinical workflow of the postoperative quality improvement (POQI) platform as piloted at St. Paul's Hospital. This illustrates the flow of patients through their perioperative care journey and delineates which pieces the system performs and when the patient is involved in this process; it shows key decision points, such as when the patient is risk-stratified before their procedure and if patients require enhanced follow-up post-discharge. A poor PROM score (bottom right) was indicated if the patient reported having an unplanned hospital admission for pain, having to seek urgent care for pain, or that they were still taking opioids beyond postoperative day seven. MOA – medical office assistant; HHQ – health history questionnaire; OR – operating room; PROM – patient-reported outcome measure

Data collection and management

The patient-specific data, including HHQ, preoperative baseline, QoR-15 questionnaires, and PROM surveys, were fed directly to the data broker from the respective POQI-L or POQI-H platforms. The surgery details and opioid utilization data from the medication administration record were pulled from the EMR. These data were made available in a data lake by the Excelar data broker for analysis. The unifying variables used to link the multiple platforms were the patient's Personal Health Number (PHN) and the ThriveID, assigned at initial onboarding for HHQ completion. Data for this evaluation were aggregated and de-identified (**Figure 2**). The de-identified datasets were then exported to the research team for analysis.

Outcomes

Risk stratification

To evaluate the risk stratification, we elected to focus on inpatient opioid utilization. Analyzing long-term opioid use was not possible: records of opioids dispensed from the provincial medication system (PharmaNet) were not made available due to provincial policy constraints at the time, and patient self-report was deemed to be unfeasible and incomplete or biased. Hence, the primary outcome used to evaluate the accuracy of the risk stratification was based on inpatient daily opioid utilization, using a threshold of >90 MME per day to indicate high opioid utilization, in line with recommendations for opioid therapy and chronic noncancer pain [23]. MME was computed by multiplying the dosage of opioids delivered to the patient with the MME conversion factor of the corresponding drug and route of administration (**Multimedia Appendix 3**). For oral methadone, the MME conversion factor varies with the dosage administered per day; consequently, an aggregation algorithm was used to calculate the total methadone administered per day.

Patient-controlled analgesia was typically used for in-hospital IV opioid administration. Nurses regularly recorded the number of doses delivered to the patient, and the patient-controlled analgesia pump was reset every 12 hours at the end of their shift. The net amount of drug delivered to the patient was computed using the number of doses and the amount of drug in each dose. The MME values from IV and oral administration were then summed for every patient over a 24-hour period, starting at 06:00 and ending at 06:00 the following day.

Electronic medical record data structures and export limitations prevented us from including MMEs of drugs delivered through continuous opioid infusion or boluses; these patients were excluded from

MME evaluation. Intraoperative opioids were not included when computing MME/day; i.e., on the day of surgery, only opioids administered after the surgery up to 06:00 the following day were included for the MME/day calculation.

Utilization, utility, and perceived benefit

The user experience outcomes of utilization, utility, and perceived benefit were evaluated using mixed methods.

Utilization was measured quantitatively by evaluating both uptake and attrition with the platform. Uptake was measured by the number of patients completing the HHQ survey and the number completing the preoperative baseline QoR-15. Attrition was evaluated by measuring continued use of the system postoperatively; that is, by the number of patients completing at least one postoperative QoR-15 survey, at least one PROM survey, and the number of patients completing their postoperative data collection period up to the 90-day mark.

Utility and perceived benefit were evaluated through a series of semi-structured interviews with both patients and clinicians over Zoom (Zoom Video Communications, San Jose, CA). To obtain a representative sample, a randomly selected group of 10 patients deemed high-risk and a random group of 10 patients deemed low-risk for significant post-surgical pain were contacted approximately one week after hospital discharge and invited to participate. For clinicians, we included anesthesiologists and nurses in St. Paul's Transitional Pain Clinic and aimed for a sample of five clinicians.

Brief (~10-15 mins) interviews focused on three domains: a) experience with the platform technologies, b) perceived benefit of the platform for the healthcare experience, and c) feedback or concerns about the platform (**Multimedia Appendix 4**). Interviews were conducted in a safe environment of mutual respect and facilitated by a medical student (SS) assisting with the project. Transcripts were automatically obtained from Zoom and downloaded from the videoconferencing platform for all interviews. A research team member (MDW) thematically analyzed the transcripts using NVivo (QSR International, Burlington, MA).

Additional secondary outcomes

Additional secondary outcomes included emergent readmissions, pain scores over the first three postoperative days (PODs), and continued opioid utilization at 30, 60, and 90 days, collected through the additional PROM surveys. To determine the number of patients who had emergent readmissions, we filtered the inpatient and emergency department visit datasets for patients with prior surgery. We confirmed that the admission time in the new visit was after the discharge time post-surgery. As inpatients could have had non-emergent readmissions for scheduled procedures, and not all emergent visits require admissions, only the inpatient visits categorized as "Urgent/Emergent" and the patients admitted after emergency visits were included. The dataset was split into readmissions within 30 days and readmissions within 180 days after discharge.

Statistical Analysis

The available data were summarized for high- and low-risk patients, including patient count, age distribution, surgical wait time (time to surgery after referral for surgical care), procedure duration, length of hospital stay, the identified risk factors from the HHQ (see *the POQI digital health platform* section above), preoperative and postoperative QoR-15 scores, the proportion of the population that completed the QoR-15, length of follow-up, the number of emergent readmissions, in-hospital opioid utilization in MME/day, and most prevalent surgeries. Frequency data are reported

as n/N (%); the denominator N changes due to data linking issues and loss of follow-up during the study period.

Due to the small sample size, data for low- and high-risk groups were compared using non-parametric statistical tests: Fisher's exact test for counts and Mann-Whitney U for continuous data; a logistic regression of all risk factors for high in-hospital opioid utilization was performed to generate adjusted odds ratios (ORs), reported with 95% confidence intervals (CIs). Analyses were performed using Python 3.10: Pandas 1.5.0, SciPy 1.9.3, and NumPy 1.23.3 were used for data cleaning, processing, and analysis; Matplotlib 3.6.0 was used to generate plots; and Openpyxl 3.0.10 was used to create analysis reports. R 4.2.2 (R Foundation for Statistical Computing, Vienna, Austria) was used for statistical comparisons.

The accuracy of the risk stratification was assessed to determine if the algorithm was sensitive enough to categorize patients based on their health history. This was achieved by constructing confusion matrices using the high- and low-risk labels generated by the risk prediction algorithm (using HHQ data, not POQI-L or POQI-H enrolment labels) and the outcome: high (>90 MME/day) and low (≤90 MME/day) opioid utilization. These data were used to estimate sensitivity, specificity, false negative rate, false positive rate, and positive and negative likelihoods.

Scatter with line (median) plots and box plots were created to determine the trend of opioid utilization by patients on PODs 0-10 and to compare the trend between low- and high-risk patients.

Results

Population

A total of 276 eligible patients were admitted for one of the colorectal procedures selected for inclusion in the study at St. Paul's between 01-Jan-2022 and 30-Sep-2022 and completed the HHQ before surgery (**Figure 3**). Note that the denominators vary in the following tables due to the selective completion of surveys and the availability of linked data.

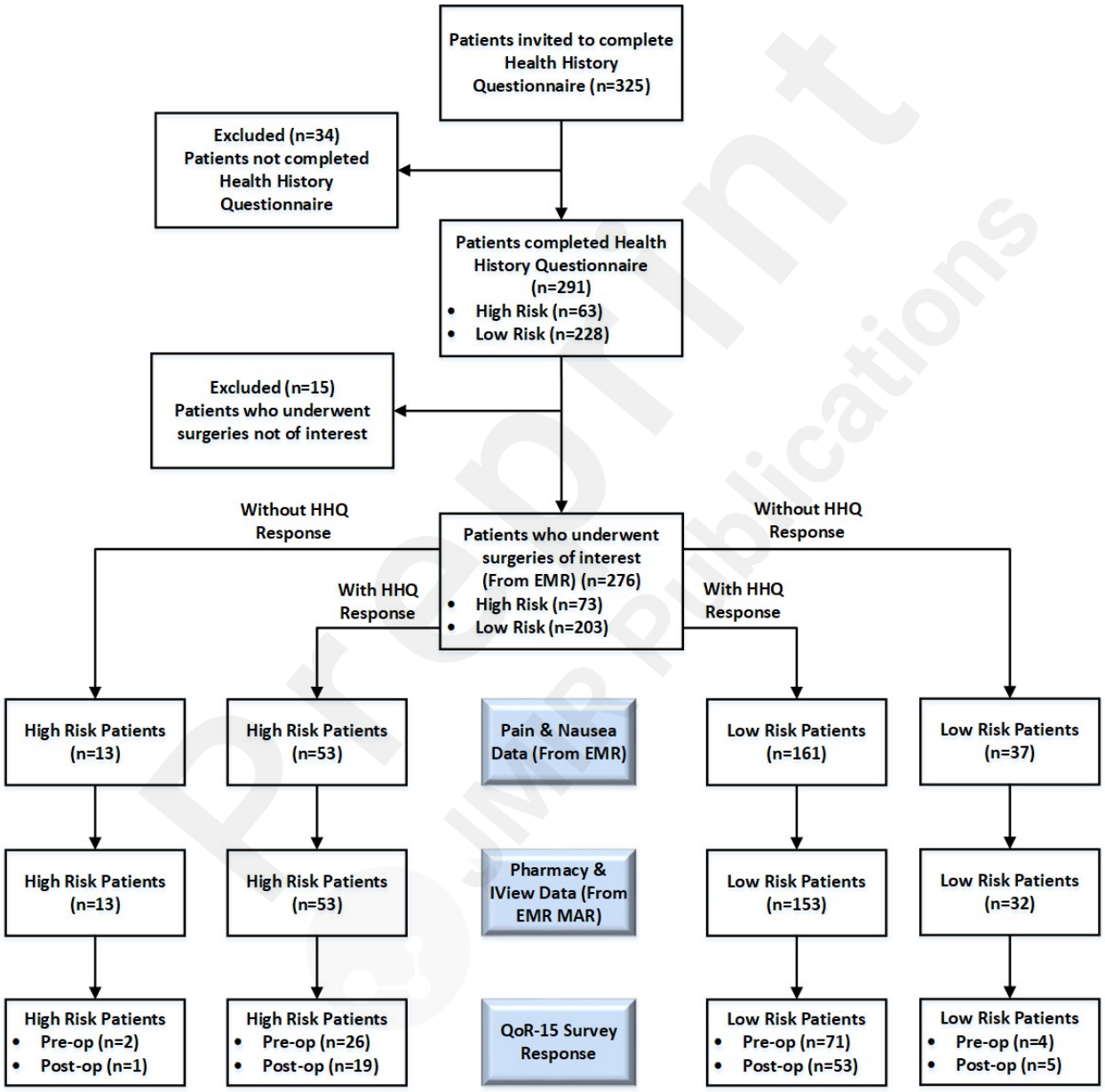

Figure 3: Platform uptake, attrition, and data completeness in high-risk and low-risk patients; EMR, electronic medical record; MAR, medication administration record; QoR, quality of recovery.

Risk stratification characteristics

The risk stratification algorithm identified 203/276 (74%) as low-risk and 73/276 (26%) as high-risk. The most common surgeries for low-risk patients were laparoscopic resection of the anterior colon, transanal resection of a rectal lesion by assisted microsurgery, and laparoscopic resection of the bowel. The most common surgeries for high-risk patients were laparoscopic resection of the anterior colon, laparoscopic resection of the bowel, and lysis of adhesions.

The most significant differences in risk factors between the high-risk and low-risk groups were history of depression (OR 29.4, risk score weight=2), antidepressant prescription (OR 23.4, risk score weight=4), current opioid prescription (OR 20.4, risk score weight=5), and history of chronic pain (OR 19.4, risk score weight=4) (**Table 1**).

Table 1: Risk factor distribution among cohort and risk groups, with the odds ratios for being in the high-risk group. Note that while risk factor details were not available in all cohort patients, the label from the calculation was.

Risk Factor	Total sample (N=214)	Low-risk (n=161)	High-risk (n=53)	Odds Ratio [95% CI]
Substance use disorder	9 (4%)	3 (2%)	6 (11%)	6.6 [1.4, 42.6]
Current opioid prescription	13 (6%)	2 (1%)	11 (21%)	20.4 [4.2, 196.4]
Benzodiazepine prescription	9 (4%)	3 (2%)	6 (11%)	6.6 [1.4, 42.6]
Antidepressant prescription	28 (13%)	5 (3%)	23 (43%)	23.4 [7.9, 85.2]
Recreational drug use	29 (14%)	10 (6%)	19 (36%)	8.3 [3.3, 22.0]
History of chronic pain	29 (14%)	6 (4%)	23 (43%)	19.4 [6.9, 63.3]
History of anxiety	46 (21%)	18 (11%)	28 (53%)	8.8 [4.0, 19.7]
History of depression	27 (13%)	4 (2%)	23 (43%)	29.4 [9.2, 125.0]
History of poorly controlled pain	26 (12%)	11 (7%)	15 (28%)	5.3 [2.1, 14.0]
Female sex	90 (42%)	59 (37%)	31 (58%)	2.4 [1.2, 4.8]
Age (< 40 years)	32 (15%)	20 (12%)	12 (23%)	2.1 [0.8, 4.9]

High-risk patients were younger than low-risk patients (median age 53 vs. 59 years, median difference [MD] 5 years, 95%CI 1 to 9, p=0.021) and more often female (62% vs. 38%, OR 2.5, 95%CI 1.4 to 4.5, p=0.002) (**Table 2**). High-risk patients also reported lower baseline (pre-operative) quality of recovery scores (median 122 vs. 131, MD 12, 95%CI 2 to 23, p=0.016).

Table 2: Preoperative and surgical characteristics of the overall cohort and separate risk groups

	Total sample (N=276)	Low-risk (n=203)	High-risk (n=73)	p	Median difference or odds ratio [95% CI]
Age (years)	59 (47-68)	59 (49-69)	53 (40-65)	0.021	5 [1, 9]

		Total sample (N=276)	Low-risk (n=203)	High-risk (n=73)	p	Median difference or odds ratio [95% CI]
Sex	***Male***	151 (55%)	123 (61%)	28 (38%)	0.002	OR: 2.5 [1.4, 4.5]
	Female	125 (45%)	80 (39%)	45 (62%)		
Surgery type	***Closed***	183 (66%)	140 (69%)	43 (59%)	0.149	OR: 1.5 [0.9, 2.8]
	Open	93 (34%)	63 (31%)	30 (41%)		
Time to surgery (days)		30 (18-68)	29 (16-54)	34 (19-86)	0.211	-4.9 [-13.3, 2.7]
*Data available **		*267*	*195*	*72*		
Length of surgery (hrs)		2.1 (1.2-3.1)	2.1 (1.1-3.0)	1.9 (1.2-3.3)	0.854	0.0 [-0.3, 0.4]
Pre-op QoR15 score		129 (104-139)	131 (116-140)	122 (91-136)	0.016	12 [2, 23]
*Data available **		*110*	*77*	*33*		

Values are reported as median (IQR) or counts (percentages). CI: confidence interval. OR: odds ratio; QoR-15, quality of recovery 15.

** The heading indicates the number included in the analysis unless in the row below the measure. (e.g. surgical decision time is not available for all patients).*

Postoperative outcomes

Overall inpatient opioid utilization was not significantly different between the two risk groups, with a median (interquartile range [IQR]) of 20 (10-45) MME/day in the low-risk cases vs. 25 (10-50) MME/day in the high-risk cases (MD -2, 95%CI -5 to 0, p=0.096) (**Table 3**). Similarly, no significant difference was observed in opioid utilization across the recovery profile of low- vs. high-risk patients over the first ten postoperative days (**Figure 4**). Our risk factors were not strong predictors for high MME/day: none of the odds ratios from logistic regression were significant (i.e. 95% CI range included 1 for all predictors), which differs from our original model building cohort [20] (**Table 4**, right column).

Table 3: Inpatient opioid utilization in patients with patient-controlled analgesia and/or oral opioid medications (N=231)*

	Total (N=231)	Low risk (n=165)	High risk (n=66)	p	Median difference or odds ratio [95% CI]
MME/day (mg)	24 (10-47)	20 (10-45)	25 (10-50)	0.096	-2 [-5, 0]
Total MME (mg)	48 (15-145)	43 (15-130)	65 (18-237)	0.086	-10 [-38, 1]
Patients using >90 MME/day	31 (13%)	21 (13%)	10 (15%)	0.671	OR: 1.2 [0.5, 2.9]

Values are reported as median (IQR) or counts (percentages); CI, confidence interval; MME, morphine milligram equivalents; OR, odds ratio.
** some patients, not included here, had a continuous opioid infusion only or no opioid medications.*

Table 4: Risk factor distribution among cohort and outcome groups, with the odds ratios for patients using >90 MME/day for which the pre-surgical health history questionnaire details were available. The adjusted odds ratios from the derivation cohort [20] are provided for reference.

Risk Factor	Total sample (N=201)	≤90 MME/day (n=177)	>90 MME/day (n=24)	Unadjusted Odds Ratio [95% CI]	Adjusted Odds Ratio [95% CI] *	Adjusted Odds Ratio in derivation cohort [20] [95% CI]
Substance use disorder	9 (5%)	7 (4%)	2 (8%)	2.2 [0.2-12.6]	1.8 [0.2-9.5]	1.6 [1.0-2.3]
Current opioid prescription	12 (6%)	9 (5%)	3 (13%)	2.6 [0.4-11.8]	2.9 [0.5-12.4]	1.1 [0.7-1.6]
Benzodiazepine prescription	9 (5%)	8 (5%)	1 (4%)	0.9 [0.0-7.4]	0.6 [0.0-4.4]	1.0 [0.8-1.3]
Antidepressant prescription	28 (14%)	23 (13%)	5 (21%)	1.8 [0.5-5.5]	1.6 [0.4-6.2]	1.2 [0.7-1.8]
Recreational drug use	28 (14%)	25 (14%)	3 (13%)	0.9 [0.2-3.2]	0.7 [0.1-2.5]	1.1 [0.6-1.7]
History of chronic pain	28 (14%)	24 (14%)	4 (17%)	1.3 [0.3-4.3]	0.9 [0.2-3.1]	1.6 [1.0-2.6]
History of anxiety	44 (22%)	35 (20%)	9 (38%)	2.4 [0.9-6.5]	2.5 [0.8-7.3]	0.8 [0.5-1.2]
History of depression	26 (13%)	22 (12%)	4 (17%)	1.4 [0.3-4.8]	0.8 [0.2-3.2]	0.9 [0.6-1.3]
History of poorly controlled pain	25 (12%)	23 (13%)	2 (8%)	0.6 [0.1-2.8]	0.5 [0.1-2.1]	1.1 [0.6-1.7]
Female sex	82 (41%)	72 (41%)	10 (42%)	1.0 [0.4-2.7]	0.8 [0.3-2.0]	1.0 [0.6-1.6]

Age (< 40 years)	30 (15%)	26 (15%)	4 (17%)	1.2 [0.3-3.9]	1.2 [0.3-4.0]	1.0 [0.9-1.0]
Open surgery	N/A	N/A	N/A	N/A	N/A	1.2 [0.7-2.0]

* from multivariate logistic regression, including all other risk factors

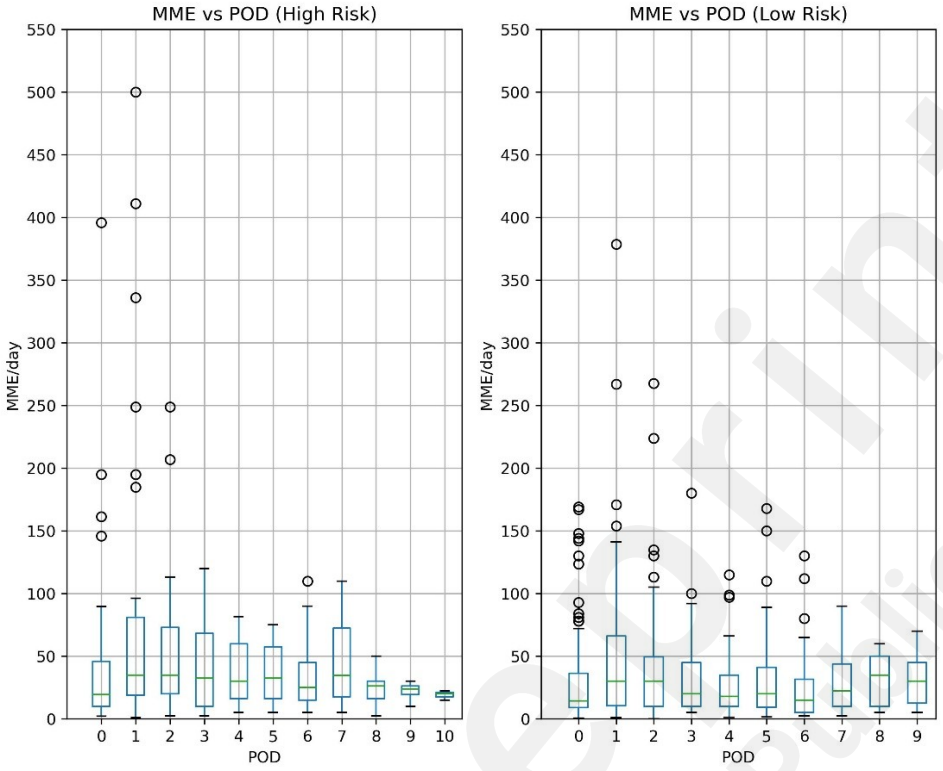

Figure 4: Box plots of morphine milligram equivalents (MME) per day comparing low-risk and high-risk patients.

Readmissions and other postoperative outcomes did not differ between high- and low-risk groups, although the overall median postoperative QoR-15 score was higher in low-risk vs. high-risk cases (MD 11, 95%CI 4 to 19, p=0.002) (**Table 5**).

Table 5: Postoperative outcomes

	Total (N=276)	**Low risk (n=203)**	**High risk (n=73)**	**p**	**Median difference or odds ratio [95% CI]**
Total readmissions	75 (32%)	51 (31%)	24 (36%)	0.221	OR: 1.5 [0.8, 2.7]
Emergent readmissions (within 30 days of surgery)	20 (9%)	13 (8%)	7 (11%)	0.43	OR: 1.5 [0.5, 4.4]
Emergent readmissions	7 (3%)	4 (2%)	3 (5%)	0.386	OR: 2.1 [0.3, 12.9]

(30-180 days following surgery)					
Length of hospital stay (days)	4 (2-6)	4 (2-6)	5 (1-7)	0.557	0 [-1, 0]
Overall Post-op QoR15 Score	118 (100-133)	121 (107-134)	108 (89-128)	0.002	11 [4, 19]
*Data available **	*85*	*59*	*26*		

Values are reported as median (IQR) or counts (percentages); CI, confidence interval; OR, odds ratio; QoR15, quality of recovery 15.
** The heading indicates the number included in the analysis unless in the row below the measure.*

Risk stratification performance

In terms of performance, with an incidence of opioid usage >90 MME/day as the primary outcome, the pilot risk stratification algorithm was reasonably specific (true negative rate = 72%) but not sensitive (true positive rate = 32%). These equate to a high false negative rate of 68% with a false positive rate of 28%, a positive likelihood of 1.15, and a negative likelihood of 0.94.

Postoperative utilization of the POQI platform

Data are available for 214 of the 276 (78%) patients who completed the HHQ and were risk-stratified by the POQI platform: 161/203 (79%) low-risk patients and 53/73 (73%) high-risk patients. Of the population, 85/276 (31%) completed any postoperative QoR-15 questionnaire: 59/203 (29%) were low-risk patients, and 26/73 (36%) were high-risk patients. Similarly, 31/203 (15%) low-risk patients and 3/73 (4%) high-risk patients reported any postoperative opioid utilization (**Table 6**).

Table 6: Postoperative utilization of the postoperative quality improvement (POQI) platform

	Total sample (N=276)	Low-risk (n=203)	High-risk (n=73)	p	Median difference or odds ratio [95% CI]
Data available from pre-op HHQ	214 (78%)	161 (79%)	53 (73%)	0.255	OR: 0.7 [0.4, 1.4]
Completed at least one post-op questionnaire	85 (31%)	59 (29%)	26 (36%)	0.622	OR: 0.9 [0.4, 1.7]
Length of follow-up post-surgery (days)	25 (11, 54)	24 (11, 53)	29 (11, 57)	0.797	-1 [-9, 10]
*Data available**	*85*	*59*	*26*		
Completed follow-up questionnaires at POD 31 - 60	15 (5%)	11 (5%)	4 (5%)	1.0	OR: 1.0 [0.3, 4.4]
Completed follow-up questionnaires beyond POD 90	3 (1%)	0 (0%)	3 (4%)	0.568	OR: 0.0 [0.0, 6.8]
Patients reporting	34 (12%)	31 (15%)	3 (4%)	0.012	OR: 4.2 [1.2, 22.1]

	Total sample (N=276)	Low-risk (n=203)	High-risk (n=73)	p	Median difference or odds ratio [95% CI]
post-op medication utilization					

Values are reported as median (IQR) or counts (percentages); CI, confidence interval; HHQ, health history questionnaire; OR, odds ratio; POD, postoperative day
** The heading indicates the number included in the analysis unless in the row below the measure.*

Qualitative interviews

We conducted feedback interviews with three patients (two POQI-L users and one POQI-H user) of the 20 invited; most patients approached declined to participate in this portion of the study. We interviewed all four clinicians (anesthesiologists and nurses who used both platforms) involved in the platform deployment in St. Paul's Transitional Pain Clinic.

Perceived benefit of the platforms for the healthcare experience

Patients recognized that the POQI-L had improved their healthcare experience by making them mindful of their behaviour, such as "*stating how I was feeling, anxiety about things, etc.",* which gave them "*a sense of agency*" over their care. It also provided a sense of reassurance that the healthcare team was continually monitoring their health status after they returned home following hospital discharge. Similarly, the POQI-H user believed there was a potential benefit: "*this will help me keep track of things and have some kind of two-way communication*"; however, they did not feel that potential had been met with the current version.

The clinical users perceived minimal benefits of the POQI-H, such as improving their workflows and allowing them to manage their patients better. Still, they recognized potential patient benefits, including access to educational information, with one clinician stating, "*for the patients, there is good access to many resources*", and another stating that the platform "*provided people with resources to manage their pain well while they're at home* [with] *an option to access further information*" as needed. The clinical users identified benefits of the POQI-L, which administered the HHQ to all patients, as a screening and triage tool: clinicians reported that it was helpful to display the pain risk score and "*to see whether they're a high or low risk as a quick way to screen patients.*" Integrating patient information in a single document was also helpful: "*[it was] also useful as a way to gather all the patient's medical history*."

User experience with the platforms

Patients experienced issues using both platforms, though this may have resulted from poor communication of the purpose of the application and potential benefits for them: for example, one POQI-L user said, "*I'm not sure what that tool is trying to be*"; and the POQI-H user said, "*[…] I didn't feel like I had much guidance in using [it].*" There was also a lack of clarity in instructions for using both platforms: for example, the POQI-L users expressed frustration about redundant emails/messages, which were unclear about "*what was supposed to be completed and when,*" and the POQI-H user said, "*I wasn't sure if I was supposed to initiate certain things, or if like somebody from my care team would go in*." Furthermore, the two POQI-L participants were unaware of their postoperative risk score and its details and viewed this as a missed opportunity to benefit from understanding their personalized risk for significant post-surgical pain.

Similarly, usability issues during the initial deployment contributed to attrition among clinical users: for example, one clinician admitted that they had not signed patients up on the POQI-H for four

months, as they did not find it easy to use, were not satisfied with the functionality, and could not quickly locate necessary information; another clinician had "*stopped using [POQI-L] as a method to look up patients and filter them out to see who should be put on [POQI-H].*" The clinicians who had used both platforms expressed concerns with quality assurance and usability: "*I think both platforms have much potential when they're working…* [but] *there have been many [issues] to deal with in the development of the programs, which have been both challenging and frustrating*."

Both patients and clinicians expressed a desire for greater platform integration. One patient stated they "*would have hoped that there would have been things populated in it*" to "*show the integration of services that I was accessing post-surgery*." Clinicians indicated that there should be a single platform with a unified vision; for example, "*I want to be able to do everything from one platform; I don't want to have to be on multiple different platforms. So that's my ideal scenario*".

Discussion

Principal Results

A pragmatic risk prediction algorithm was used to categorize 276 colorectal surgery patients into high-risk or low-risk for significant postoperative pain. The algorithm's performance was evaluated using a primary outcome threshold of >90 MME/day during in-hospital recovery: it was found to be reasonably specific (true negative rate = 72%) but not sensitive (true positive rate = 32%). The risk categorization was also used to drive dedicated preoperative and postoperative patient surveys using the high-risk (POQI-H) or low-risk (POQI-L) platforms. Preoperative surveys, including HHQ, were completed by 214/276 (78%) patients, but there was a significant loss to follow-up with postoperative surveys, including QoR-15, completed by only 85/214 (40%) patients. Qualitative feedback from clinician and patient users indicated shortcomings in the design and implementation of the patient- and clinician-facing components of the POQI platform.

Comparison with Prior Work

The motivation was that POQI would establish a platform to support personalized multi-modal pain management techniques and patient preparation/education to reduce reliance on opioids during recovery from surgery, both in-hospital and post-discharge. Identifying those at most significant risk of postoperative pain and providing tailored care plans based on their risk levels may help reduce initial opioid consumption. A recent systematic review suggested that a higher risk of developing persistent post-surgical pain is associated with younger age, female sex, and preoperative pain [24], which are consistent with the characteristics observed in the patients classified as high-risk by our algorithm (**Table 2**). Furthermore, a recent multicentre study in the US identified preoperative opioid use as the most significant predictor of prolonged opioid use post-surgery [25]. Again, this factor was a significant distinguishing characteristic of our high-risk patients, along with a history of depression, antidepressant use, and chronic pain (**Table 2**).

Virtual care solutions for post-surgical patients can support tracking various postoperative outcomes, including prescription drug use. Although the development of perioperative electronic health (eHealth) or mobile health (mHealth) solutions for telemonitoring is still maturing [26], these technologies show promise: implementation is feasible, and can streamline clinical workflow and improve patient outcomes [27,28]. Web-based patient portals integrated with the EMR can improve patient satisfaction, enable more effective healthcare utilization [29], and improve outcomes such as glycemic control in patients with diabetes [30]. However, there are several barriers to successful implementation, as our experience with poor patient retention indicates (**Figure 3**). To improve patient engagement through an EMR portal, it is essential to avoid high attrition rates, which requires addressing the requirements of diverse patients, focusing on usability and functionality, and adopting implementation science approaches [31]; using apps can also have a positive impact [32]. Perioperative solutions must be designed with frequent and meaningful clinician and patient input and evaluated in large, robust clinical trials [26,28]. Particular attention is needed when developing and evaluating tools for vulnerable populations, such as patients with chronic pain issues and older patients, though a recent systematic review reported generally positive results from seven studies in patients ≥65 years [33]. In contrast, our population was relatively younger, with a median (IQR) age of 59 (47-68) years. Furthermore, an evaluation of a patient-centric digital pain management app reported acceptable patient engagement and improved anxiety and pain catastrophizing in similarly aged patients who had experienced chronic pain of moderate-to-severe intensity for at least three months [32].

The lack of follow-up data prevented us from effectively evaluating or optimizing the risk stratification algorithm we implemented. The risk model was reasonably specific, based on in-hospital MME, but with poor sensitivity and a subsequent high false negative rate, as it failed to identify patients who may have benefitted from the POQI-H platform. None of our eleven patient-reported pre-operative risk factors had a significant adjusted odds ratio for high in-hospital opioid utilization (>90 MME/day), in which the 95% CI range excluded 1 (Table 4). This indicates that, by themselves, none would have predicted high postoperative opioid usage in this cohort, although these are recognized risk factors. This contradicts the findings from our retrospective study in the same hospital, which found that a history of chronic pain and substance use disorder was associated with high postoperative opioid requirements [20]. The small sample sizes in both our retrospective and prospective cohorts may have limited our ability to detect these associations reliably in the chosen population. Alternatively, despite being evidence-based [23], our selected threshold of >90 MME/day may not be optimal. Future work should explore other potentially self-reportable risk factors, such as open surgery, pain catastrophizing, or lack of planned regional anesthesia, as well as interactions between synergistic or antagonistic risk factors. Finally, data science approaches show promise in predicting post-surgical outcomes, with generally positive findings in a recent systematic review [34]. Such technology has been used to predict prolonged opioid use after orthopedic surgery [35] or estimate the risk of an adverse outcome within 30 days of an opioid dispensation [36]. These techniques may help refine local models, such as our algorithm, but we need more data at this stage.

Importantly, our platform was an amalgamation of various existing (or slightly adapted) technologies that lacked adequate workflow integration and did not adapt to varying clinical or patient needs to allow evaluation when there were any deviations from the pre-defined workflow. For example, we could not access clinically relevant long-term outcomes for many high-risk patients. Improving access to available administrative and clinical data could facilitate improved prediction performance using machine learning techniques [36].

Lessons learned

We cannot report a fully realized solution due to a lack of integration with the provincial medication system and the reduced scope of the platform in light of the COVID-19 pandemic. However, the problems we encountered and lessons learned during our implementation can benefit other research, specifically clinical and industry teams endeavouring to build perioperative virtual care solutions to improve postoperative opioid use after discharge. Any work addressing this critical public health problem should ensure frequent engagement of patient and clinical partners, including co-design [37], to confirm that the design addresses patient and provider needs and delivers meaningful benefits to patient care and healthcare practice.

Next, when including a research component in healthcare system technical development and implementation, it is essential to ensure that research endpoints are integrated into project plans. This ensures that industry partners and clinical teams contribute to and approve evaluation plans so that the teams understand and support each other’s priorities. We also suggest including all partners in frequent data quality assessments and using an objective committee to oversee project activities, focusing on system-level goals while enabling each partner to achieve their respective objectives.

Given the likelihood that the requirement for virtual care solutions in the perioperative setting will grow, preparing for the transition to a long-term sustainable implementation is essential [38,39]. This should leverage experiences from stakeholders, focus on user experience, and ensure data are collected, validated, and delivered to the right people at the right time to improve the quality of care. Feedback is essential to a learning health system [40]: process metrics, patient trajectories, and

benchmarking tools will enable clinicians to learn from their patients. PROMs and PREMs [41] will be fundamental to improving the quality of care provided, focusing on patient-relevant outcomes rather than only system-relevant ones and enabling the personalization of care.

Limitations

As well as the implementation issues already discussed, we must acknowledge many limitations in the data we can present. Firstly, restrictions to hospital access due to COVID-19 care considerations leading up to and during the pilot recruitment period likely caused significant delays. It also hampered effective engagement between patients, the research team, clinical teams, and industry partners and disrupted the opportunity to refine the software solution through further design iterations.

Secondly, it is unclear from our data how patients used the information provided through the platform. The qualitative results from a limited number of patients willing to be interviewed and clinicians suggest that some patients glimpsed the potential value of the tool. However, they did not use or benefit from the educational materials and saw the platform as a survey tool rather than a virtual care platform. This may have contributed to the observed attrition rate and lack of interest in participating in usability interviews. Further design iterations were needed to respond to end-user concerns and improve engagement in the platform. The lack of long-term follow-up was further compounded by technical issues and the lack of completed PROM survey data from patients. To prevent this from happening in the future, it may be better to engage and support patients' needs through a prospective approach that uses a near real-time data pipeline and integrated interfaces directly into workflows at the point of care. The lack of bi-directional EMR integration is a limitation of our implementation. It likely contributed to our high attrition rates and compromised the quality of the data we could report on. As discussed, improving patient engagement through an EMR portal requires a more robust implementation approach than we could apply here.

Thirdly, the primary aim of the algorithm to identify persistent postoperative opioid requirements could not be determined without access to prescription data to verify dispensed medications after discharge. Gaining such access using patient-directed/authorized access through the BC Health Gateway was a project goal, and implementation was explored. Yet, it was found not to be possible due to provincial policy constraints. Hence, we cannot know whether the intervention impacted prolonged opioid use after surgery. Future studies should explicitly include long-term follow-up but may have to augment it with self-reports to capture the difference between dispensed and taken medications.

Finally, this analysis is limited due to a small sample size from a single centre (including only 24/201 who used >90 MME/day) and missing follow-up outcomes from many patients designated as high-risk. This is partly due to low engagement during a pandemic and challenges in achieving the project’s objectives within a limited funding period. Similarly, we planned to recruit 10 POQI-L patients, 10 POQI-H patients, and five clinicians to participate in semi-structured interviews. However, we only obtained feedback from three patients (two POQI-L users and one POQI-H user) and four clinicians. A broader sample would have provided more insight into the shortcomings and potential benefits of the system and should be built into any future evaluation.

Again, this final limitation was, at least in part, due to COVID-19. On the other hand, COVID-19 created a greater motivation for developing and implementing systems that support virtual care through the perioperative process. This may be particularly relevant in a hospital such as St. Paul’s, a tertiary care academic hospital with patients from all over British Columbia, a geographically vast

Canadian province with a widely distributed population. Finally, pain management requires multidisciplinary care that may not be available in rural communities. A well-designed platform could fill this gap and enable patients to benefit from personalized risk prediction and virtual pre-habilitation while overcoming potential resource constraints.

Conclusions

Our Postoperative Opioid Quality Improvement (POQI) platform categorized colorectal surgery patients into high-risk or low-risk for significant postoperative pain and opioid use, using a pragmatic risk prediction algorithm. The algorithm's performance was reasonably specific but not sensitive in predicting in-hospital opioid requirements. Yet, a significant loss in follow-up with post-discharge surveys suggested shortcomings in the design and implementation of the platform, which may have been improved with additional development work and the opportunity to engage patients more comprehensively. Important lessons learned during implementation included the early and frequent engagement of patients and clinical partners in the design and evaluation process. Finally, POQI platform users appreciated its potential impact on reducing opioid exposure, streamlining perioperative care, and improving patient outcomes, suggesting a re-design and evaluation before wider implementation is desirable.

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Conflicts of Interest

Jean Gelinas is a consultant for Excelar Technologies.

Abbreviations

BC	British Columbia
CI	Confidence Interval
EMR	Electronic Medical Record
EMPI	Enterprise Master Patient Index
ERAS	Enhanced Recovery After Surgery
HHQ	Health History questionnaire
IQR	Interquartile range
IV	Intravenous
MAR	Medication Administration Record
MD	Median Difference
MME	Morphine milligram equivalents
MOA	Medical Office Assistance
OR	Odds Ratio
PHN	Personal Health Number
POD	Postoperative day
POQI	Postoperative opioid quality improvement
PROM	Patient-reported outcome measure
QoR-15	Quality of recovery 15 questionnaire
SQUIRE	Standards for Quality Improvement Reporting Excellence
UBC	University of British Columbia

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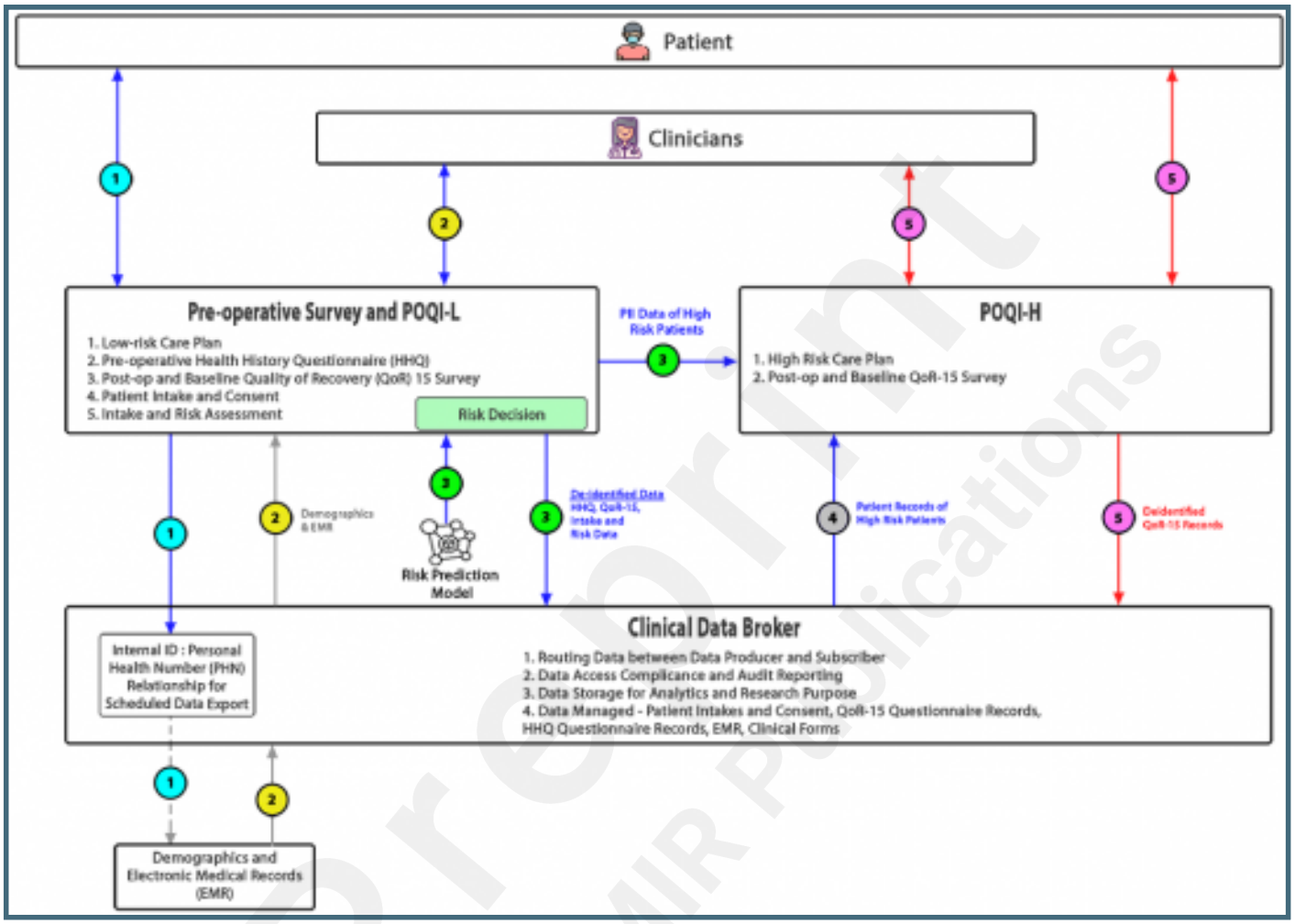
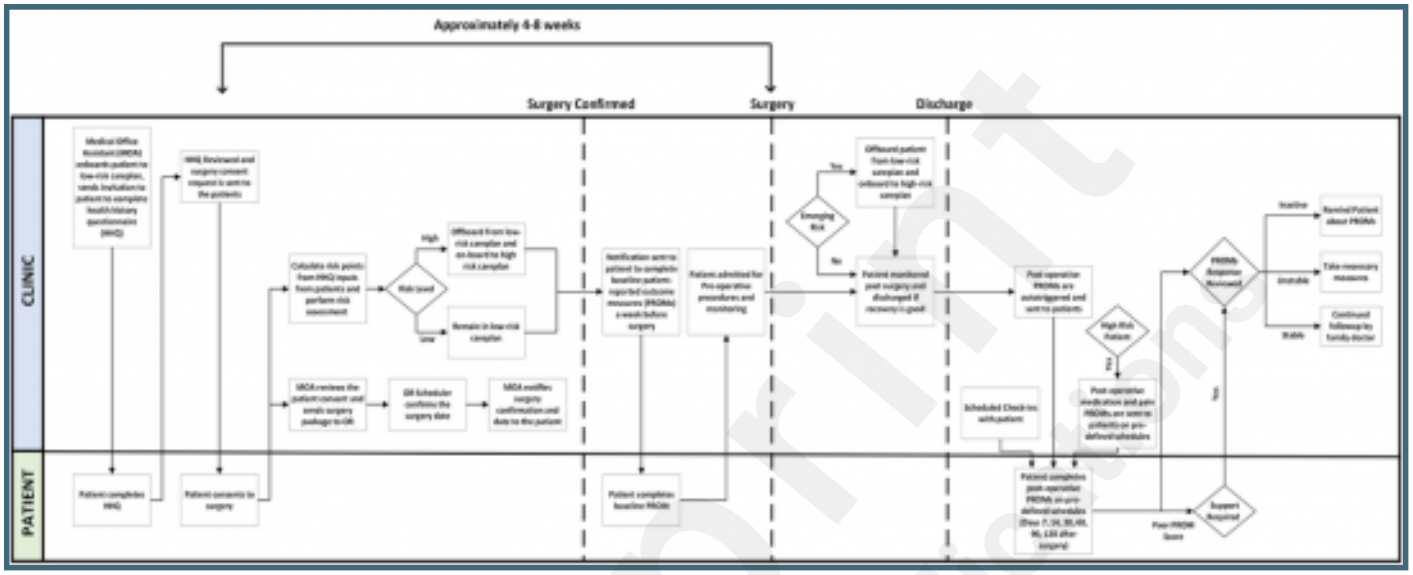
Supplementary Files

Figures

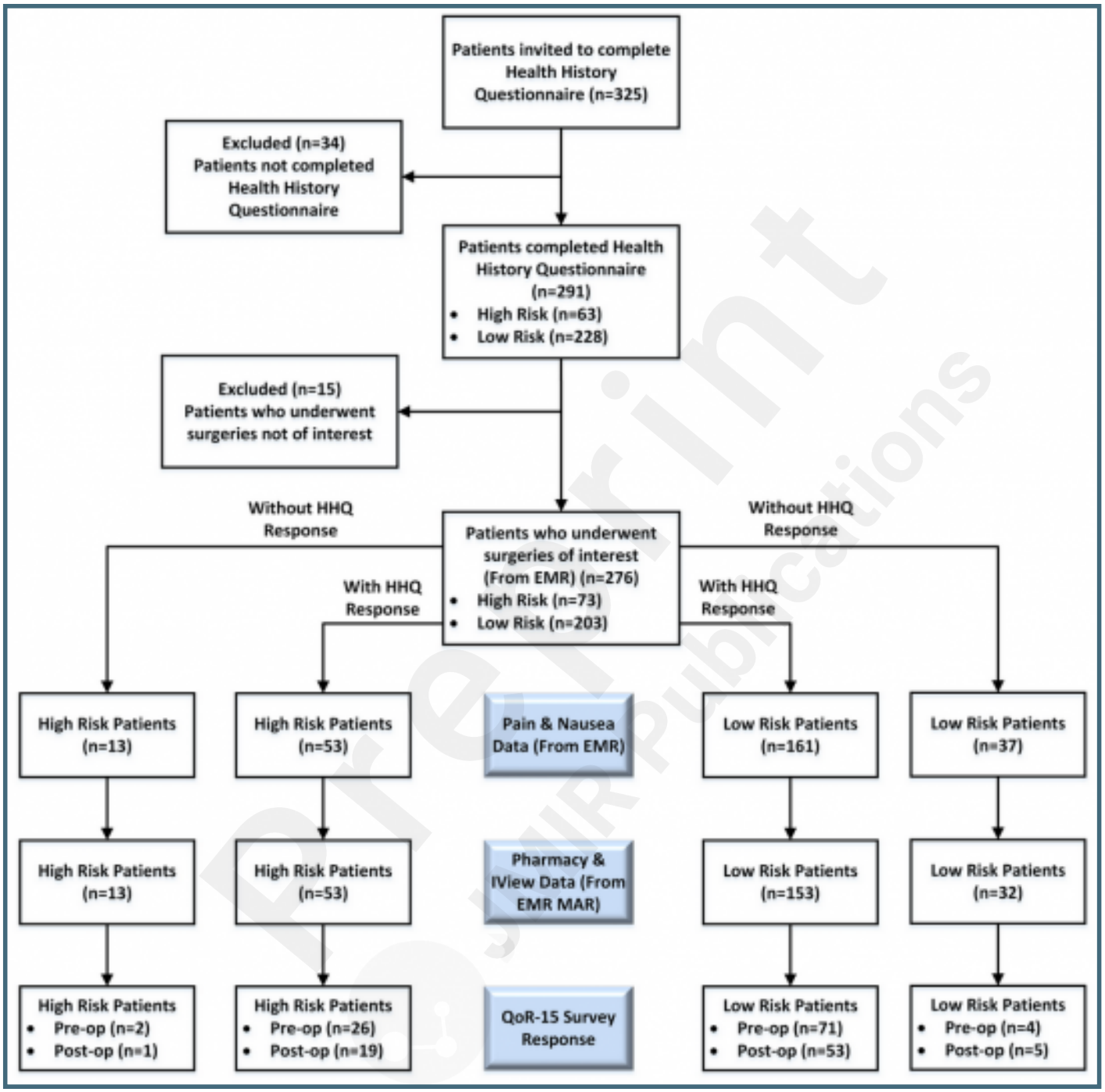
Workflow in the postoperative quality improvement (POQI) platform showing the integration of clinical and patient-reported data from patient-facing components and the electronic medical record (EMR) integrated by a data broker; PII – personally identifiable information; PHN, personal health number; POQI-L, POQI platform for low-risk patients; POQI-H, POQI platform for high-risk patients; QoR, quality of recovery.



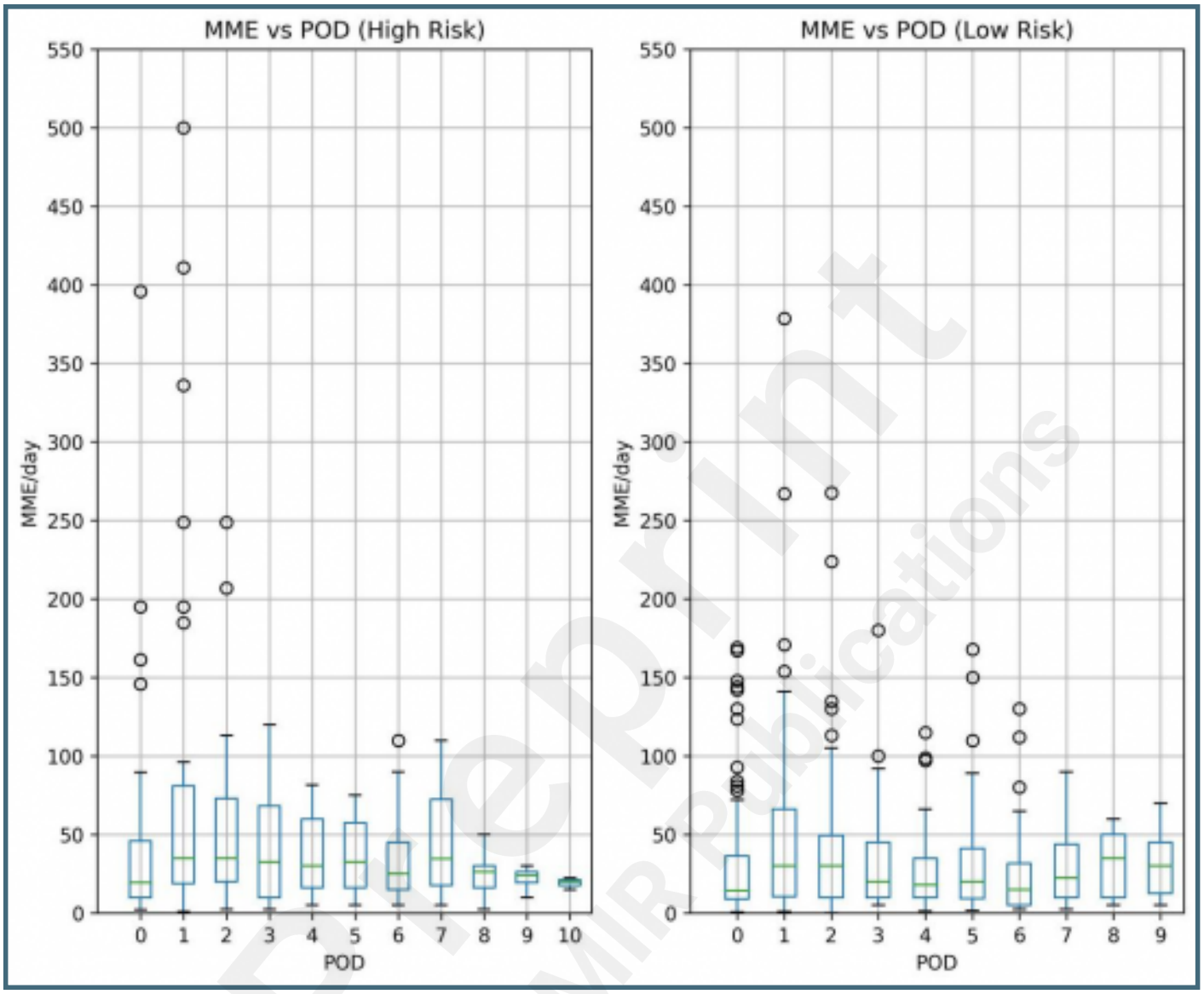
Clinical workflow of the postoperative quality improvement (POQI) platform as piloted at St. Paul's Hospital. This illustrates the flow of patients through their perioperative care journey and delineates which pieces the system does and when the patient is involved in this process; it shows key decision points, such as when the patient is risk-stratified before their procedure and post-discharge if patients require enhanced follow-up. A poor PROM score (bottom right) was indicated if the patient reported having an unplanned hospital admission for pain, having to seek urgent care for pain, or reporting that they were still taking opioids beyond postoperative day seven. MOA – medical office assistant; HHQ – health history questionnaire; OR – operating room; PROM – patient-reported outcome measure.



Platform uptake, attrition, and data completeness in high-risk and low-risk patients; EMR, electronic medical record; MAR, medication administration record; QoR, quality of recovery.



Box plots of morphine milligram equivalents (MME) per day comparing low-risk and high-risk patients.



Multimedia Appendixes

Risk Factors and relevant question from Health History Questionnaire.
URL: http://asset.jmir.pub/assets/1726a291347a832137be3ca3914cc47d.docx

List of included colorectal surgeries in pilot implementation.
URL: http://asset.jmir.pub/assets/019ca70bae586a7d66a3485d6acd5d06.docx

Morphine Milligram Equivalent (MME) Conversion Factors.
URL: http://asset.jmir.pub/assets/c7460d784425c052bf7dbca79e48bc62.docx

Interview Guides.
URL: http://asset.jmir.pub/assets/3c94ea9804009815fa068f4454c8f2c4.docx