JMIR Perioperative Medicine

Contents

Viewpoint

Original Papers

Review

The Effectiveness of Patient Education on Laparoscopic Surgery Postoperative Outcomes to Determine Whether Direct Coaching Is the Best Approach: Systematic Review of Randomized Controlled Trials (e51573)

XSL•FO

RenderX

Blood Management: A Current Opportunity in Perioperative Medicine

Moises Auron[1,2,3], MD

[1]Department of Hospital Medicine, Cleveland Clinic, Cleveland, OH, United States

[2]Department of Pediatric Hospital Medicine, Cleveland Clinic Children's, Cleveland, OH, United States

[3]Outcomes Research Consortium, Cleveland, OH, United States

Corresponding Author:
Moises Auron, MD
Department of Hospital Medicine
Cleveland Clinic
9500 Euclid Ave
Cleveland, OH, 44195
United States
Phone: 1 2164458383
Fax: 1 2164448530
Email: auronm@ccf.org

Abstract

The purpose of this viewpoint is to provide awareness of the current opportunities to enhance a high-value care approach to blood product transfusion. It provides a historical context to the evolution of blood management, as well as of the patient safety and high-value care movement. Leveraging current technology for enhanced education, as well as clinical decision support, is also discussed.

Origins of High-Value Care

The need to improve patient outcomes, with emphasis on patient safety, evidence-based decision-making, and a strong focus on high-value care, stemmed from the US Institute of Medicine's seminal publication *To Err Is Human* [1], which was very influential in enhancing awareness of the impact of individual human behavior and decision-making on patients' outcomes. It was a humbling and necessary perspective that spearheaded a movement toward more effective, efficient, cost-effective, and high-value–oriented practice of medicine.

Historical Perspective on Blood Management

Blood management is not an exception to this movement. Transfusional medicine underwent tremendous development during the second half of the 20th century, faced with specific challenges such as the need for bloodless surgery in patients who refused blood transfusions and the rise of transfusion-associated viral diseases [2]. In addition, there was

growing evidence of the adverse consequences associated with liberal blood transfusion, including increased mortality, sepsis, and increased length of hospitalization. This led to an awareness of the need to focus efforts on developing blood product transfusion based on the individual need of the patient, and in 2005, Isbister [3] coined the term "patient blood management." This is a complex approach that focuses on three pillars: (1) optimizing patient hematopoiesis and enhancing red cell mass, (2) minimizing blood losses with improved source control and optimization of coagulopathy, and (3) enhancing patient tolerance to anemia [2]. In the past 30 years, substantial evidence grew to support a more restrictive transfusional approach once there was evidence that patients could tolerate lower hemoglobin values without major adverse effects; this evidence came from multiple patient populations, such as critically ill patients, older patients with high cardiovascular risk undergoing surgery, and patients with active gastrointestinal bleeding [4]. Another very important aspect that must be considered is the increasing cost associated with transfusion of blood products. Furthermore, procedures aimed to enhance patient safety (eg, pathogen reduction in platelets) substantially increase the overall cost of transfusion. A high-value care approach helps to gain insight

into nontransfusional alternatives to optimize underlying hematologic conditions, but also to be cost conscious and aware of the financial impact of indiscriminate use of blood [5,6].

Aim

The aim of this viewpoint is to allow physicians and clinicians caring for surgical patients who order blood products to reflect on the impact of the high-value care movement in blood management and transfusional medicine, as well as on the currently prevailing opportunities to enhance better decision-making; this is particularly relevant after considering the historical perspective. Ideally, the best scenario would be that patients undergo procedures and hospitalizations with minimal exposure to blood products, aiming to leverage nontransfusional correction of underlying hematologic processes. This requires enhanced awareness of current guidelines and standards of care, as well as leveraging current technology (eg, electronic health records) to help gain insight into current transfusion practices and to provide direct clinical decision-support tools that facilitate best practices in blood product ordering.

There is strong evidence of the increasing complexity of hospitalized and surgical patients [7]. It can be hypothesized that this complexity is also associated with anemia and coagulopathy as increasingly encountered comorbid conditions, especially in surgical patients. The physicians and health care professionals caring for these patients must have enhanced awareness to identify and recognize anemia and coagulopathy, with a subsequent diagnostic approach aiming to not just treat but to identify its etiology to optimize a nontransfusional approach (eg, the use of intravenous iron) [8]. A pharmacologic approach to anemia provides a more efficient and patient-centered optimization of these comorbidities with consequent enhanced treatment effectiveness and decreased adverse outcomes associated with unnecessary blood transfusion [4].

Current Challenges

The current 2023 Association for the Advancement of Blood & Biotherapies (AABB) red blood cell transfusion guidelines have reinforced this parsimonious approach to blood transfusion, with even more conservative and restrictive levels to trigger transfusion in patients with acute coronary syndromes and pediatric patients [9]. Nonetheless, more widespread enhanced adherence to the AABB guidelines in regard to red blood cell transfusion is a necessity. In addition, plasma transfusion offers a strong opportunity for improvement in health care delivery, especially as there is a need to minimize unnecessary plasma transfusion as well as its inappropriate dosing; plasma should be transfused with weight-based dosing and in appropriate clinical scenarios. Undertransfusion of plasma, by not using weight-based dosing, is a current challenge as this not only does not have a therapeutic corrective effect on coagulopathy but is a source of wastage [10]. Enhanced education efforts worldwide, as well as leverage of current technology, create awareness and encourage adoption of a high-value approach to plasma and red blood cell transfusion. Another element to consider as a

balancing measure to enhanced patient safety is the increased associated cost; in the case of platelet transfusion, in the United States the current standard of care is the use of pathogen-reduced platelets; this approach increases costs of individual blood products substantially [6].

The perioperative continuum of care provides different stages to ensure that patients are properly evaluated and treated. In the preoperative setting, the optimization of anemia carries the most significant value through raising hemoglobin values to levels high enough to minimize reaching the transfusion threshold while also enhancing overall oxygen delivery [4]. In the intraoperative setting, the leverage of cell-saver technology, as well as optimization of coagulopathy, can mitigate the risk of blood product use; however, awareness of appropriate indications as well as of dosing of blood products promotes a high-value approach and minimizes wastage [9,10]. In the postoperative realm, it involves ensuring appropriate monitoring of ongoing blood losses, as well as monitoring the patient for potential complications associated with postsurgical anemia, such as myocardial ischemia in noncardiac surgery [11].

Potential Solutions and Opportunities

What can be done to mitigate the inappropriate overuse of blood products, inappropriate dosing, and lack of awareness of the associated costs? Appropriate data bank analysis and data-driven interventions, as well as the implementation of human factors engineering and newer technologies such as artificial intelligence within the current workflow (like the electronic health record), can enhance the effectiveness of patient blood management efforts [12]. This entails having a database of all patients being transfused in a hospital or health care system and being able to have granularity to drill down to data on the individual patient, ordering physician, and baseline and posttransfusion laboratory values (eg, complete blood count), as well as associated outcome metrics like readmissions, length of stay, and cost of care. In addition, short-cycle data, which allow immediate identification of patients who can benefit from further stratification and assessment of underlying anemia and coagulopathy, permits guiding clinicians to pursue real-time high-value care and evidence-based interventions supported by clinical decision support tools. Also, data governance of anemia and coagulopathy assessment, as well as blood transfusion practices, provides a platform for permit auditing, benchmarking best practices, and providing real-time feedback to individual physicians, increasing awareness of areas of success and opportunities [13].

The electronic health record also provides a strong platform for education, as clinical decision-support tools can be embedded in the orders [14]. For instance, in our institution, we default red blood cell transfusion orders to single units and have a formal indication: What is the current transfusion threshold? This allows the ordering health care professional to reflect and select a reason when the order does not follow the current AABB guidelines. Also, when plasma is ordered, there is an indication to use weight-based volumes to minimize undertransfusion, as well as education that transfusion for an international normalized ratio <1.8 will not have a meaningful impact. Order overriding

can occur, but with the need to provide a rationale. The more the orders are used and experience increases with blood product transfusion, the more exposure there will be to this workflow, allowing for enhanced education. Also, the electronic health record can facilitate improved documentation of blood product transfusions, allowing the development of increased insight into potential blood product overuse [15].

In this issue of *JMIR Perioperative Medicine*, we provide the opportunity to outline the evidence for evaluation and optimization of perioperative anemia in different surgical populations, as well as to discuss the opportunities for leverage of current technologies to enhance the effectiveness of approaches to improve patient outcomes and enhance the high-value care approach, minimizing not only financial costs, but more importantly, decreasing patient harm.

Conflicts of Interest

MA is an associate editor of *JMIR Perioperative Medicine*.

References

1. Institute of Medicine (US) Committee on Quality of Health Care in America. In: Kohn LT, Corrigan JM, Donaldson MS, editors. To Err Is Human: Building a Safer Health System. Washington, DC: National Academies Press; 2000.
2. Franchini M, Marano G, Veropalumbo E, Masiello F, Pati I, Candura F, et al. Patient blood management: a revolutionary approach to transfusion medicine. Blood Transfus 2019 May;17(3):191-195 [FREE Full text] [doi: 10.2450/2019.0109-19] [Medline: 31246561]
3. Isbister J. Why should health professionals be concerned about blood management and blood conservation? Updates in Blood Conservation and Transfusion Alternatives 2005;2:7.
4. Auron M, Duran Castillo MY, Kumar A. Parsimonious blood use and lower transfusion triggers: What is the evidence? Cleve Clin J Med 2017 Jan;84(1):43-51 [FREE Full text] [doi: 10.3949/ccjm.84a.15134] [Medline: 28084984]
5. Jacobs JW, Diaz M, Arevalo Salazar DE, Tang A, Stephens LD, Booth GS, et al. United States blood pricing: A cross-sectional analysis of charges and reimbursement at 200 US hospitals. Am J Hematol 2023 Jul;98(7):E179-E182. [doi: 10.1002/ajh.26940] [Medline: 37096559]
6. Kacker S, Bloch EM, Ness PM, Gehrie EA, Marshall CE, Lokhandwala PM, et al. Financial impact of alternative approaches to reduce bacterial contamination of platelet transfusions. Transfusion 2019 Apr;59(4):1291-1299 [FREE Full text] [doi: 10.1111/trf.15139] [Medline: 30623459]
7. Naik H, Murray TM, Khan M, Daly-Grafstein D, Liu G, Kassen BO, et al. Population-based trends in complexity of hospital inpatients. JAMA Intern Med 2024 Feb 01;184(2):183-192. [doi: 10.1001/jamainternmed.2023.7410] [Medline: 38190179]
8. Auron M, Duran Castillo MY. Preoperative anemia optimization: role of iron supplementation. J Xiangya Med 2018 Oct;3:-37 [FREE Full text] [doi: 10.21037/jxym.2018.09.05]
9. Carson JL, Stanworth SJ, Guyatt G, Valentine S, Dennis J, Bakhtary S, et al. Red blood cell transfusion: 2023 AABB International Guidelines. JAMA 2023 Nov 21;330(19):1892-1902. [doi: 10.1001/jama.2023.12914] [Medline: 37824153]
10. Drake R, Jackson B, Murphy C. Single plasma unit transfusions in adults are either unnecessary or underdosed. Am J Clin Pathol 2022 Jul 01;158(1):148-152. [doi: 10.1093/ajcp/aqac020] [Medline: 35218358]
11. Turan A, Cohen B, Rivas E, Liu L, Pu X, Maheshwari K, et al. Association between postoperative haemoglobin and myocardial injury after noncardiac surgery: a retrospective cohort analysis. Br J Anaesth 2021 Jan;126(1):94-101 [FREE Full text] [doi: 10.1016/j.bja.2020.08.056] [Medline: 33039122]
12. Gammon RR, Almozain N, Jindal A, Nair AR, Vasovic LV, Bocquet C. Patient blood management, past, present and future. Ann Blood 2024 Mar;9:-7 [FREE Full text] [doi: 10.21037/aob-22-45]
13. Gammon RR, Coberly E, Dubey R, Jindal A, Nalezinski S, Varisco JL. Patient blood management—it is about transfusing blood appropriately. Ann Blood 2022 Apr;7:-21 [FREE Full text] [doi: 10.21037/aob-21-70]
14. Goodnough LT, Shah N. The next chapter in patient blood management: real-time clinical decision support. Am J Clin Pathol 2014 Dec;142(6):741-747. [doi: 10.1309/AJCP4W5CCFOZUJFU] [Medline: 25389326]
15. Bahmad HF, Oh KS, Delgado R, Azimi R, Olivares E, Poppiti R, et al. Improving documentation of blood product administration using a standardized electronic health record-based system: a single-institution experience. Am J Clin Pathol 2023 Sep 01;160(3):268-275. [doi: 10.1093/ajcp/aqad049] [Medline: 37186872]

Abbreviations

AABB: Association for the Advancement of Blood & Biotherapies

XSL•FO
RenderX

Original Paper

Gamified Mobile App (MobERAS) for Telemonitoring Patients in the Postoperative Period Based on the Enhanced Recovery after Surgery Program: Development and Validation Study

Aline Evangelista Santiago[1*], PhD; Victor Pezzi Gazzinelli Cruz[2*], MSc; Rafaela Souza Furtado[3*], MD; Eduardo Batista Cândido[3*], PhD; Wladmir Cardoso Brandão[2*], PhD; Agnaldo Lopes Silva Filho[1,3*], PhD

[1]Department of Gynecology, Obstetrics and Mastology, Faculdade de Medicina de Botucatu, Universidade Estadual Paulista "Júlio de Mesquita Filho", Botucatu, Brazil

[2]Department of Computer Science, Pontifícia Universidade Católica de Minas Gerais, Belo Horizonte, Brazil

[3]Department of Gynecology and Obstetrics, Universidade Federal de Minas Gerais, Belo Horizonte, Brazil

*all authors contributed equally

Corresponding Author:
Aline Evangelista Santiago, PhD
Department of Gynecology, Obstetrics and Mastology
Faculdade de Medicina de Botucatu
Universidade Estadual Paulista "Júlio de Mesquita Filho"
Avenue Professor Mário Rubens Guimarães Montenegro
Botucatu, 18618-687
Brazil
Phone: 55 11975998003
Fax: 55 143880 1134
Email: alinevajf@gmail.com

Abstract

Background: Digital technology and gamified apps can be useful in the health care context. Gamification uses technology to influence users' actions and motivations through experiences that resemble games. Patient adherence to the enhanced recovery after surgery (ERAS) program is crucial for achieving early recovery after surgery and continuous monitoring is essential for obtaining good results.

Objective: This study aimed to describe the development and validation of a mobile app for enhanced recovery after surgery (MobERAS), a gamified mobile health app for telemonitoring patients in the postoperative period based on the ERAS program, and to evaluate its functionality and usability and the experience of patients, health care professionals, and computer professionals with its use.

Methods: We developed MobERAS for postoperative telemonitoring, with active participation of patients in the process, and offering availability of real-time information for the health team. The app development process included idealization, interdisciplinary team formation, potential needs assessment, and product deployment. Usability tests were conducted throughout the development process with improvements, technical adjustments, and updates. After finalization, comprehensive verification tests were performed. The parameters evaluated are those that can influence the length of hospital stay, such as nausea, vomiting, pain scales, return to normal gastrointestinal function, and thromboembolic events. MobERAS was designed to be downloaded by users on their phones, tablets, or other mobile devices and to provide postoperative data. The app has a GPS that monitors the patient's walking time and distance and is connected to a virtual database that stores the collected data.

Results: Women undergoing medium and major gynecologic oncologic surgeries were included. We included 65 patients with an average age of 53.2 (SD 7.4, range 18-85) years. The time of use ranged from 23.4 to 70 hours (mean 45.1, SD 19.2 hours). Regarding adherence to the use of MobERAS, the mean fill rate was 56.3% (SD 12.1%, range 41.7%-100%), and ambulation data were obtained for 60 (92.3%) of the 65 patients. The researcher had access to the data filled out by the patients in real time. There was good acceptance of the use of MobERAS by the patients, with good evaluation of the app's usability. MobERAS was easy to use and considered attractive because of its gamified design. The app was rated as good or very good in all items by health care professionals (n=20) and professionals specializing in technological innovation (n=10).

Conclusions: MobERAS is easy to use, safe, well accepted by patients, and well evaluated by experts. It can be of great use in clinical surgical practice and an important tool for greater engagement of patients and health care professionals with the ERAS program.

Introduction

The usefulness of digital technology in the health field has been well recognized for its great potential to aid in the prevention, diagnosis, and management of diseases [1,2]. Moreover, given that the COVID-19 pandemic has promoted digital disruption worldwide, further incorporation of technology into health care practices can be expected [3].

Through mobile apps, patients can access health-related data, schedule medical appointments, manage medication dosages, improve well-being, and perform other health-related activities [1]. Many of these apps are aimed at patients with chronic illnesses, such as diabetes mellitus, obesity, mental disorders, malignant neoplasms, smoking, and alcoholism, leading to apparent improvements in self-management of the disease and aiding in promoting health [4-11]. Therefore, the use of technology to improve health is promising [12].

A *mobile medical app* incorporates the functionality of the device's software or transforms a mobile platform into a regulated medical device [13]. In this scenario, there is gamification, which consists of using technology to influence users' actions and motivations through experiences that resemble games [14]. Gamified apps have several purposes in the context of health care, including managing comorbidities, preventing disease, encouraging the practice of healthy lifestyle habits, providing information, and building character [12]. Associating the gamification proposal to stimulate some practices and the need for better adoption of medical recommendations, we proposed the development of a gamified medical app, which represents 1 strategy for adopting the measures recommended by the enhanced recovery after surgery (ERAS) program and for promoting greater patient engagement.

The ERAS program comprises multimodal perioperative assistance designed to achieve early recovery of patients undergoing surgery, with the objective of reducing hospitalization time and accelerating the return of patients to regular activities without increasing complications, hospital readmission rates, or costs. For better recovery, the program focuses mainly on reducing perioperative stress, satisfactory pain control, return to normal gastrointestinal function, and early mobilization. Adherence to the program is crucial, and continuous monitoring is essential for obtaining good results. Among the program's postoperative recommendations, patients are encouraged to follow some steps that can help them achieve good postoperative results, such as encouraging early mobilization, as well as early oral intake [15,16]. For example,

it is known that the incentive to walk early exerts a positive impact on the incidence of thromboembolic events [17].

Aiming at optimized postoperative recovery and using the current concept of mobile technology in health, we developed an app (mobile app for enhanced recovery after surgery [MobERAS]) for postoperative telemonitoring, with active participation of the patients in this process and the availability of real-time information for the health team. MobERAS is used as a tool to simultaneously guide and encourage patients to follow medical recommendations through the use of gamification. This study aimed to describe the development and validation of MobERAS, evaluating its functionality and usability and the experience of patients, health care professionals, and computer professionals with its use.

Methods

Development Process

Development Approach and Regulatory Context

Determining the most appropriate development strategy was challenging, given the existence of different sources of guidance and few well-established regulations. To establish the app's development strategies, we followed the recommendations of the Regulation of the European Parliament, which set high quality and safety standards for medical devices. According to the Regulation of the European Parliament, MobERAS can be defined as a "medical device, because it is a software designed for specific medical purposes, such as diagnosis, prevention, and monitoring, without the use of pharmacological, immunological, or metabolic means." The device must be safety and efficacious, without compromising the clinical condition of patients. Risks must be managed such that they are minimized and considered acceptable. According to the European Regulation classification rules, MobERAS belongs to the class IIa category or moderate risk, as it is a noninvasive app designed to provide information for decision-making, diagnostic purposes, or therapeutic purposes without causing any immediate danger to the patient [18].

Under the specific definitions, MobERAS can be classified as an "active device intended for diagnosis and monitoring," as it is an active device for monitoring physiological processes and health conditions in the postoperative period. To meet the regulatory requirements of the class IIa category, general safety and performance adjustments are required, in addition to delivery of clinical evidence. To deal with general security and performance requirements, it is necessary to describe the

software design and validation process with information that allows the project stages to be understood [18].

To comply with these regulations, a MobERAS validation study was performed. The app development process included (1) idealization; (2) interdisciplinary team formation; (3) assessments of potential needs, feasibility, user population, and concept finalization; (4) app construction and product development; and (5) validation.

Apps, in general, must be usable in different countries; therefore, cultural and linguistic differences must be considered during their development [19]. Thus, MobERAS was developed in Portuguese for validation in Brazil using internationally validated scales, such as the visual analog scale for pain, as well as figures representative of the respective health status, enabling translation into other languages and interpretation by different cultures. A new version in English and Spanish has already been planned.

Concept Development and the Use of Gamification

The concept of MobERAS emerged from the need to encourage patients to comply with medical recommendations in the postoperative period. According to the ERAS program, active participation of patients in their recovery process is essential for obtaining good outcomes [16]. Accordingly, the app was designed such that patients could receive guidance on recommendations to follow in the postoperative period and be monitored and encouraged to adopt the targeted measures. In this context, the development of a gamified app was initiated.

By combining gameplay mechanics and experiences, gamification creates situations that resemble games, such as reward systems, using points, achievement badges, and leaderboards. The idea was to increase participation and promote the engagement and commitment of patients in their postoperative care through gamification. Encouraging measures such as early ambulation and oral intake improves the return to normal gastrointestinal function, decreases thromboembolic event risks, promotes early hospital discharge, and reduces complication rates [16]. To improve patient adherence to

medical recommendations, the artifice of gamification was added. For example, when a patient positively fills in an item or walks for more time (>5 minutes) or a longer distance (>10 steps), they earn a bonus represented by stars or an incentive animation, similar to that in a game. Accordingly, goals are established with a reward-based strategy to obtain results, encouraging the patient to comply with medical recommendations.

Interdisciplinary Research Team

Interdisciplinarity in research involves sharing scientific knowledge among research team members [19]. In this study, intercommunication of the health and information technology areas was important. Researchers with training in information technology and those with experience in postoperative care were involved. The research team included a computer science professor, a computer science graduate student, a medical gynecologist oncology professor, a doctoral student in oncological gynecology, and a medical student.

All the researchers studied the ERAS program. After several meetings by the professionals involved in the project, the app's focus was reached. Goals to be achieved by patients were also defined. Subsequently, the app's functions, interface, and design were determined.

Assessments of Potential Needs, Feasibility, User Population, and Concept Finalization

According to ERAS program recommendations, the parameters evaluated in postoperative monitoring—simple interventions, such as early feeding, early ambulation, and multimodal analgesia—have shown to decrease the rate of postoperative ileus [20]. In the 1990s, Kehlet [21] introduced the idea of a multimodal approach to enhance functional rehabilitation postoperatively. One study suggested that avoiding limiting procedures (eg, using a urinary catheter or excessive venous hydration), implementing practices involving the use of local analgesia, and encouraging early nutrition can lead to faster postoperative recovery, as well as reduced morbidity and costs [22]. The recommendations are summarized in Table 1.

Table 1. Recommendations of the ERAS[a] program considered during app conceptualization.

Item	ERAS recommendations
Venous catheter	• Remove venous catheter when patient tolerates 500 cc of oral diet
Diet	• Regular diet in immediate postoperative period • Oral hydration
Ambulation	• Walk 8 times a day • Have all meals sitting in a chair • Stay out of bed for 8 hours a day
Bladder catheter	• Remove on first postoperative day
Nausea and vomiting/pain	• Multimodal approach • Avoid opioids

[a]ERAS: enhanced recovery after surgery.

Thus, these parameters were defined as those to be assessed in the first version of the product (Figure 1). Through frequent

and intermittent alerts triggered by the app, patients are encouraged to follow medical instructions, such as walking and

moving their legs, and to complete assessments in the form of scales evaluating pain, nausea, and vomiting. Moreover, the app has a GPS that monitors the patient's walking time and distance.

The ERAS program and, therefore, MobERAS are applicable to patients undergoing elective surgeries in general, and MobERAS was developed for use in the postoperative period. Patients can download the app on their phones, tablets, or other mobile devices. There is an easy-to-understand login that requests the user's name, individual registration (in Brazil, the "Cadastro de Pessoas Físicas"), and date of birth. The information provided by the patient can be accessed remotely in real time by the assistant health care team through cell phones (Figure 2). Thus, the app functions as a health care tool for patients.

After a detailed elaboration of the product concept, an app development plan was generated, including issues such as design, usability, validation, and integration with the online database, in addition to assessment of possible risks. The product concept and development plan included functional and nonfunctional design requirements based on stakeholder specifications, such as architecture documentation, software integration, and unit test specifications.

For attractiveness, mobile device technology needs to be easy to navigate, be self-explanatory, and not contain much screen text [23]. Moreover, user instructions must be written for easy understanding and, when appropriate, supplemented with figures and diagrams [18]. Thus, an app was designed with multiple playful resources, such as symbols and images, with the minimal use of words. The texts were written using a language as close as possible to the popular colloquial language, without the use of many technical terms that could make it difficult for patients to understand. Furthermore, there was significant focus on developing an app that was easy to navigate, as some target patients were elderly and possibly unfamiliar with advanced and complex technologies.

As the app was designed with several playful resources, it can be translated and applicable in other countries without the need for additional programming. The app was built using the backend system and the Flutter framework. The app is connected to a virtual database (Firestore) to store the collected data. Every answer provided by the patient and all walking times are stored in this database on the internet for further analysis. The text used by the graphical user interface is managed separately to ensure easy software upgrades (eg, providing the ability to add new languages by simply translating the source text without additional programming).

The source code of the MobERAS system is available at Ref. [24].

Figure 1. Summary of postoperative parameters assessed by MobERAS created for this study based on the ERAS protocol. ERAS: enhanced recovery after surgery; MobERAS: mobile app for enhanced recovery after surgery.
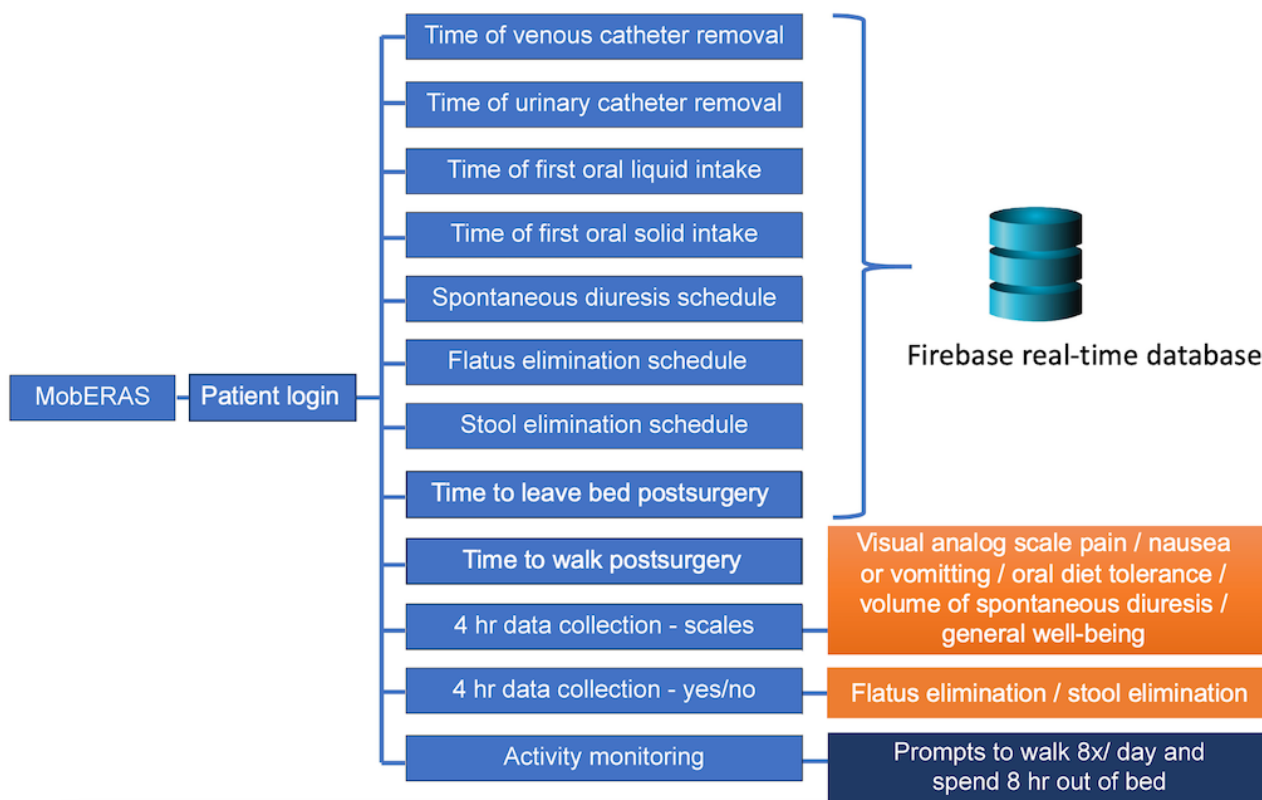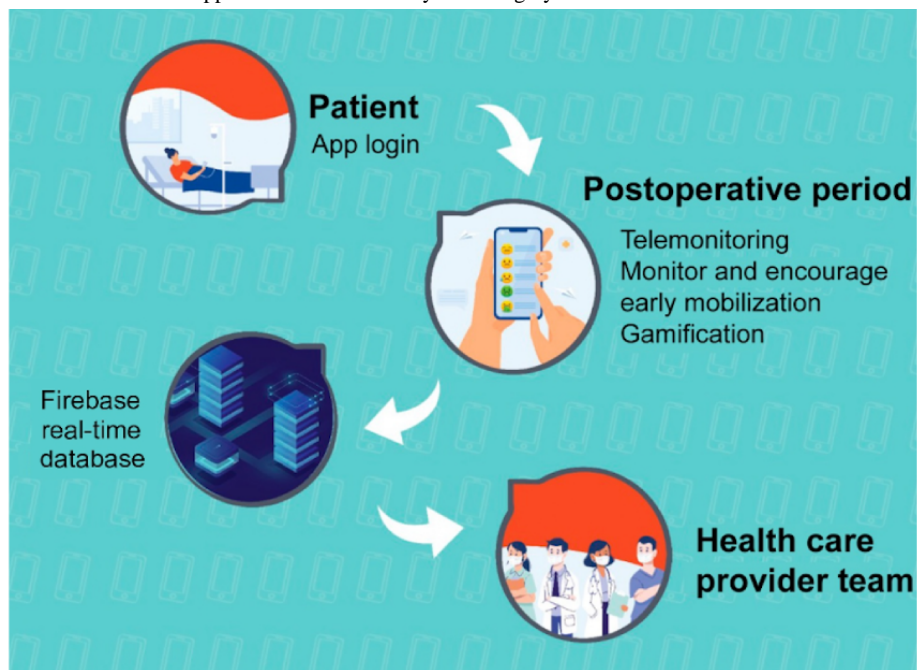
Figure 2. MobERAS enables real-time telemonitoring of the postoperative course and aims to improve patients' adherence to medical recommendations using gamification tools. MobERAS: mobile app for enhanced recovery after surgery.

Validation Process

To validate MobERAS, the study included the participation of a multidisciplinary team, including physicians and nurses from the health care team, computer professionals, and patients who used the app.

Study Population

Although the app is applicable to several surgical specialties, it was validated in the patient population attended by the physicians participating in the study. Patients with proposed medium and major gynecologic oncologic surgeries were invited to participate in the study. The patients were recruited from a public teaching hospital and a private hospital, both in Brazil and references in the care of women with gynecological cancer.

In total, 69 patients were invited to participate in the study, all of whom were undergoing medium and major gynecologic oncologic surgery. Of these, 4 (5.8%) patients refused to participate in the study: 2 (50%) of these 4 patients argued that they had no contact with any mobile device. These were an 83-year-old and a 72-year-old patient, the first one with no educational background and family income of 1 minimum wage and the second with incomplete primary education and family income between 1 and 2 minimum wages. Thus, 65 (94.2%) patients were included in the study, 35 (53.8%) patients from the public teaching hospital and the other 30 (46.2%) from the private hospital.

MobERAS Functioning

MobERAS was tested in the postoperative period as soon as patients arrived in the postanesthetic recovery room. The time of use was determined by the length of hospitalization of patients in the postoperative period. We evaluated adherence to the use of the app through the percentage of completion of the requested topics and through data collection regarding mobility and ambulation.

Patients' Evaluation of MobERAS

Aiming at evaluating the usability of MobERAS and its acceptance by users, at the end of its use by patients, at the time of hospital discharge, the patients were invited to fill out a survey, evaluating their experience with using the app and providing their opinion about it (Table 2). For this evaluation, we used the System Usability Scale (SUS), a usability scale developed by Brooke [25] in 1986. The SUS is a simple scale that offers a global view of subjective evaluations of usability [25].

The SUS is composed of 10 statements that are scored on a 5-point agreement strength scale, where 1 means "I totally disagree" and 5 means "I totally agree." The final scores range from 0 to 100, where higher scores indicate better usability. The statements alternate between positive and negative [25] because there are features in the statements that tend to result in generally positive or negative evaluations [26].

The SUS produces a single number (SUS score) that represents a measure of the overall usability of the system. Individual item scores are not meaningful in isolation. To calculate the SUS score, 1 is subtracted from the score that the user provides to the odd items (1, 3, 5, 7, and 9) and the user's score provided to the even items (2, 4, 6, 8, and 10) is subtracted from 5. For example, if the user scores an even item 2, the item score is 5 – 2 = 3. Thus, the contribution score for each item ranges from 0 to 4. After this, all the scores of the 10 questions are added, and the total value is multiplied by 2.5, resulting in the final score [25]. A score above 68 is considered above average, and a value below 68 is below average. However, Despite the wide use of the SUS, there is little guidance on the interpretation of SUS scores [27].

Table 2. MobERAS[a] evaluation questionnaire answered by the patients[b].

Item #	Item	I totally disagree	I disagree	I neither agree nor disagree (indifferent)	I agree	I totally agree
1	I would use MobERAS again.					
2	I found MobERAS unnecessarily complex.					
3	I found MobERAS easy to use.					
4	I would need help from a person with technical knowledge to use MobERAS.					
5	I think MobERAS functions are very well integrated.					
6	I think MobERAS is too inconsistent.					
7	I imagine that people will learn how to use MobERAS quickly.					
8	I found MobERAS confusing to use.					
9	I felt confident using MobERAS.					
10	I had to learn several new things before I could use MobERAS.					

[a]MobERAS: mobile app for enhanced recovery after surgery.

[b]Adapted from Brooke [25].

Evaluation of MobERAS by Health Care and Computer Professionals

To evaluate the quality of the information contained and provided by MobERAS, we used a multidimensional scale developed by Stoyanov et al [28] to rate and evaluate the quality of mobile health (mHealth) apps [28]. According to the Mobile App Rating Scale (MARS), the app quality was evaluated in 4 dimensions (engagement, functionality, aesthetics/design, and information) by 20 health care professionals (physicians and nurses) and 10 professionals with a computer science background working in technological innovation. All items were evaluated on a 5-point scale, from 1 for "inadequate" to 5 for "excellent." The minimum-possible score for each item was 30 and the maximum was 150 (1 and 5 points for each professional, respectively).

Ethical Considerations

The study was approved by the Ethics Committee of both hospitals (Women's Hospital Prof. Dr. José Aristodemo Pinotti and Vera Cruz Hospital), in addition to the ethics committee of São Paulo State University "Júlio de Mesquita Filho" (approval number 98361118.0.0000.5411), the proponent institution of the research, and all participants signed an informed consent form.

Results

Constructing a Mobile App: Product Development

The Initial Product (Prototype)

An initial product (prototype) was developed to run on the Android operating system, based on Figures 1 and 2. Usability tests were performed throughout the development process, with improvements, technical adjustments, and updates. Usability problems were verified using Nielsien's heuristics [29]. Usability tests were performed using this preliminary version of MobERAS in 10 women undergoing gynecological oncological surgery. Patients were interviewed to verify the difficulties in app use and obtain suggestions for app improvement. In this preliminary phase, system failures were analyzed and the necessary corrections and improvements were made. After the finalization of app development, comprehensive verification tests of the final product were conducted and validation tests were performed.

The Final Product

The final product complies with General Data Protection Regulations (GDPR), guaranteeing preservation of patient privacy. The patient account registers the patient's name, date of birth, and nationality (Figure 3A). After the patient logs in, a text with instructions on how the app works is displayed. The patient is then shown a video that uses drawings and visual animations to convey guidelines from the ERAS program aiming to improve recovery time and postoperative outcomes (Figure 3B). No intervention that causes changes in the treatment planning of the patient is proposed. The ERAS program guidelines are recommended for routine clinical and surgical practice.

After the end of the video, MobERAS displays a screen containing the first questionnaire, which refers to the occurrence of events usually monitored in the postoperative period, such as removal of the venous access and bladder catheter. The patient answers each question when the respective intervention occurs. The patient is also asked to record the first occurrence of certain events, such as the time of the first oral intake or spontaneous diuresis (Figure 4C-E). The events recorded by the questionnaire are presented in Textbox 1.

Figure 3. Sequence of MobERAS operation created for this study. (A) Login, (B) a video describing ERAS guidelines using drawings and visual animations, (C) the first questionnaire referring to the occurrence of events usually monitored in the postoperative period, and (D and E) the date and time of events recorded in (C). ERAS: enhanced recovery after surgery; MobERAS: mobile app for enhanced recovery after surgery.
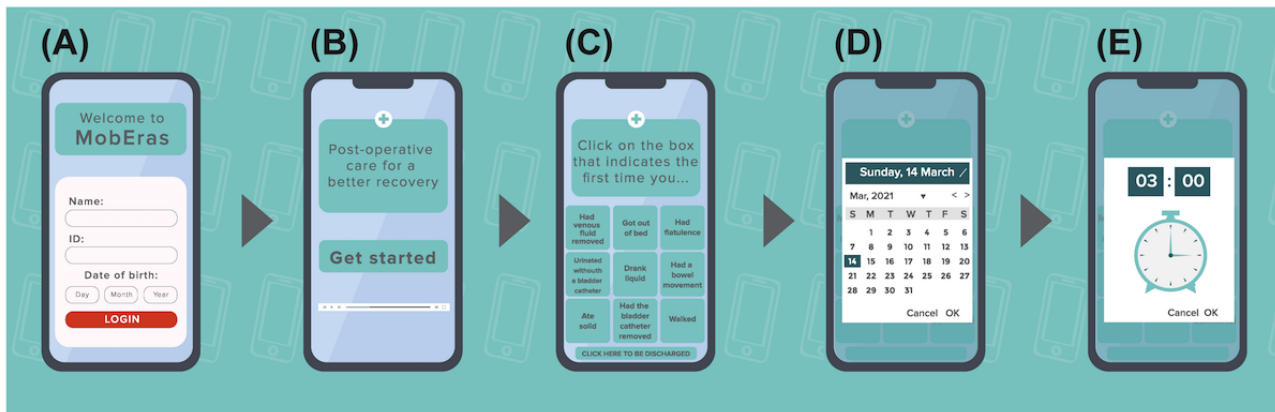
Figure 4. The second questionnaire, which the patient completes every 4 hours, when prompted by MobERAS. The patient is invited to click the number or figure that best represents their health status in the past 4 hours. (A) Pain level, (B) nausea and vomiting level, (C) amount of urine, (D) amount of food and liquid ingested, (E) general well-being, (F) occurrence of flatus, (G) whether bowels were opened, and (H) notice that a new notification to complete the questionnaire will be sent in 4 hours. MobERAS: mobile app for enhanced recovery after surgery.
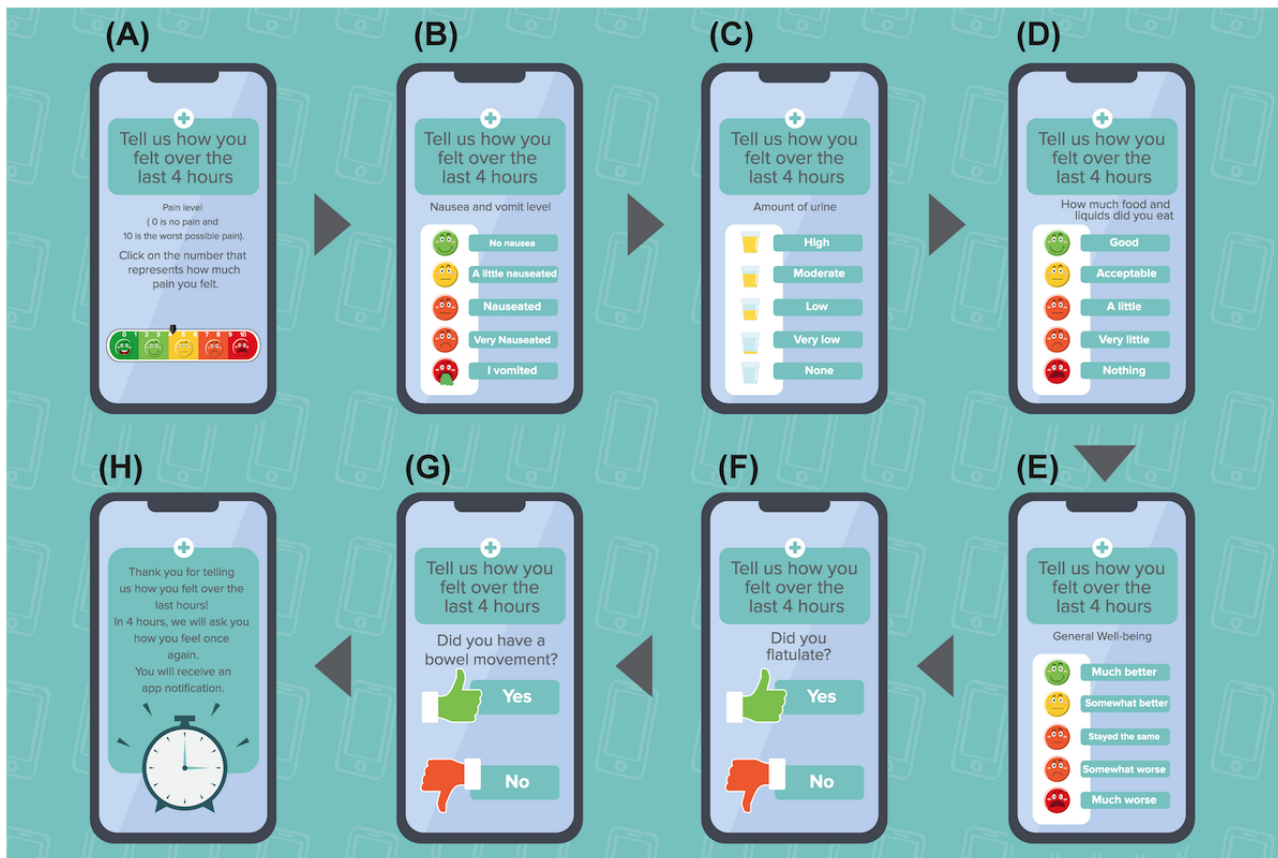
Textbox 1. Questionnaires and parameters monitored by the mobile app for enhanced recovery after surgery (MobERAS).

First Questionnaire

Click on the box that indicates the first time you:

- Drank liquid
- Ate solid
- Had the bladder catheter removed
- Urinated without a bladder catheter
- Had flatulence
- Had a bowel movement
- Had venous fluid removed
- Got out of bed
- Walked

Second Questionnaire

Tell us how you felt over the last 4 hours. Click on the figure or number that best represents your last 4 hours.

- Visual analog scale for pain (Figure 4A): pain level (0: no pain; 10: worst-possible pain). Click on the number that represents how much pain you felt.
- Nausea and vomiting level: 5 levels of intensity (Figure 4B). No nausea, a little nauseated, nauseated, very nauseated, or vomited.
- Amount of urine: 5 levels of intensity (Figure 4C). High, moderate, low, very low, or none.
- How much food and liquids did you eat: 5 levels of intensity (Figure 4D). Good, acceptable, a little, very little, or nothing.
- General well-being: 5 intensity levels (Figure 4E). Much better, somewhat better, stayed the same, somewhat worse, or much worse.
- Did you flatulate? (Figure 4F): yes or no.
- Did you have a bowel movement? (Figure 4G): yes or no.

Simultaneously, the app screen continuously displays motivational messages on the upper scroll bar: "Try to eat all meals at the table and not in bed," "Try to stay at least 8 hours out of bed," "Try to walk at least 6 times throughout the day," "Try to move your legs when you are lying down," "Get moving! It is the best way for your recovery to be faster," "Have you answered the questions of how you are today?" "Remember to answer the questions!", and "Remember: your participation is essential for your recovery!"

At 4-hour intervals, alerts are triggered to complete a second questionnaire. Through this questionnaire, the patient is asked to score some scales and provide information on parameters to be monitored in the postoperative period. The patient is invited to click the number or figure that best represents their health status in the past 4 hours. These alerts are not triggered during the night (sleep period). The basic questions and scales are listed in Textbox 1, and examples of how the questions appear within the app are illustrated in Figure 4. With each positive note, the patient receives emojis or animations of recognition and congratulations to show that the event that occurred is desired for better recovery. Here, the use of gamification, through the reward system, is evident. Conversely, with each negative note, the patient receives emojis or animations to encourage improvement.

During app usage, the mobile device captures, through the GPS attached to it, the walking time and distance covered by the patient. At the time of hospital discharge, the patient confirms the date and time of the surgery and hospital discharge and then receives a final text with the guidelines to be followed at home in the postoperative period. All information recorded by the patient is sent to an online database connected to the attending physician's cell phone, with the possibility of accessing the information in real time. This enables fast and targeted telemonitoring of patients.

Validation of the Final Product

MobERAS Functioning

MobERAS was used by all 65 (100%) patients in the study. The age of the women ranged from 18 to 85 years (mean 53.2, SD 7.4) years. Regarding the level of education, 29 (44.6%) women reported a medium level, and only 2 (3.1%) said they had no education. The number of women with elementary school and higher education was similar (n=18, 28.3%, and n=16, 24%, respectively). Regarding family income, most (n=51, 78.5%) reported an income of more than 4 minimum wages, with only 1 (1.5%) woman reporting an income below 2 minimum wages.

The average time of use was 45.1 (SD 19.2) hours, ranging from 23.4 to 70 hours. All patients completed the static questionnaire. Regarding the dynamic questionnaire, a completion rate ranging from 41.7% to 100% was observed (mean 56.3%, SD 12.1%).

There was a failure to capture data related to mobility and ambulation in 5 (7.7%) patients. Of these 5 patients, 3 (60%) did not move with the mobile device, and in the other 2 (40%) cases, there was a GPS malfunction. After expert evaluation,

GPS connection failure was identified. Thus, mobility and ambulation data were obtained for 60 (92.3%) of 65 patients.

Patients' Evaluation of MobERAS

The average SUS score of studies available in scientific databases is 68. In this study, the patients' perceived usability was found to be of a satisfactory level, with a mean SUS score of 81.3 (SD 9.4). Individual scores ranged from 70 to 100. The SUS score was calculated individually for each patient using MobERAS, and then, the scores were averaged. Of the 65 patients participating in the study, the majority (n=60, 92.3%) answered the final MobERAS usability evaluation questionnaire (SUS).

Evaluation of MobERAS by Health Care and Computer Professionals

In the evaluation of MobERAS by health care professionals and professionals specialized in technological innovation, it was possible to observe good general compliance with the proposed requirements for app evaluation. Considering a score of less than 70 as bad or very bad, from 70 to 110 as average, and higher than 110 as good or very good, the app was rated on all items evaluated according to MARS as good or very good, as shown in Table 3.

Table 3. MARS[a] used in the evaluation of the quality of information contained in or provided by MobERAS[b,c].

Dimension of MARS and assessments	Score
Engagement	
Entertainment (1: dull; 2: mostly boring; 3: OK; 4: moderately fun; 5: highly fun)	137
Interest (1: not interesting at all; 2: mostly uninteresting; 3: OK; 4: moderately interesting; 5: very interesting)	145
Customization (1: does not allow any customization; 2: allows insufficient customization; 3: allows basic customization; 4: allows numerous options for customization; 5: allows complete customization to the individual's characteristics)	128
Interactivity (1: no interactive features; 2: insufficient interactivity; 3: basic interactive feat; 4: offers a variety of interactive features; 5: very high level of interactive features)	119
Target group (1: completely confusing; 2: mostly confusing; 3: acceptable; 4: well targeted; 5: perfectly targeted)	147
Functionality	
Performance (1: inaccurate response; 2: major technical problems; 3: some technical problems; 4: mostly functional with minor problems; 5: perfect response)	111
Ease of use (1: no instructions; 2: usable after a lot of effort; 3: usable after some effort; 4: easy to learn how to use, clear instructions; 5: immediate use; intuitive)	143
Navigation (1: disconnected and random sections/navigation difficult; 2: usable after a lot of effort; 3: usable after some effort; 4: easy to use; 5: perfectly logical and intuitive screen flow throughout)	145
Gestural design (1: completely confusing; 2: often confusing; 3: OK, with some confusing elements; 4: intuitive, with negligible problems; 5: perfectly intuitive)	144
Aesthetics/design	
Layout (1: very bad design, some options impossible to select; 2: bad design, some options difficult to select; 3: satisfactory, few problems with selecting; 4: mostly clear, able to select; 5: professional, clear device display)	118
Graphics (1: amateurs; 2: lowqality / resolution; 3: moderate quality; 4: high quality; 5: very high quality)	122
Visual appeal (1: no visual appeal; 2: little visual appeal; 3: some visual appeal; 4: high level of visual appeal, professionally designed; 5: very attractive, memorable, stands out)	115
Information	
Accuracy of app description (1: has no description; 2: inaccurate; 3: OK; 4: accurate; 5: highly accurate description of app components/functions)	145
Goals (N/A[d]: app goals irrelevant to research goal; 1: has no chance of achieving its stated goals; 2: has very little chance of achieving goals; 3: clear goals, which may be achievable; 4: clearly specified goals and achievable; 5: specific and measurable goals, which are highly likely to be achieved)	140
Quality of information (N/A: no information within the app; 1: irrelevant/incoherent; 2: barely relevant/coherent; 3: moderately relevant/coherent; 4: relevant/coherent; 5: highly relevant/coherent)	144
Quantity of information (N/A: no information within the app; 1: minimal; 2: insufficient; 3: OK but not comprehensive; 4: broad range of information, some gaps; 5: comprehensive and concise, contains links to more information and resources)	117
Visual information (N/A: no visual information within the app; 1: completely confusing; 2: mostly confusing; 3: OK but often confusing; 4: mostly clear; 5: perfectly clear)	147
Credibility (1: legitimacy worthiness of source questionable; 2: legitimate source but cannot be verified; 3: developed by small nongovernmental organization/institution/specialised commercial business/funding body; 4: developed by government, university, or as above but larger in scale; 5: developed using nationally competitive government or research funding)	120
Evidence base (N/A: app not tested; 1: app not working; 2: trialled and partially positive outcomes in studies that are not RCTs[e]; 3: trialled and positive outcomes in studies that are not RCTs; 4: trialled and positive outcomes in 1-2 RCTs; 5: trialled and positive outcomes in >3 high-quality RCTs)	N/A

[a]MARS: Mobile App Rating Scale.

[b]MobERAS: mobile app for enhanced recovery after surgery.

[c]Adapted from Stoyanov et al [28].

[d]N/A: not applicable.

[e]RCT: randomized controlled trial.

XSL•FO
RenderX

Discussion

Principal Findings

This study described the development and validation process of an app (MobERAS) for telemonitoring, guiding, and encouraging the adoption of medical recommendations for use in the postoperative period. To the best of our knowledge, this is the first study to describe such an app for telemonitoring patients in the postoperative period using gamification. There are few apps developed to be used in the perioperative period, and most of these apps are intended to provide information to patients. An example is the Heal Better app [30], which aims to help educate and empower patients to comply with a recovery care plan after abdominal surgery by providing clinical information. The difference between MobERAS and these other apps is the real-time monitoring of the patient in the postoperative period and the use of gamification as a tool to encourage recommended medical practices. By combining telemonitoring with gamification, MobERAS aims to (1) monitor the postoperative course using data provided by patients; (2) evaluate the incorporation of the ERAS program recommendations into clinical and surgical practice and patients' responses to the adopted recommendations; (3) promote greater participation of patients in their postoperative recovery process and better adherence to medical recommendations, aiming to achieve faster recovery, early discharge from the hospital, and lower rates of complications; and (4) enable remote and real-time access of health data and postoperative evolution by physicians.

Worldwide, over 300,000 health apps are currently under development. Both the US Food and Drug Administration (FDA) and the European Medicine Agency of the European Union (EU) have recognized the importance of the software in diagnostic and therapeutic devices. Guidelines related to the use of digital tools in health were published by the World Health Organization in 2018, organizing the different digital and mobile interventions and their use in favor of the health system [31]. Significant progress has been made in app development, building an evidence base, validating functionality, and creating standards for development and design structures for app reviews. Nonetheless, even if an app is well developed, with evident quality, its ability to improve the health and well-being of patients can only be achieved if the app is actually used [1]. Features such as gamification can significantly increase users' attention and involvement. The most accepted definition of gamification is "the use of game design elements in nongame contexts." There are many gamification strategies that increase engagement, such as narrative structure, symbols, or avatars based on self-image, as well as integration tutorials. Resources present in smartphones, such as sensors and GPS services, have been useful for gamified health care interventions [15]. Considering this, gamification strategies were used to develop MobERAS, including the use of figures representing the health status of patients, a reward system, avatars, and motivational figures, as well as a GPS attached to the system to monitor walking. We believe that this will motivate patients to fulfill their goals and consequently follow medical recommendations, thus reaching the desired postoperative objectives.

It is known that walking 10 m (or 30 steps) without interruption can reduce the risk of thromboembolic phenomena by up to 50% [32]. It is also known that mobile device tools, such as sensors, can be useful in the delivery of health care resources [28]. Mobile devices have sensors integrated into them, and this type of resource can assist health care professionals in treating their patients with permanent connectivity [33]. In this context, the GPS integrated into MobERAS is used for continuous monitoring of mobility time and walking distance.

MobERAS was designed to start being used in the postoperative period for patients still in the hospital, showing the first signs of occurrence of important events, such as bladder catheter removal or the first oral intake, in addition to collecting postoperative data at short intervals, considering the need for more frequent monitoring during the hospital stay, such as monitoring pain, diet acceptance, or diuresis volume. For this reason, the app was validated in the hospital in the postoperative period within less than 72 hours of use. Nonetheless, the app can be programmed to collect information at longer intervals (eg, once or twice a day), and its domestic use can be evaluated in another study.

MobERAS collects self-reported data from patients just as if they were having an appointment with a doctor. The idea is for the app to become a tool to help with postoperative monitoring and not a replacement for regular supervision by the health care team. All information received by health care professionals in real time enables the early diagnosis of possible postoperative complications, resulting in better patient supervision after surgery being able to prevent more serious complications.

Postoperative adverse events are associated with longer hospital stays and increased mortality rates. The ERAS program represents a paradigm shift in conventional perioperative care, replacing some traditional practices with better evidence-based practices, minimizing overall health care spending, allowing for faster and safer rehabilitation, and improving well-being and patient satisfaction [15,16]. With this objective, the program focuses mainly on a decrease in perioperative stress, adequate pain control, return to normal gastrointestinal function, and early mobilization [22]. The app developed and described in this study was based on recommendations of the ERAS program. The parameters evaluated are those that can influence the length of hospital stay, such as nausea, vomiting, pain, return to normal normal gastrointestinal function, and thromboembolic events.

Thus, according to the guidelines recommended by the ERAS program and because MobERAS is gamified, we believe that the app can encourage longer walking times, with a consequent faster return to normal gastrointestinal function, and fewer thromboembolic events, resulting in benefits such as faster postoperative recovery, shorter hospital stay, and a lower rate of postoperative complications. Through the continuous collection of data from patients and the sharing of this knowledge with the doctor in real time, better pain control and better management of nausea and vomiting are expected with the use of the app. Moreover, the hospital will benefit from lower hospitalization costs without increasing the rate of complications.

Although mobile device ownership is widespread, its use in disease management and self-care is still in its early stages, and there is limited knowledge about its use in the perioperative setting [12]. MobERAS has as some of its objectives the collection of postoperative data and the telemonitoring of patients undergoing surgery. Using validation tests, these objectives were achieved, with the collection of clinical data and the monitoring of patients' health status, sharing information with health care professionals in real time. Objective symptoms are traditionally monitored as part of care and treatment, but patients' subjective descriptions are considered a key element of monitoring [15]. Through the app, patient self-reported information was collected, both regarding symptoms, such as pain, nausea, and vomiting, and objective parameters, such as serum and catheter withdrawal times.

Most health apps for smartphones have simple functions and do a little more than providing basic information. However, there is great potential for developing more effective gamified apps, depending on the repertoire and combinations of techniques used that are appropriate for a gamified platform. This development requires multidisciplinary collaboration between game developers, behavior change specialists, and public health experts [34]. In response to this need, this study involved health care professionals and experts in innovation technology in both the development and evaluation of MobERAS. As a result, we developed an app that, in addition to collecting data, uses gamification as a tool to guide and encourage patients to engage in their postoperative recovery process and comply with medical recommendations.

Given the rapid proliferation of smartphone apps, it is increasingly difficult for users, health care professionals, and researchers to identify and evaluate high-quality apps. Little information about the quality of apps is available [29]. One of the critical issues is the lack of evaluation of the reliability of mHealth monitoring systems [33]. In addition, there is little evidence that health care professionals and users participate in the design of health apps, and most apps do not contain theoretically consistent behavior change techniques. Few apps are compliant with the regulatory processes or have had their effectiveness formally evaluated, leading to concerns about the lack of benefits or even potentially harmful apps [34]. For this reason, we chose to perform a comprehensive validation of our app in this study, with quality assessment both from a subjective point of view, using the SUS answered by patients using the app, and from a technical point of view, using MARS and expert assessments.

Through the SUS answered by the patients, good evaluation was observed regarding usability, which suggests good acceptance of the use of the app by the patients. The SUS was chosen because of its widely recognized use in assessing product usability and its flexibility to adapt, because it is quick and easy to use, and because it offers a unique score that is easily understood by people who are involved in product and service development [26]. In addition, MobERAS was rated by the experts as good or very good on all MARS parameters, which also suggests a well-developed app with regard to engagement, functionality, design, and information. This leads us to conclude

that this is a safe app with potential benefits and possible applicability in clinical practice.

Limitations and Strengths

One limitation of this work is that no case-control study was conducted to assess the impact of using the software on the occurrence of postoperative complications and the length of hospital stay. Furthermore, the use of MobERAS depends on an internet connection and active patient participation, and there may be changes in the level of awareness, pain, and other parameters that limit the correct use of MobERAS during the early postoperative period. The gamification process and app design also require further improvement. Although the app involved participation of patients during initial construction of the product and validation tests were performed with the participation of patients and professionals, the app was not codesigned with patients and health care professionals. In addition, the difficulty or ease of use of the app according to different age groups and socioeconomic levels was not analyzed.

However, the study also highlights the strengths of the app and its usefulness, which include the contribution of a multidisciplinary team and international applicability. Moreover, the technology used is compatible with current trends in health practices, and the app is compatible with cell phones and devices present in the daily life of the population. Another important point is that MobERAS was examined by experts, with good evaluation. In addition, the app's good functionality was proven, with postoperative data capture and its potential clinical applicability, in addition to good acceptance of its use by the patients.

Challenges

Challenges in the field of digital health care include issues related to development, validation, and use [35]. Despite such challenges, it is expected that these obstacles will be overcome by a growing number of apps that will become increasingly suitable for use in clinical practice. However, the first challenge in the dissemination of apps for clinical use is to increase awareness of the technologies available to doctors [1]. We believe that MobERAS can be of great help in the health care of patients, with possible early detection of postoperative complications, in addition to better monitoring of patients. We believe that the app can contribute to the health team acting immediately and more effectively when facing complications. Moreover, because the app is easy to navigate and attractive through the use of gamification tools, the patient can be stimulated to follow medical recommendations for better recovery. The app will work as a "virtual companion" during the patient's postoperative stay in the hospital. A subsequent randomized clinical trial will help us understand better the impact of MobERAS on postoperative clinical practice.

Conclusion

In conclusion, MobERAS can be used to orient patients, obtain postoperative data, and monitor patients in real time. The app is easy to use and attractive, given its gamified design. MobERAS is well accepted by patients and well evaluated by experts. Overall, MobERAS can be of great use in clinical practice, promoting the engagement and commitment of patients

in their postoperative care. We believe that the app can contribut to better postoperative assistance and outcomes. Further studies are required to verify the clinical applicability of MobERAS in a greater number of patients and the impact of its use on postoperative recovery.

Acknowledgments

Authors' Contributions

Data collection was managed by EBC, AES, and ALSF; data analysis by AES and ALSF; technical application development by VPGC; manuscript writing by AES, ALSF, and RSF; and overseeing of app technical development by WCB.

Conflicts of Interest

None declared.

References

1. Gordon WJ, Landman A, Zhang H, Bates DW. Beyond validation: getting health apps into clinical practice. NPJ Digit Med 2020 Feb 03;3(1):14 [FREE Full text] [doi: 10.1038/s41746-019-0212-z] [Medline: 32047860]
2. Johnson D, Deterding S, Kuhn K, Staneva A, Stoyanov S, Hides L. Gamification for health and wellbeing: a systematic review of the literature. Internet Interv 2016 Nov;6:89-106 [FREE Full text] [doi: 10.1016/j.invent.2016.10.002] [Medline: 30135818]
3. Andrews E, Berghofer K, Long J, Prescott A, Caboral-Stevens M. Satisfaction with the use of telehealth during COVID-19: an integrative review. Int J Nurs Stud Adv 2020 Nov;2:100008 [FREE Full text] [doi: 10.1016/j.ijnsa.2020.100008] [Medline: 33083791]
4. Batch BC, Spratt SE, Blalock DV, Benditz C, Weiss A, Dolor RJ, et al. General behavioral engagement and changes in clinical and cognitive outcomes of patients with type 2 diabetes using the Time2Focus mobile app for diabetes education: pilot evaluation. J Med Internet Res 2021 Jan 20;23(1):e17537 [FREE Full text] [doi: 10.2196/17537] [Medline: 33470947]
5. Alsalman D, Bu Ali ZM, Alnosaier ZF, Alotaibi NA, Alanzi TM. Gamification for diabetes type 1 management: a review of the features of free apps in google play and app stores. J Multidiscip Healthc 2020 May;13:425-432. [doi: 10.2147/jmdh.s249664]
6. Hernández-Reyes A, Cámara-Martos F, Molina Recio G, Molina-Luque R, Romero-Saldaña M, Moreno Rojas R. Push notifications from a mobile app to improve the body composition of overweight or obese women: randomized controlled trial. JMIR Mhealth Uhealth 2020 Feb 12;8(2):e13747 [FREE Full text] [doi: 10.2196/13747] [Medline: 32049065]
7. Giunti G, Giunta D, Guisado-Fernandez E, Bender J, Fernandez-Luque L. A biopsy of breast cancer mobile applications: state of the practice review. Int J Med Inform 2018 Feb;110:1-9 [FREE Full text] [doi: 10.1016/j.ijmedinf.2017.10.022] [Medline: 29331247]
8. Drissi N, Ouhbi S, Janati Idrissi MA, Ghogho M. An analysis on self-management and treatment-related functionality and characteristics of highly rated anxiety apps. Int J Med Inform 2020 Sep;141:104243 [FREE Full text] [doi: 10.1016/j.ijmedinf.2020.104243] [Medline: 32768994]
9. Kazemi DM, Borsari B, Levine MJ, Lamberson KA, Dooley B. REMIT: development of a mHealth theory-based intervention to decrease heavy episodic drinking among college students. Addict Res Theory 2018 Dec 26;26(5):377-385 [FREE Full text] [doi: 10.1080/16066359.2017.1420783] [Medline: 32694964]
10. García-Pazo P, Fornés-Vives J, Sesé A, Pérez-Pareja FJ. Apps for smoking cessation through cognitive behavioural therapy. A review. Adicciones 2021 Nov 05;33(4):359-368 [FREE Full text] [doi: 10.20882/adicciones.1431] [Medline: 32677688]
11. Greene EM, O'Brien EC, Kennelly MA, O'Brien OA, Lindsay KL, McAuliffe FM. Acceptability of the pregnancy, exercise, and nutrition research study with smartphone app support (PEARS) and the use of mobile health in a mixed lifestyle intervention by pregnant obese and overweight women: secondary analysis of a randomized controlled trial. JMIR Mhealth Uhealth 2021 May 12;9(5):e17189 [FREE Full text] [doi: 10.2196/17189] [Medline: 33978597]
12. Krishna S, Boren SA, Balas EA. Healthcare via cell phones: a systematic review. Telemed J E Health 2009 Apr;15(3):231-240. [doi: 10.1089/tmj.2008.0099] [Medline: 19382860]
13. Policy for device software functions and mobile medical applications. Guidance for industry and Food and Drug Administration staff. Food and Drug Administration. URL: https://www.fda.gov/vaccines-blood-biologics/guidance-compliance-regulatory-information-biologics [accessed 2023-09-01]
14. Sardi L, Idri A, Fernández-Alemán JL. A systematic review of gamification in e-Health. J Biomed Inform 2017 Jul;71:31-48 [FREE Full text] [doi: 10.1016/j.jbi.2017.05.011] [Medline: 28536062]
15. Patient guidelines. Eras Society. URL: https://erassociety.org/patients/ [accessed 2023-08-25]

XSL•FO
RenderX

16.   Myriokefalitaki E, Smith M, Ahmed AS. Implementation of enhanced recovery after surgery (ERAS) in gynaecological oncology. Arch Gynecol Obstet 2016 Jul 2;294(1):137-143. [doi: 10.1007/s00404-015-3934-4] [Medline: 26525694]

17.   Talec P, Gaujoux S, Samama C. Early ambulation and prevention of post-operative thrombo-embolic risk. J Visc Surg 2016 Dec;153(6S):S11-S14 [FREE Full text] [doi: 10.1016/j.jviscsurg.2016.09.002] [Medline: 27789264]

18.   The European Parliament and the Council of the European Union. Regulation (EU) 2017/745 of the European Parliament and of the Council of 5 April 2017 on medical devices, amending Directive 2001/83/EC, Regulation (EC) No 178/2002 and Regulation (EC) No 1223/2009 and repealing Council Directives 90/385/EEC and 93/42/EEC. Off J Eur Union 2017 May 5:1-175 [FREE Full text]

19.   Ferretti A, Ronchi E, Vayena E. From principles to practice: benchmarking government guidance on health apps. Lancet Digital Health 2019 Jun;1(2):e55-e57. [doi: 10.1016/s2589-7500(19)30027-5]

20.   Nelson G, Bakkum-Gamez J, Kalogera E, Glaser G, Altman A, Meyer LA, et al. Guidelines for perioperative care in gynecologic/oncology: Enhanced Recovery After Surgery (ERAS) Society recommendations-2019 update. Int J Gynecol Cancer 2019 May 15;29(4):651-668. [doi: 10.1136/ijgc-2019-000356] [Medline: 30877144]

21.   Kehlet H. Multimodal approach to control postoperative pathophysiology and rehabilitation. Br J Anaesth 1997 May;78(5):606-617 [FREE Full text] [doi: 10.1093/bja/78.5.606] [Medline: 9175983]

22.   Miralpeix E, Nick AM, Meyer LA, Cata J, Lasala J, Mena GE, et al. A call for new standard of care in perioperative gynecologic oncology practice: impact of enhanced recovery after surgery (ERAS) programs. Gynecol Oncol 2016 May;141(2):371-378 [FREE Full text] [doi: 10.1016/j.ygyno.2016.02.019] [Medline: 26906066]

23.   Jaensson M, Dahlberg K, Eriksson M, Grönlund Å, Nilsson U. The development of the recovery assessments by phone points (RAPP): a mobile phone app for postoperative recovery monitoring and assessment. JMIR Mhealth Uhealth 2015 Sep 11;3(3):e86 [FREE Full text] [doi: 10.2196/mhealth.4649] [Medline: 26362403]

24.   userThiagoRamos/moberas. GitHub. URL: https://github.com/userThiagoRamos/moberas.git [accessed 2023-04-05]

25.   Brooke J. SUS: a quick and dirty usability scale. ResearchGate. 1995 Nov. URL: https://www.researchgate.net/publication/228593520_SUS_A_quick_and_dirty_usability_scale [accessed 2023-10-09]

26.   Bangor A, Kortum PT, Miller JT. An empirical evaluation of the System Usability Scale. Int J Hum-Comput Interact 2008 Jul 30;24(6):574-594. [doi: 10.1080/10447310802205776]

27.   System Usability Scale (SUS): improving products since 1986. Digital.gov. URL: https://digital.gov/2014/08/29/system-usability-scale-improving-products-since-1986/ [accessed 2023-12-11]

28.   Stoyanov SR, Hides L, Kavanagh DJ, Zelenko O, Tjondronegoro D, Mani M. Mobile app rating scale: a new tool for assessing the quality of health mobile apps. JMIR Mhealth Uhealth 2015 Mar 11;3(1):e27 [FREE Full text] [doi: 10.2196/mhealth.3422] [Medline: 25760773]

29.   Molich R, Nielsen J. Improving a human-computer dialogue. Commun ACM 1990 Mar;33(3):338-348. [doi: 10.1145/77481.77486]

30.   Heal Better app. Heal Better. URL: https://healbetter.com.au/pages/heal-better-app-1 [accessed 2023-04-10]

31.   Classification of digital health interventions v1.0: a shared language to describe the uses of digital technology for health. World Health Organization. 2018 Jan 1. URL: https://www.who.int/publications/i/item/WHO-RHR-18.06 [accessed 2023-11-10]

32.   Caprini J. Caprini score for venous thromboembolism (2005): stratifies risk of VTE in surgical patients. MDCalc. URL: https://www.mdcalc.com/caprini-score-venous-thromboembolism-2005 [accessed 2023-06-10]

33.   Pires IM, Marques G, Garcia NM, Flórez-Revuelta F, Ponciano V, Oniani S. A research on the classification and applicability of the mobile health applications. J Pers Med 2020 Feb 27;10(1):11 [FREE Full text] [doi: 10.3390/jpm10010011] [Medline: 32120849]

34.   Edwards EA, Lumsden J, Rivas C, Steed L, Edwards LA, Thiyagarajan A, et al. Gamification for health promotion: systematic review of behaviour change techniques in smartphone apps. BMJ Open 2016 Oct 04;6(10):e012447 [FREE Full text] [doi: 10.1136/bmjopen-2016-012447] [Medline: 27707829]

35.   Food and Drug Administration. Prescription drug-use-related software; establishment of a public docket; request for comments. Federal Register, Daily Journal of the United States Government. Doc No. Doc-25206. 2018 Nov. URL: https://tinyurl.com/5dcpn2ec [accessed 2023-11-12]

36.   userThiagoRamos/moberas. GitHub. URL: https://github.com/userThiagoRamos/moberas.git [accessed 2023-04-05]

Abbreviations

ERAS: enhanced recovery after surgery
MARS: Mobile App Rating Scale
mHealth: mobile health
MobERAS: mobile app for enhanced recovery after surgery
RCT: randomized controlled trial
SUS: System Usability Scale

XSL•FO

RenderX

Review

The Effectiveness of Patient Education on Laparoscopic Surgery Postoperative Outcomes to Determine Whether Direct Coaching Is the Best Approach: Systematic Review of Randomized Controlled Trials

Bhagvat Maheta[1], BS; Mouhamad Shehabat[1], BS; Ramy Khalil[1], BS; Jimmy Wen[1], BA; Muhammad Karabala[1], MS; Priya Manhas[1], MS; Ashley Niu[1], MS; Caroline Goswami[1], MS; Eldo Frezza[1], MBA, MD

California Northstate University College of Medicine, Elk Grove, CA, United States

Corresponding Author:
Eldo Frezza, MBA, MD
California Northstate University College of Medicine
9700 W Taron Dr
Elk Grove, CA, 95757
United States
Phone: 1 (916) 378 3491
Email: eldo.frezza@cnsuedu.onmicrosoft.com

Abstract

Background: As of 2022, patient adherence to postoperative guidelines can reduce the risk of complications by up to 52.4% following laparoscopic abdominal surgery. With the availability of various preoperative education interventions (POEIs), understanding which POEI results in improvement in patient outcomes across the procedures is imperative.

Objective: This study aims to determine which POEI could be the most effective on patient outcomes by systematically reviewing all the POEIs reported in the literature.

Methods: In total, 4753 articles investigating various POEIs (eg, videos, presentations, mobile apps, and one-on-one education or coaching) were collected from the PubMed, Embase, and Scopus databases. Inclusion criteria were adult patients undergoing abdominal laparoscopic surgery, randomized controlled trials, and studies that provided postoperative outcomes. Exclusion criteria included studies not published in English and with no outcomes reported. Title and abstract and full-text articles with POEI randomized controlled studies were screened based on the above criteria through a blinded, dual review using Covidence (Veritas Health Innovation). Study quality was assessed through the Cochrane Risk of Bias tool. The included articles were analyzed for educational content, intervention timing, intervention type, and postoperative outcomes appropriate for a particular surgery.

Results: Only 17 studies matched our criteria, with 1831 patients undergoing laparoscopic cholecystectomy, bariatric surgery (gastric bypass and gastric sleeve), and colectomy. In total, 15 studies reported a statistically significant improvement in at least 1 patient postoperative outcome. None of these studies were found to have an overall high risk of bias according to Cochrane standards. In total, 41% (7/17) of the included studies using direct individual education improved outcomes in almost all surgery types, while educational videos had the greatest statistically significant impact for anxiety, nausea, and pain postoperatively ($P<.01$). Direct group education demonstrated significant improvement in weight, BMI, exercise, and depressive symptoms in 33% (2/6) of the laparoscopic gastric bypass studies.

Conclusions: Direct education (individual or group based) positively impacts postoperative laparoscopic surgery outcomes.

Trial Registration: PROSPERO CRD42023438698; https://www.crd.york.ac.uk/prospero/display_record.php?RecordID=438698

KEYWORDS

patient; education; surgeries; laparoscopic; postoperative; outcomes; systematic review

XSL•FO
RenderX

Introduction

Background

Adherence to postoperative guidelines can impact the risk of complications by up to 52.4% after laparoscopic surgery, as shown by a 2022 prospective study [1]. The enhanced recovery after surgery (ERAS) protocol is a systematic approach to minimize postoperative pain, complications, and duration of hospital stay in patients undergoing surgical procedures [2-4]. The protocol, established by the ERAS Society, a not-for-profit multiprofessional multidisciplinary medical-academic society, aims to determine the optimal approach for delivering care to patients undergoing surgical procedures, with the goal of facilitating quicker postoperative recovery [4]. The ERAS protocol consists of patient education, preemptive analgesia, and other practical procedures to improve patient outcomes [4,5]. The ERAS protocol continues to be implemented in a wide range of surgical fields and has been shown to significantly decrease patient complications from 35.7% to 16.4% in a prospective cohort study in 2016 [6].

As the ERAS protocol demonstrates, patient compliance after laparoscopic abdominal surgery is essential to reducing postoperative complications [7]. Nonadherence to the recommendations set by the surgical team, such as medication consumption or general lifestyle suggestions, can have a significant impact on postoperative recovery and patient complications [1,8]. For instance, studies have documented that poor compliance in patients undergoing gastric banding surgeries results in poorer outcomes, including reduced weight loss postoperatively [9]. Educating patients on their surgical procedure, potential postoperative consequences, and preventive steps to minimize complications has improved patient compliance and reduced hospital stays following laparoscopic surgery [5,10]. These preemptive measures may play a profound role in mitigating the psychological burden of pain, anxiety, and fear during recovery [11].

Objectives

As the laparoscopic approach in surgical procedures is considered to be newer, the research following its patient education for postoperative care is limited [12]. To adapt to these novel approaches, modernized educational formats that have been shown to improve surgical patient outcomes include verbal, written, multimedia, mobile apps, and one-on-one or group counseling [11,13,14]. As intervention types continue to be explored, there is no gold standard preoperative education intervention (POEI) that has shown consistent improvement in patient outcomes across the procedures. The aim of this study is to systematically review the literature on POEIs to ascertain which POEI is more effective in improving outcomes in patients undergoing laparoscopic abdominal surgery.

Methods

Our review adhered to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) statement and EQUATOR (Enhancing the Quality and Transparency of Health Research) guidelines This protocol is registered in the PROSPERO database (CRD42023438698) [15].

Search Strategy

A systematic search was performed using 3 databases: PubMed, Embase, and Scopus. The search strategy was developed through an iterative process, using the methodology recommended by the Study Center of the German Society of Surgery, and included key terms related to laparoscopic abdominal surgeries and patient education [16]. The full search algorithm was used to identify potential articles in all 3 databases (Multimedia Appendix 1).

Article Selection

A total of 4753 articles investigating POEI were collected from the 3 databases after the removal of duplicates. Inclusion criteria were inclusion of a patient education intervention, adult patients undergoing abdominal laparoscopic surgery, randomized controlled trials (RCTs), and articles including postoperative outcomes (Figure 1). Exclusion criteria were articles not published in English, no patient education intervention included, nonabdominal laparoscopic procedures, pediatric patients, and articles without outcomes reported. Eligibility criteria are described using the population, intervention, comparator, outcomes, timing, and setting framework (Table 1). Title and abstract and full-text articles were screened using the inclusion and exclusion criteria via a blinded, dual review with 2 independent reviewers using Covidence (Veritas Health Innovation). If the decision was not unanimous, discrepancies were resolved after further review until a consensus was reached to determine final article inclusion or exclusion.
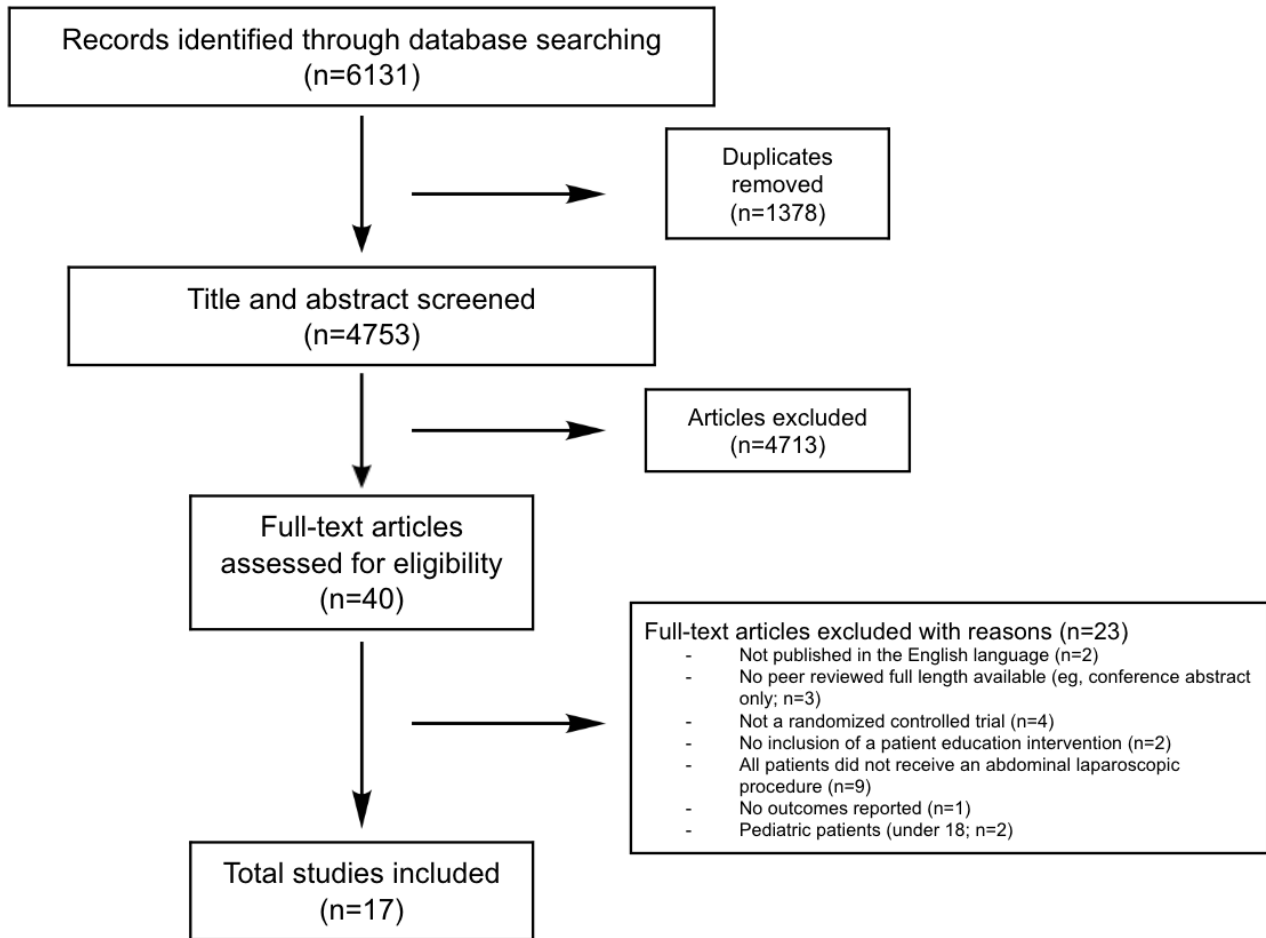
Figure 1. PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) flowchart illustrating the process of selecting articles.

Table 1. Population, intervention, comparator, outcomes, timing, and setting eligibility criteria.

Domain	Description

Population	• Inclusion
	  • Adults (ie, aged >18 years) undergoing an abdominal laparoscopic procedure
	
	• Exclusion
	  • Pediatric (ie, aged <18 years) patients
	  • Not an abdominal laparoscopic procedure

Intervention	• Inclusion
	  • Inclusion of a patient education intervention preoperatively including direct individual education (7 studies), direct group education (2 studies), educational video (4 studies), multimedia presentation (2 studies), and mobile app (2 studies). Some education interventions continued postoperatively.
	
	• Exclusion
	  • No inclusion of a patient education intervention

Comparator	• Randomized controlled trial • Usual preoperative care (eg, surgeon consult and required presurgical routine before bariatric surgery) was the control group. Some interventions included the usual preoperative care along with the education intervention • If applicable, preoperative measures were compared to postoperative measures in the intervention group and between intervention and control group

Outcomes	• Inclusion
	  • Outcomes analyzed
	    • Varied between intervention type (ie, nausea, pain, anxiety, fatigue, percentage of unexpected hospitalizations, quality of life, weight, caloric intake, complication rate, first exhaust time, first defecation time, intensive care unit admissions, BMI, exercise, depressive symptoms, Self-Care Mean Agency scores, Body Image Scale scores, and postoperative patient compliance)
	
	• Exclusion
	  • Articles without outcomes reported
	
	• Outcomes were categorized into 3 categories: patient discomfort, surgical outcomes, and quality of life

Timing	• Interventions with any follow-up period were included
Setting	• Any care setting (including in-patient clinics or outpatient and ambulatory care)

Data Extraction and Analysis and Study Quality

Study quality was assessed through the Cochrane Risk of Bias tool as all included studies were RCTs [17]. Each domain assessed (ie, sequence generation, allocation concealment, blinding of participants and personnel, blinding of outcome assessment, incomplete outcome data, selective outcome reporting, and other sources of bias) were evaluated as "high," "low," or "unclear" risk of bias. An abstraction form was developed through an iterative process to standardize the data extraction process (Multimedia Appendix 1). Data extraction was performed via a blinded, dual review with 2 independent reviewers on Covidence, with any discrepancies resolved after further review. Study variables analyzed in this systematic review included educational content, intervention timing and duration, intervention type, surgery type, and postoperative outcomes related to a particular surgery. POEIs included educational videos, multimedia presentations, mobile apps, direct individual education, and direct group education. All extracted data were compiled for analysis using Google Sheets (Google Drive; Google, LLC).

Results

Literature Selection

Using PubMed, Embase, and Scopus, the initial search yielded 6131 articles, of which 1378 (22.5%) duplicates were removed, leaving 4753 (77.5%) articles. Of the 4753 articles, during the title and abstract screening, we excluded 4713 (99.2%) and included 40 (0.8%). During the second phase, after a full-text review of the 40 articles, 17 (42.5%) were included in this systematic review. From the 17 studies that matched the inclusion criteria, 15 (88.2%) reported a statistically significant improvement in ≥1 patient postoperative outcomes (Table 2) [18-34].

Table 2. Summary of the included articles.

Study	Surgery type	Patient demographics	Intervention type (timing+duration)	Content and modality of patient education	Outcome

Abbasnia et al [18]	Laparoscopic cholecystectomy	145 patients (average age 43.54 years) with cholecystitis undergoing laparoscopic cholecystectomy	Educational video (animation 1 shown 2 hours before the surgery and animation 2 shown after the surgery; preoperative and postoperative)	• Content
				  • Animation 1 was used before surgery to reduce anxiety.
				    • "A 40-year-old man entered the operating room with a nurse. History-taking was carried out by an anesthesiologist, and the patient entered the operating room. The equipment and devices that were connected to the patient for monitoring and the method of general anesthesia were shown to the patient. After anesthesia, the recovery room and dressings of the operation site were displayed to the patient. Subsequently, the anatomy of the gall-bladder and its function, as well as the gallbladder surgery by laparoscopy, were demonstrated. Moreover, the patient observed the advantages of the laparoscopy method compared with open surgery."
				  • Animation 2 was used after surgery to manage pain.
				    • "A 40-year-old man was seated in a semisitting position, and the narrator states that this condition made it easier to breathe and reduce the pressure inside the abdomen, thereby reducing the pain. Deep breathing and effective coughing were displayed to the patient step by step, and an emphasis was put on the importance of causing faster CO_2 (carbon dioxide) gas release from the abdominal cavity and secretions. In addition, the method of fixing the surgical incision with the help of a hand or a small pillow, which helps to reduce pain during coughing, deep breathing, and movement in bed, was demonstrated to the patient. Thereafter, movement in bed was shown to prevent blood clots and encourage faster expulsion of gas from the abdominal cavity. These movements included exercising the sole of the feet, ankles, and thighs. Finally, the patient was shown how to get out of bed step by step."
				• Modality: virtual reality headsets
					There was a statistically significant improvement in preoperative state anxiety, the Bonferroni test for anxiety and patient distraction, pain reported by the VAS[a], and quality and intensity of subjective pain reported by the McGill Pain Questionnaire.

Study	Surgery type	Patient demographics	Intervention type (timing+duration)	Content and modality of patient education	Outcome

Bollschweil-er et al [20]	Laparoscop-ic cholecys-tectomy	76 patients (average age 55.16 years) with chole-cystitis un-dergoing la-paroscopic cholecystec-tomy	Multimedia presen-tation (preopera-tive education ses-sion was provided)	• Content
				  • Chapters with disease features, therapeutic alternatives, and the hospital stay, including a description of the operation itself. Certain pages are mandatory for the procurement of informed consent.
				
				• The chapters focus on the following:
				  • Why does the operation need to be performed? The risks of gallstones are presented.
				  • Preoperative examinations are described in detail. Complex examinations are presented with videos of each procedure.
				  • The chapter explaining that the operative procedure is divided into different sections. The cholecystectomy is clarified using an an-imated graphic of the operation with a parallel description of the procedure by the surgeon. For interested patients, video from an actual operation is also available.
				  • Potential complications from surgery or post-operative risks are related objectively, without focusing on emotional aspects. All risks are shown with rates of occurrence (as described in the literature) and a severity index. Each topic is shown on a navigation bar. By click-ing on a risk, background information appears.
				  • "The next 4 weeks" chapter includes practical information regarding the length of hospital stay, postoperative nutrition, and aspects of wound treatment for the first 4 weeks after the operation.
				
				• Modality: in-person with a combination of docu-ments, presentations, and videos
					There was a statistically sig-nificant improvement in perceived information; however, no statistically significant improvement was found in the Knowledge and Skills Acquisition for anxi-ety.

da Silva Schulz et al [21]	Laparoscop-ic cholecys-tectomy	43 patients (average age 69.35 years) with chole-cystitis un-dergoing la-paroscopic cholecystec-tomy	Direct individual education (ie, fourth, eighth, 12th, 18th, and 25th day postopera-tive)	• Content • "The experimental group received the 'Tele-phone Consultation' intervention from a re-searcher on the 4th (D4), 8th (D8), 12th (D12), 18th (D18) and 25th (D25) postopera-tive day; a total of 5 telephone consultations were attempted for each participant in the ex-perimental group. During the patient's follow-up, we used the guidelines developed by NIC standardization and a literature review (e.g., questions about mobility at home, food intake and wound care)." • Modality: telephone consultation intervention from a researcher	There was a statistically sig-nificant decrease from first to second evaluation and from first to third evaluation for loss of appetite with nausea in the experimental group. Both groups saw a significant decrease from first to third evaluation for pain and reduction was ob-served in the experimental group for postoperative ex-pectations.
Ster-giopoulou et al [30]	Laparoscop-ic cholecys-tectomy	60 patients (average age 51.5 years) with cholelithiasis undergoing laparoscopic cholecystec-tomy	Educational video (20-minute preoper-ative session was performed in the patient ward; infor-mation leaflet and MCD[b] was avail-able to patients for as long as they wished for)		Groups A, B, and C showed a statistically significant in-crease in knowledge score regarding laparoscopic cholecystectomy when compared to group D. Fur-thermore, there was a statis-tically significant decrease in postoperative pain and nausea during the first 16 hours across all intervention-al groups when compared to control.

Study	Surgery type	Patient demographics	Intervention type (timing+duration)	Content and modality of patient education	Outcome
				• Content • "Multimedia CD contains animation, narration, and photographs with six sections: fundamental elements of bile anatomy and physiology, aspects of the disease, details on the procedure and alternative options, possible complications and duration of hospital stay, and advice about recovery and life after laparoscopic cholecystectomy. Each section has pages, with a total of 28 pages, six of which contained extra photographs and animations. Each page had text fields and the same layout and background graphics. Content was selected in collaboration with surgeons and was written in simple Greek at a senior high school grade level. Leaflet and personalized presentation was developed using the exact contents of MCD." • Modality: multimedia CD with a laptop or leaflet	
Subirana Magdaleno et al [31]	Laparoscopic cholecystectomy	62 patients (average age 46.8 years) with cholelithiasis undergoing laparoscopic cholecystectomy	Direct individual education (15-30 days before the scheduled surgery; preoperative)	• Content • Intensified preoperative education with personalized oral and written information of the entire surgical and anesthetic process from a specialized nurse. They were informed about the following points of the process: type of operation, symptoms to be treated in the postoperative period, probable complications, wound care, and diet. • Modality: oral and informative brochure	No statistically significant differences were found in terms of pain levels or postoperative nausea, morbidity, percentage of unexpected hospitalizations, quality of life, or degree of satisfaction.
Toğaç and Yılmaz [32]	Laparoscopic cholecystectomy	124 patients (average age 48.72 years) with cholelithiasis undergoing laparoscopic cholecystectomy	Educational video (30- to 45-minute session in 4 stages; preoperative)	• Content • The first stage included providing information about cholelithiasis, including its causes, preoperative preparation, exercises, surgery, complications, wound care, nutrition, and medicines. Then, a video of laparoscopic cholecystectomy was played on a notebook. Finally, a leaflet about laparoscopic cholecystectomy was shown. In the second stage, knowledge about transfer to the operating room, its physical ambience and waiting room, surgical instruments, and explanations about anesthesia and surgical team were ensured. Information concerning what was expected of the patient before and during general anesthesia and how to join, recovery period, and how the patient is transferred were told. Besides, operating room pictures and surgical instruments were shown via the notebook. In the third stage, photographs and leaflets were used to train patients regarding postoperative care, both in the clinic and at home, such as how to mobilize and change dressing. In the fourth stage, any questions on different issues about laparoscopic cholecystectomy that were not mentioned by the researchers in patient's education were answered. Afterward, the patients were provided with a leaflet prepared by the researcher to reinforce what they had learned. • Modality: photographs, leaflets, and videos	

Study	Surgery type	Patient demographics	Intervention type (timing+duration)	Content and modality of patient education	Outcome
					There was a statistically significant decrease in the VAS-pain and VAS-nausea scores of the intervention group at postoperative hours 0, 2, 4, 6, and 8. In addition, the 24-hour VAS-pain score of the intervention group was significantly lower than that of the control group. The VAS-vomiting scores of the control group were higher than those of the intervention group at postoperative hours 6 and 8. Moreover, a significant difference was noted between the intervention and control groups in terms of changes in the VAS-pain, nausea, and vomiting scores over time. Before the intervention, there was no significant difference between the groups in terms of the STAI[c]-I scores; however, a statistically significant difference was determined before surgery and at the postoperative hour 24. There was also a significant difference between the groups in terms of the changes in the STAI-I scores over time. No significant difference was observed between the 2 groups in relation to the STAI-II scores obtained before the intervention, before surgery, and at postoperative hour 24. When the patient learning needs subscale scores were compared before education, there was a significant difference between the 2 groups in terms of activities of living, community and follow-up, feelings related to condition, and enhancing quality of life.
Udayasankar et al [33]	Laparoscopic cholecystectomy	50 patients (average age 40.14 years) undergoing laparoscopic cholecystectomy	Multimedia presentation (preoperative)	**Content** • Information about the surgical procedure and planned anesthetic was given via a PowerPoint presentation on a mobile phone or tablet. The information was a customized collection of graphical representations of surgical and anesthetic procedures that were limited but appropriate. • Modality: PowerPoint presentation on a mobile phone or tablet.	Statistically significant reduction was observed in anxiety in ERAS[d] group compared to control on the day before surgery and 6 hours postoperatively. In addition, there was a statistically significant reduction in hunger, thirst, fatigue, and overall perioperative experience.
	Laparoscopic gastric bypass				

Study	Surgery type	Patient demographics	Intervention type (timing+duration)	Content and modality of patient education	Outcome
Deniz Doğan and Arslan [22]		51 patients (average age 38.78 years) undergoing laparoscopic gastric bypass or sleeve gastrectomy	Mobile app (before the operation and first, second, and third months after the operation; preoperative and postoperative)	• Content • "The app includes care, nutrition, and exercise training for patients undergoing bariatric surgery, starting from the preoperative period, and covering the first 3 months after surgery, as well as a food and an exercise diary, and weight tracking interfaces that will help patients develop healthy lifestyle behaviors while adapting to their new lives. In addition to these, there is a live consultation where patients can communicate with researchers and interfaces with questionnaires and answers to frequently asked questions by patients." • Modality: mobile app and live consultation with researchers and interfaces	There was a statistically significant decrease in the first, second, and third month BMI (kg/m^2) mean scores of the experimental group; no statistically significant difference was found between Self-Care Mean Agency scores and mean scores of the Body Image Scale.
Kalarchian et al [23]	Laparoscopic gastric bypass	40 patients (average age 46.9 years) undergoing laparoscopic gastric bypass	Direct individual education (4 months of meal plans with monthly individual telephone calls with dietary coach consisting of 4 calls of 15 minute each; postoperative)	• Content • "That patient intervention included 4 monthly deliveries of portion controlled foods and a personalized menu plan for grocery store items. The participants also received menus that included 3 small meals and 1-2 snacks per day to maintain their portion sizes." • Modality: delivered meal and menu plans	There was a statistically significant improvement in improved weight trajectory and reduced caloric intake relative to a control group.
Kalarchian et al [24]	Laparoscopic gastric bypass	143 patients (average age 44.9 years) with obesity undergoing Roux-en-Y gastric bypass or laparoscopic adjustable gastric banding	Direct individual education (24 weekly contacts, including 12 face-to-face and 12 telephone sessions; postoperative)	• Content • "consisted of participation in any physician-supervised diet program, in promoting postsurgery weight loss and minimizing complications in comparison with usual care." • Modality: face-to-face and telephone education sessions	There was a statistically significant weight loss from enrollment to postintervention follow-up compared to control. However, at 24 months, the intervention group lost less compared to control.
Mata et al [26]	Laparoscopic gastric bypass	97 patients (average age 59.95 years) undergoing laparoscopic gastric bypass	Mobile app (education intervention was given preoperatively, daily during hospital stay, and at 4 weeks; postoperative)		There was no statistically significant improvement of this app on mean adherence to a bundle of 5 postoperative interventions (ie, mobilization, GI motility stimulation, breathing exercises, and consumption of oral liquids and nutritional drinks) that are dependent on patient participation.

Study	Surgery type	Patient demographics	Intervention type (timing+duration)	Content and modality of patient education	Outcome
				• Content: • "Postoperatively, participants randomized to the intervention group received a tablet computer (Apple iPad, Cupertino, USA) containing a novel mobile app. In brief, it included three sections: • (1) Milestones checklist: A checklist was always visible in the app's home page listing the day's recovery goals with a brief description of the requirements to achieve each one. Next to each description, a button icon was available for the patients to press when the milestone was achieved, and an overall score of the number of milestones achieved compared to the total number for that day was constantly visible in the app's main dash-board. • (2) Daily clinical questionnaires: A brief questionnaire assessing adherence and outcomes for the previous day. In contrast with the milestones checklist, which assessed progress for the present day, the clinical questionnaire assessed the previous day to give an overall summary. Items regarding bowel function and passage of gas were modified for the group of patients with a stoma (i.e., Did you pass stool? Or, did your bag have stool?). After submitting the information, the app displays a total score of the number of 'milestones met' (one for every enhanced recovery pathway element of interest they achieved), with a brief phrase of encouragement for goals that were achieved and advice for how to reach the mile-stones that were not yet achieved. Patients could review this feedback at any time in the app's home page. • (3) Education: access to educational material was always available in the app's home page. Accessing one of the modules produced a detailed description of the milestones for each postoperative day. An exact replica of the education booklet received in their preoperative visit was also included in the educational module." • Modality: novel mobile app on a tablet computer (Apple iPad)	
Nijamkin et al [28]	Laparoscopic gastric bypass	144 patients (mean age 44.8 years) with obesity undergoing Roux-en-Y gastric bypass surgery.			

Study	Surgery type	Patient demographics	Intervention type (timing+duration)	Content and modality of patient education	Outcome
			Direct group education (intervention was given 7 months postoperatively, education was received for 90 minutes every other week for a total of 6 sessions in small groups and frequent contact with a registered dietician; patients were re-assessed at 12 months following surgery)	• Content • "The first session of the education intervention addressed the daily meal planning guide and the maintenance diet. It provided recommendations on identifying and avoiding unhealthful foods, tips to promote proper nutrition by controlling portion size, new routine eating habits, and using an exchange list for weight management. This session was based on the Dietary Guidelines for Americans due to their reliable science-based advice on promoting health and lowering risk for chronic diseases via diet and physical activity. Daily energy intake was limited to 1,000-1,400 kcal and the minimum daily protein intake was 60-70 g with the goal of preserving lean tissue and prevent nutritional deficiencies. Additionally, the session also emphasized characteristics of typical Hispanic diets and the dietary changes that come with acculturation. The session also emphasized traits of typical Hispanic diets and the dietary changes that come with acculturation. Throughout the program, the importance of physical activity and a healthy diet were stressed in the postoperative life. The following session was designed to guide sedentary individuals to begin a regular exercise program and understanding how physical activity can aid in keeping weight off after bariatric surgery. Sessions 3 through 6 focused on emotional support interventions. These include behavior change strategies, stress relief without food, self-motivation, and relapse prevention. Overall, the intervention provided strategies that could facilitate change, increase self-esteem, help establish a consistent exercise program, recognize binge eating problems, and other motivational strategies." • Modality: comprehensive nutrition and lifestyle educational intervention with a registered dietician	At preoperative and 6 months postoperatively, there were no significant differences between intervention and control groups. However, at 12 months, both groups lost significant weight, with the intervention group losing significantly greater weight and significantly greater BMI reduction. Walking mean time, intensity of exercise, and involvement in physical activity was also significantly increased compared to control group at 12 months. No significant difference was found in daily energy intake and number of meals between groups.
Petasne Nijamkin et al [29]	Laparoscopic gastric bypass	144 patients (average age 44.5 years) with obesity undergoing laparoscopic Roux-en-Y gastric bypass	Direct group education (preoperative baseline, 6 months, and 12 months postoperatively)	• Content • "Those in the comprehensive support intervention received a total of 6 educational sessions focused on behavior change strategies and motivation along with nutrition counseling in groups of up to 12 participants, in addition to the postbariatric standard care. Sessions were conducted every other week in English or Spanish, according to participants' preference, in a nonjudgmental and nonconfrontational approach, expressing empathy and accepting participants' unwillingness to change. Group meetings started immediately after the randomization at 6 months after surgery. A psychologist and a registered dietitian guided the educational sessions. Every meeting lasted approximately 90 minutes." • Modality: educational support interventions	Statistically significant decrease of depressive symptoms and greater excess body weight loss were found 12 months after surgery in the interventional group.
	Laparoscopic sleeve gastrectomy				

Study	Surgery type	Patient demographics	Intervention type (timing+duration)	Content and modality of patient education	Outcome
Yayla and Menevşe [34]		66 patients (average age 37.09 years) with obesity undergoing laparoscopic sleeve gastrectomy	Educational video (3 times a day at 09 AM, 3 PM, and 9 PM the day before surgery [preoperative] and every postoperative day [days 1-5])	• Content • "The 9-minute animation education, which was prepared for postoperative sleeve gastrectomy patients, was written and directed by the researchers. The nurse explained how the deep breathing exercise was done using the benefits of respiration exercises (2 minutes) in the first part and the diaphragmatic breathing exercises and incentive spirometry (4 minutes) in the second part. In the third part, the researcher first showed how to do the exercises and then repeated the exercises with the patients (3 minutes)." • Modality: animated video sequences	There was a statistically significant difference between the mean postoperative fifth-day pain scores of the experimental and control groups. There was a statistically significant difference between the mean postoperative fifth-day scores of the experimental and control groups.
Li et al [25]	Laparoscopic colectomy	200 patients (average age 55.75 years) undergoing laparoscopic radical resection of colorectal cancer.	Direct individual education (unspecified preoperative or perioperative length, but education continued until discharge)	• Content • "The preoperative issues were communicated to the patients in ERAS group through face-to-face communication, written notice, or multimedia. Preoperative education includes anesthesia and surgical procedure, encouragement of early postoperative feeding and activity, promotion of pain management and respiratory therapy, presetting discharge criteria, and notification of follow-up and readmission pathway. The education continues through the entire process of the perioperative period until the patient is discharged." • Modality: face-to-face communication, written notice, or multimedia	There were statistically significant differences in complication rate, first exhaust time, and first defecation time between the 2 groups.
Molenaar et al [27]	Laparoscopic colectomy	251 patients (average age 70 years) with colorectal cancer undergoing colorectal cancer resection	Direct individual education (assessments were performed at baseline, preoperatively [approximately 4 weeks after baseline, except for CPET^e], and 8 weeks postoperatively. Surgical outcomes were evaluated 30 days after surgery)		There was a statistically significant reduction in the rate of severe complications and fewer medical complications observed in patients undergoing prehabilitation compared with standard care. Secondary outcomes regarding admission to intensive care unit were significantly reduced.

Study	Surgery type	Patient demo-graphics	Intervention type (timing+duration)	Content and modality of patient education	Outcome
				• Content • "The supervised training consisted of a 1-hour session of aerobic and strength exercises 3 times per week with resting days in between. The aerobic part, preferably performed on a bicycle, consisted of a high-intensity interval training using baseline CPET-derived variables. It consisted of 4 intervals of 2-minute high-intensity bouts conducted at 85% to 90% of peak power, alternated with 4 intervals of 4-minute moderate intensity bouts at 30% of peak power. Resistance exercise consisted of 2 series of 10 repetitions targeting major muscle groups. The intensity was set at 65% to 70% of the calculated baseline indirect 1 repetition maximum (1 RM). Professional strength equipment, body weight, elastic bands, or calibrated dumbbells were used. Based on nutritional assessment and dietary habits, a registered dietitian provided a full nutritional intervention. The program aimed to balance macronutrients and to achieve a daily amount of proteins of 1.5g per kg. Additionally, participants were provided with a whey protein supplement and were instructed to ingest 30g within 1 hour after the in-hospital training session and 1 hour before sleeping daily. Vitamin D and multivitamin supplements were also provided. Anxiety-coping interventions consisted of relaxation techniques and deep breathing exercises provided by psychology trained personnel in a 1-to-1 session. If a high risk of mental distress was detected by medical history or baseline scores of the Generalized Anxiety Disorder 7-item scale of 10 or higher or Patient Health Questionnaire 9-item of 15 or higher, participants were additionally referred to a medical psychologist. A smoking cessation program was offered, if indicated. The program consisted of individual counseling and nicotine replacement therapy." • Modality: 4-week multimodal personalized in-hospital supervised preoperative program	
Aydal et al [19]	Mixed laparoscopic abdominal surgery	135 patients (average age 43.96 years) undergoing laparoscopic cholecystectomy (n=77, 57%), appendectomy (n=27, 20%), hernia repair (n=15, 11.1%), colon resection (n=7, 5.2%), or gastrectomy (n=6, 4.5%)	Direct individual education (20- to 30-minute preoperative education session)	• Content • "For the standardization of patient education, an education booklet was prepared in consultation with academic nursing experts. The content included information on the operating room environment and surgical team, anesthesia process, postoperative care, and surgical process. The patient education was not given by the researchers in order to prevent research bias. To avoid any differences between the educators, all education was carried out by one voluntary service nurse and one operating room nurse. About two hours of education was given to the nurses to ensure they adopted a similar approach in patient education and to prevent bias caused by individual factors." • Modality: in-person by a voluntary service nurse and an operating room nurse	There was a statistically significant improvement in anxiety levels (Spielberger State-Trait Anxiety Inventory) directly after the intervention; however, no statistically significant difference was found in anxiety or pain (ie, VAS) levels in the postoperative period.

[a]VAS: Visual Analog Scale.

[b]MCD: multimedia CD.

[c]STAI: State-Trait Anxiety Inventory.

[d]ERAS: enhanced recovery after surgery.

[e]CPET: cardiopulmonary exercise test.

A total of 1831 patients undergoing laparoscopic cholecystectomy, bariatric surgery (ie, gastric bypass and gastric sleeve), and colectomy were included. There were a wide range of patient postoperative outcomes reported in the included studies, including nausea, complication rate, and weight loss (Table 3). These patient outcomes were categorized into *patient discomfort, surgical outcomes, and quality of life.* No included studies had an overall high risk of bias (Table 4). The PRISMA flowchart illustrates the process of selecting articles in Figure 1 [35].

Table 3. Patient education interventions and patient outcomes.

Intervention type (number of studies)	Surgery type	Patient outcomes
Direct individual education (n=7)	Laparoscopic cholecystectomy	• Nausea[a] • Pain[a] • Percentage of unexpected hospitalizations • Quality of life
Direct individual education (n=7)	Bariatric surgery: laparoscopic gastric bypass	• Weight[b] • Caloric intake[a]
Direct individual education (n=7)	Laparoscopic colectomy	• Complication rate[a] • First exhaust time[a] • First defecation time[a] • Intensive care unit admission[a]
Educational video (n=4)	Laparoscopic cholecystectomy	• Anxiety[b] • Pain[b] • Nausea[a]
Educational video (n=4)	Bariatric surgery: laparoscopic gastric sleeve	• Pain[b]
Direct group education (n=2)	Bariatric surgery: laparoscopic gastric bypass	• Weight[b] • BMI[b] • Exercise[b] • Depressive symptoms[b]
Multimedia presentation (n=2)	Laparoscopic cholecystectomy	• Anxiety[b] • Fatigue[b]
Mobile app (n=2)	Bariatric surgery: laparoscopic gastric bypass	• BMI[a] • Self-Care Mean Agency Scores • Body Image Scale scores • Postoperative patient compliance

[a]$P<.05$.

[b]$P<.01$.

Table 4. Risk of bias of the included studies.

Study	Sequence generation	Allocation concealment	Blinding of participants and personnel	Blinding of outcome assessors	Incomplete outcome data	Selective outcome reporting	Other source of bias
Abbasnia et al [18]	Low	Low	Unsure	Unsure	Low	Low	Low
Aydal et al [19]	High	High	High	High	High	Unsure	Low
Bollschweiler et al [20]	Low	Low	High	Low	Low	Low	Low
da Silva Schulz et al [21]	Low	Low	High	Low	High	Low	Low
Deniz Doğan and Arslan [22]	Low	High	High	Low	Low	Low	Low
Kalarchian et al [23]	Low	Low	High	Low	Low	Low	Low
Kalarchian et al [24]	High	High	High	Low	High	Low	Low
Li et al [25]	Unsure	Low	Low	Low	High	Unsure	Low
Mata et al [26]	Low	Low	High	Low	Low	Low	Low
Molenaar et al [27]	Low	Low	High	Low	Low	Low	Low
Nijamkin et al [28]	Low	Low	High	Low	Low	Low	Low
Petasne Nijamkin et al [29]	Low	Low	High	Low	Low	Low	Low
Stergiopoulou et al [30]	High	High	Low	Low	Low	Low	Low
Subirana Magdaleno et al [31]	High	High	High	High	Low	Low	Low
Toğaç and Yılmaz [32]	Low	Low	High	Low	Low	Low	Low
Udayasankar et al [33]	Low	Low	Low	Low	Low	Low	Low
Yayla and Menevşe [34]	Low	Low	High	Low	Low	Low	Low

Patient Discomfort

The *Patient Discomfort* category consisted of nausea, pain, and anxiety as patient's postoperative outcomes.

Nausea was significantly *(P<.05)* reduced in 2 intervention types. Following laparoscopic cholecystectomy, 43 patients who received direct individual education demonstrated a decrease in postoperative nausea, as measured by the Mini Nutritional Assessment test and the simplified Apfel scale [21]. Educational videos preoperatively also proved to decrease patients' reporting of nausea [30,32]. The educational video study by Toğaç and Yılmaz [32] was conducted on 124 patients, and the results were obtained using the Visual Analog Scale (VAS). The study by Stergiopoulou et al [30] was conducted on 60 patients, and the results were obtained using the Numerical Rating Scale ranging from 0 to 10. These 2 studies demonstrated statistical significance.

Pain was reduced postoperatively following 2 main interventions: direct individual education [21] and educational videos [18,30,32,34]. Direct individual education and educational videos displayed a statistically significant reduction in pain *(P<.05* and *P<.01*, respectively). The educational video study conducted by Abbasnia et al [18] included 145 patients, and results were obtained with the VAS and McGill Pain Questionnaire. Yayla and Menevşe [34] analyzed 66 patients via the VAS.

Anxiety was shown to be statistically decreased *(P<.01)* in POEIs that incorporated both educational videos [18,30] and presentations [33]. The educational video intervention used by Abbasnia et al [18] included 145 patients and collected data via the State-Trait Anxiety Inventory. While Stergiopoulou et al [30] collected data via the Amsterdam Preoperative Anxiety Scale and Information, Udayasankar et al [33] focused on 50 patients and reported a reduction in preoperative anxiety *(P=.003)* and postoperative anxiety after 6 hours *(P=.001)*.

Surgical Outcomes

Surgical outcomes category consisted of *percentage of unexpected hospitalizations, complication rate, intensive care unit (ICU) admission, first exhaust time,* and *first defecation time.* These varying patient outcomes provide insight into the patient's condition after surgery. *Percentage of unexpected hospitalizations* postoperatively was not significantly reduced when direct individual education intervention type was introduced [31]. *Complication rate, ICU admission, first exhaust time,* and *first defecation time* were all reduced postoperatively when patients were debriefed via individual education or coaching intervention [25,27]. Molenaar et al [27] included 251 patients and measured their results via Comprehensive Complication Index (*P*=.02). Li et al [25] obtained their results via observation indicators.

Quality of Life

Factors that affect *quality of life* were also considered to have a detrimental effect on a patient's long-term well-being. This category consisted of patient outcome factors such as *weight*, *BMI, caloric intake, exercise, depressive symptoms, fatigue, Self-Care Mean Agency scores*, and *Body Image Scale scores*. Patient *weight* was found to be statistically significantly decreased in both direct individual and group education POEIs *(P<.01)* [23,24,28,29]. Petasne Nijamkin et al [29] and Nijamkin et al [28] included 144 patients in a group education setting and reported weight loss in patients who received a POEI 12 months postoperatively (*P<.001*). Kalarchian et al [23,24], using a structured intervention, included 40 patients in a direct individual education method and had patients lose weight in the POEI arm at 4 months *(P=.003)*.

BMI was also found to be statistically significantly decreased in patients provided with direct group education or coaching *(P<.01)* [28] and in patients provided with a POEI using a mobile app *(P<.05)* [22]. Deniz Doğan and Arslan [22] included 51 patients in the mobile app intervention and recorded a reduced BMI *(P<.05)* in the first 3 months postoperatively.

Caloric intake was statistically decreased *(P<.05)* when patients received a direct individual education POEI [24]. An increase in *exercise* and a decrease in *depressivesymptoms* was found to be statistically significant *(P<.01)* when patients received a direct group education POEI [28,29]. In the study by Nijamkin et al [28], exercise was measured via the Short Questionnaire to Assess Health Enhancing Physical. In the study by Petasne Nijamkin et al [29], depression was measured via the Beck Depression Inventory questionnaire and demonstrated a decrease in depression incidence after 12 months *(P<.001)*.

Patient *fatigue* postoperatively was decreased when patients were given an educational presentation (*P*=.008) [33]. *Self-Care Mean Agency* scores and *Body Image Scale* scores had no significant increase in patients when provided with a POEI via a mobile app [22]. Deniz Doğan and Arslan [22] assessed *Self-Care Mean Agency scores* via a Likert-type Scale ranging from 0 to 4 with 35 items and *Body Image Scale* via a Likert-type scale ranging from 1 to 5 with 40 items. The direct group education intervention had a significant positive effect on *weight, BMI, exercise,* and *depressive symptoms* for patients

after laparoscopic bariatric surgery, suggesting potential future physician consideration as a preferred intervention choice [28,29].

Direct Individual and Direct Group Education

POEIs included direct individual education, direct group education, video education, multimedia presentations, and mobile apps. Direct individual education methods included supervised and personalized training programs lasting from 1 to 3 months postoperatively as well as nutritional guidance delivered by nurses and physicians via in-person sessions or telehealth [19,27]. POEIs that incorporated personalized training programs led to a decrease in the rate of severe complications (*P<.05*) and anxiety (*P<.05*) [19,27]. Direct individual education also involved personalized preoperative education brochures and advice given by the patient's surgeon, which reduced nausea postoperatively (*P<.05*) [21]. In addition, patients received postoperative portion-controlled meal deliveries and counseling over 4 weeks, provided by a registered dietitian, leading to weight loss (*P<.01*) and reduced caloric intake (*P<.05*) [24]. Direct group education POEIs for bariatric surgeries involved 4 to 6 comprehensive lifestyle and behavioral or motivational sessions with the research teams and registered dieticians, and it resulted in a significant decrease in weight, BMI, and depressive symptoms (*P<.01*) and a significant increase in exercise (*P<.01*) [28,29].

Educational Videos and Multimedia Presentations

Video education modalities involved short animations that served the goal of assuaging anxiety and operative fear. These animations were shown to the patient up to 3 times preoperatively and daily postoperatively for 1 week, which led to decreases in anxiety, pain, and nausea (*P<.01*) [18,34]. Likewise, preoperative multimedia presentations administered by registered nurses in the form of CDs and additional animations or brochures provided additional material to the patient before surgery, educating patients about the primary purpose of the surgery, preoperative examinations, and potential complications [20,30,33]. These POEIs led to statistically significant decreases in anxiety and fatigue in patients undergoing laparoscopic cholecystectomy (*P<.01*) [20,30,33].

Mobile App

Finally, mobile app POEIs developed by the research teams allowed patients to access educational resources on their own time, and it included information about postsurgical care, weight tracking, nutrition, and exercise regimens with recovery goals during the first 3 months of surgery [22,26]. Patients receiving this POEI experienced a decrease in BMI (*P<.05*); however, there was no statistically significant decrease in Self-Care Mean Agency scores, Body Image Scale scores, or postoperative patient compliance [22,26].

Discussion

Principal Findings

In this systematic review of RCTs, 17 studies were included, analyzing a total of 1831 patients. Approximately 38% (3/8) of the laparoscopic cholecystectomy studies tested an educational

video, which led to a statistically significant decrease in postoperative anxiety, pain, and nausea [18,30,32,34]. Nearly 50% (7/17) of the studies included in this review found that direct individual education improved outcomes for a variety of surgical procedures. Educational videos were most effective at reducing anxiety, nausea, and pain after surgery [18,30]. In about 33% (2/6) of the studies on laparoscopic gastric bypass, direct group education was shown to be effective in improving weight, BMI, exercise, and depressive symptoms. To decrease postsurgery complication rates, ICU admission, as well as first exhaust and defecation time for patients, direct individual education POEIs can be implemented before surgery [25,27].

Direct Individual Education and Direct Group Education

Direct individual education was the most effective POEI across all included procedure types: laparoscopic cholecystectomy, bariatric surgery, and colectomy [19,21,23-25,27,31]. Direct individual education has been shown to be effective in other surgical procedures as it provides patients with a personalized intervention tailored to their specific needs, which allows for patients to freely communicate and better understand their condition, treatment plan, and postoperative care [36,37]. For example, in hip or knee arthroplasty, patient education led to a significantly shorter length of stay ($P<.001$), suggesting that the effectiveness of one-on-one education or coaching found in this review is not only limited to abdominal laparoscopic procedures [10]. Direct group education had significantly improved outcomes across laparoscopic gastric bypass for weight, BMI, exercise, and depressive symptoms ($P<.01$) [28,29]. A group setting allows for bonding with others and building a support system, which can be a critical influence toward lifestyle changes necessary for improved outcomes after bariatric surgery [38,39]. In a prior systematic review analyzing POEIs in patients undergoing major surgery, the authors found that increased frequency of message exposure improved outcomes; however, this review suggests that the frequency of message exposure may not be as important as POEI type since all frequencies of one-on-one and group education or coaching POEIs had similar effectiveness across all procedure types [13]. Although the included studies incorporated in-person direct individual and group education, there are emerging technologies, such as virtual reality, that offer a new avenue to provide patients with individual or group education and coaching through a distanced modality [40,41].

Educational Videos and Multimedia Presentations

POEIs with educational videos or a presentation had the most statistically significant improvements on anxiety, pain, and fatigue after laparoscopic cholecystectomy ($P<.01$) [18,20,30,32-34]. The use of videos to educate patients allowed for increased standardization, cost-effectiveness, and accessibility due to the prerecorded nature of this intervention that can be applied broadly throughout multiple disciplines of medicine [42,43]. Incorporation of educational videos also allows for patients to receive the POEI from the convenience of their own home and reduces health care inequity related to access to transportation and proximity to the hospital [44-46]. Preoperative video education has been shown to improve

physical symptoms in the literature, as suggested by this review; however, this POEI has also been shown to improve knowledge, preparedness, satisfaction, psychological well-being, quality of life, and health care use in other surgery types [47]. Presentations allow for patients and caregivers to engage with the material and ask questions to better understand the content [48]. Both forms of POEI have demonstrated effectiveness in improving specific patient outcomes based on the content of the education; if the content is tailored toward focusing on additional aspects of the patient's postoperative recovery, more patient outcomes may be improved [49].

Mobile Apps

Newer forms of technology are also being tested for POEIs; however, more development is required within this area. In the 2 interventions that leveraged a mobile app for their POEI, there was improvement in BMI ($P<.01$); however, no statistically significant improvement was observed in Self-Care Mean Agency scores, Body Image Scale scores, or postoperative patient compliance [22,26]. Although there were limited significant improvements in patient outcomes while using mobile apps, coupling newer technology with aspects of tested POEIs, such as in-person education, educational videos, or presentations, may be a feasible option to optimize patient outcomes after laparoscopic abdominal surgery. Use of mobile apps in plastic surgery has been shown to significantly improve understanding of the surgery and postoperative patient compliance; this suggests that this modality of POEI has the potential to also improve patient quality outcomes for abdominal laparoscopic procedures if researched further [14]. Benefits of using technology through mobile apps, virtual reality, or artificial intelligence may provide increased accessibility to populations with limited mobility or access to clinical settings. These forms of communication can serve as a vital platform for enhancing the patient-physician rapport [50-53]. There are challenges associated with implementing these tools as the technology of these POEIs encompasses the associated expenses, accessibility, and maintenance. In addition, these platforms will require extensive training to ensure a user-friendly platform for different patient populations [54,55].

Limitations

This study can be considered in light of the following limitations. First, the tools to report patient outcomes were not consistent across the included studies, thus a meta-analysis or further synthesis is not possible. Second, only laparoscopic cholecystectomy, bariatric surgery (ie, gastric bypass and gastric sleeve), and colectomy surgeries were included because these were the only available surgery types with RCTs published regarding POEI. The heterogeneity of the included studies within the review provides a more diverse and holistic review of the published POEIs, which allows a narrative analysis of the pros and cons of individual interventions in each type of surgery included; however, it limits the ability to statistically compare the interventions to determine the most efficacious POEI in laparoscopic abdominal surgery. There are numerous types of abdominal laparoscopic surgeries where POEI may be beneficial, but they were not included in this systematic review due to a lack of published RCTs. Some included studies did not

report all aspects of the POEI, such as information regarding the process of developing the education content or the provision of training, supervision, or assistance with the POEI, including if there was any prototype testing or stakeholder feedback through co-design sessions. This limited the quantification of the effects of these features and their relationship with outcomes as there was significant variability in the published literature. Furthermore, the included studies may have been used for a more comprehensive, multidisciplinary intervention, confounding their direct impact on patient outcomes. However, this study provides informative insights into the current knowledge base pertaining to POEI and its applications in the field of abdominal laparoscopic surgeries.

Conclusions

This systematic review analyzed 17 RCTs that demonstrated the effect of POEIs on postoperative patient outcomes after abdominal laparoscopic surgeries. A total of 1831 patients undergoing laparoscopic cholecystectomy, bariatric surgery (ie, gastric bypass and gastric sleeve), or colectomy were included in this analysis, and 15 studies reported a statistically significant improvement in at least 1 patient postoperative outcome. Overall, direct individual education was the most effective POEI across all included procedure types; direct group education had the most significantly improved outcomes primarily among bariatric surgeries. POEIs that incorporated educational videos or presentations demonstrated the most statistically significant improvements in anxiety, pain, and fatigue following laparoscopic cholecystectomy. Direct education, whether individual or group based, has been shown to have a more positive impact on postoperative outcomes than newer POEIs, such as mobile apps. The practicality of this allows surgeons to personalize the health care delivered to each patient and provide the appropriate POEI based on which outcomes are more important for that patient. Future directions include expanding the use of POEIs to additional surgical procedures and further testing POEIs that incorporate more recent technology.

Conflicts of Interest

None declared.

Multimedia Appendix 1
Search strategy and abstraction guide.
[DOCX File , 213 KB - periop_v7i1e51573_app1.docx]

Multimedia Appendix 2
PRISMA Checklist.
[PDF File (Adobe PDF File), 284 KB - periop_v7i1e51573_app2.pdf]

References

1. Ceresoli M, Braga M. Reply to: early non compliance to enhanced recovery pathway might be an alert for underlying complications following colon surgery. Eur J Surg Oncol 2023 Feb;49(2):526. [doi: 10.1016/j.ejso.2022.10.010] [Medline: 37406080]
2. Gustafsson UO, Scott MJ, Hubner M, Nygren J, Demartines N, Francis N, et al. Guidelines for perioperative care in elective colorectal surgery: enhanced recovery after surgery (ERAS) society recommendations: 2018. World J Surg 2019 Mar;43(3):659-695. [doi: 10.1007/s00268-018-4844-y] [Medline: 30426190]
3. Stenberg E, Dos Reis Falcão LU, O'Kane M, Liem R, Pournaras DJ, Salminen P, et al. Guidelines for perioperative care in bariatric surgery: enhanced recovery after surgery (ERAS) society recommendations: a 2021 update. World J Surg 2022 Apr 04;46(4):729-751 [FREE Full text] [doi: 10.1007/s00268-021-06394-9] [Medline: 34984504]
4. Ljungqvist O, Scott M, Fearon KC. Enhanced recovery after surgery: a review. JAMA Surg 2017 Mar 01;152(3):292-298. [doi: 10.1001/jamasurg.2016.4952] [Medline: 28097305]
5. Cavallaro P, Bordeianou L. Implementation of an ERAS pathway in colorectal surgery. Clin Colon Rectal Surg 2019 Mar 28;32(2):102-108 [FREE Full text] [doi: 10.1055/s-0038-1676474] [Medline: 30833858]
6. Pisarska M, Pędziwiatr M, Małczak P, Major P, Ochenduszko S, Zub-Pokrowiecka A, et al. Do we really need the full compliance with ERAS protocol in laparoscopic colorectal surgery? A prospective cohort study. Int J Surg 2016 Dec;36(Pt A):377-382 [FREE Full text] [doi: 10.1016/j.ijsu.2016.11.088] [Medline: 27876677]
7. Pisarska M, Torbicz G, Gajewska N, Rubinkiewicz M, Wierdak M, Major P, et al. Compliance with the ERAS protocol and 3-year survival after laparoscopic surgery for non-metastatic colorectal cancer. World J Surg 2019 Oct 08;43(10):2552-2560. [doi: 10.1007/s00268-019-05073-0] [Medline: 31286185]
8. Kaye JD, Richstone L, Cho JS, Tai JY, Arrand J, Kavoussi LR. Patient noncompliance before surgery. BJU Int 2010 Jan;105(2):230-233. [doi: 10.1111/j.1464-410X.2009.08760.x] [Medline: 19624534]
9. Kim HJ, Madan A, Fenton-Lee D. Does patient compliance with follow-up influence weight loss after gastric bypass surgery? A systematic review and meta-analysis. Obes Surg 2014 Apr 26;24(4):647-651. [doi: 10.1007/s11695-014-1178-1] [Medline: 24464545]

XSL•FO

RenderX

10. Yoon RS, Nellans KW, Geller JA, Kim AD, Jacobs MR, Macaulay W. Patient education before hip or knee arthroplasty lowers length of stay. J Arthroplasty 2010 Jun;25(4):547-551. [doi: 10.1016/j.arth.2009.03.012] [Medline: 19427164]

11. Kruzik N. Benefits of preoperative education for adult elective surgery patients. AORN J 2009 Sep 06;90(3):381-387. [doi: 10.1016/j.aorn.2009.06.022] [Medline: 19735761]

12. Sadati L, Pazouki A, Mehdizadeh A, Shoar S, Tamannaie Z, Chaichian S. Effect of preoperative nursing visit on preoperative anxiety and postoperative complications in candidates for laparoscopic cholecystectomy: a randomized clinical trial. Scand J Caring Sci 2013 Dec 28;27(4):994-998. [doi: 10.1111/scs.12022] [Medline: 23350886]

13. Ronco M, Iona L, Fabbro C, Bulfone G, Palese A. Patient education outcomes in surgery: a systematic review from 2004 to 2010. Int J Evid Based Healthc 2012 Dec;10(4):309-323. [doi: 10.1111/j.1744-1609.2012.00286.x] [Medline: 23173656]

14. Noel W, Bosc R, Jabbour S, Kechichian E, Hersant B, Meningaud JP. Smartphone-based patient education in plastic surgery. Ann Plast Surg 2017 Dec;79(6):529-531. [doi: 10.1097/SAP.0000000000001241] [Medline: 29053521]

15. Bhagvat M, Mouhamad S, Ramy K, Jimmy W, Muhammad K, Priya M, et al. Effectiveness of patient education on laparoscopic surgery recovery and patient compliance: a systematic review of randomized controlled trials. National Institute for Health and Care Research. 2023. URL: https://www.crd.york.ac.uk/prospero/display_record.php?ID=CRD42023438698 [accessed 2024-04-29]

16. Kalkum E, Klotz R, Seide S, Hüttner FJ, Kowalewski K, Nickel F, et al. Systematic reviews in surgery-recommendations from the Study Center of the German Society of Surgery. Langenbecks Arch Surg 2021 Sep 15;406(6):1723-1731 [FREE Full text] [doi: 10.1007/s00423-021-02204-x] [Medline: 34129108]

17. Sterne JA, Savović J, Page MJ, Elbers RG, Blencowe NS, Boutron I, et al. RoB 2: a revised tool for assessing risk of bias in randomised trials. BMJ 2019 Aug 28;366:l4898 [FREE Full text] [doi: 10.1136/bmj.l4898] [Medline: 31462531]

18. Abbasnia F, Aghebati N, Miri HH, Etezadpour M. Effects of patient education and distraction approaches using virtual reality on pre-operative anxiety and post-operative pain in patients undergoing laparoscopic cholecystectomy. Pain Manag Nurs 2023 Jun;24(3):280-288. [doi: 10.1016/j.pmn.2022.12.006] [Medline: 36658058]

19. Aydal P, Uslu Y, Ulus B. The effect of preoperative nursing visit on anxiety and pain level of patients after surgery. J Perianesth Nurs 2023 Feb;38(1):96-101. [doi: 10.1016/j.jopan.2022.05.086] [Medline: 35970660]

20. Bollschweiler E, Apitzsch J, Obliers R, Koerfer A, Mönig SP, Metzger R, et al. Improving informed consent of surgical patients using a multimedia-based program? Results of a prospective randomized multicenter study of patients before cholecystectomy. Ann Surg 2008 Aug;248(2):205-211. [doi: 10.1097/SLA.0b013e318180a3a7] [Medline: 18650629]

21. da Silva Schulz R, Santana RF, Dos Santos CT, Faleiro TB, do Amaral Passarelles DM, Hercules ABS, et al. Telephonic nursing intervention for laparoscopic cholecystectomy and hernia repair: a randomized controlled study. BMC Nurs 2020 May 11;19(1):38 [FREE Full text] [doi: 10.1186/s12912-020-00432-y] [Medline: 32425692]

22. Deniz Doğan S, Arslan S. The effects of e-mobile training and consultancy services on bariatric surgery patients: a randomized clinical trial. Obes Surg 2022 Nov 01;32(11):3650-3657 [FREE Full text] [doi: 10.1007/s11695-022-06255-x] [Medline: 36045256]

23. Kalarchian MA, Marcus MD, Courcoulas AP, Cheng Y, Levine MD. Preoperative lifestyle intervention in bariatric surgery: a randomized clinical trial. Surg Obes Relat Dis 2016 Jan;12(1):180-187 [FREE Full text] [doi: 10.1016/j.soard.2015.05.004] [Medline: 26410538]

24. Kalarchian MA, Marcus MD, Courcoulas AP, Lutz C, Cheng Y, Sweeny G. Structured dietary intervention to facilitate weight loss after bariatric surgery: a randomized, controlled pilot study. Obesity (Silver Spring) 2016 Sep 28;24(9):1906-1912 [FREE Full text] [doi: 10.1002/oby.21591] [Medline: 27466039]

25. Li Q, Du L, Lu L, Tong Y, Wu S, Yang Y, et al. Clinical application of enhanced recovery after surgery in perioperative period of laparoscopic colorectal cancer surgery. J Laparoendosc Adv Surg Tech A 2019 Feb;29(2):178-183. [doi: 10.1089/lap.2018.0708] [Medline: 30614769]

26. Mata J, Pecorelli N, Kaneva P, Moldoveanu D, Gosselin-Tardiff A, Alhashemi M, et al. A mobile device application (app) to improve adherence to an enhanced recovery program for colorectal surgery: a randomized controlled trial. Surg Endosc 2020 Feb 13;34(2):742-751. [doi: 10.1007/s00464-019-06823-w] [Medline: 31087175]

27. Molenaar CJ, Minnella EM, Coca-Martinez M, Ten Cate DW, Regis M, Awasthi R, PREHAB Study Group. Effect of multimodal prehabilitation on reducing postoperative complications and enhancing functional capacity following colorectal cancer surgery: the prehab randomized clinical trial. JAMA Surg 2023 Jun 01;158(6):572-581. [doi: 10.1001/jamasurg.2023.0198] [Medline: 36988937]

28. Nijamkin MP, Campa A, Sosa J, Baum M, Himburg S, Johnson P. Comprehensive nutrition and lifestyle education improves weight loss and physical activity in Hispanic Americans following gastric bypass surgery: a randomized controlled trial. J Acad Nutr Diet 2012 Mar;112(3):382-390. [doi: 10.1016/j.jada.2011.10.023] [Medline: 22717198]

29. Petasne Nijamkin M, Campa A, Samiri Nijamkin S, Sosa J. Comprehensive behavioral-motivational nutrition education improves depressive symptoms following bariatric surgery: a randomized, controlled trial of obese Hispanic Americans. J Nutr Educ Behav 2013 Nov;45(6):620-626. [doi: 10.1016/j.jneb.2013.04.264] [Medline: 23819903]

30. Stergiopoulou A, Birbas K, Katostaras T, Mantas J. The effect of interactive multimedia on preoperative knowledge and postoperative recovery of patients undergoing laparoscopic cholecystectomy. Methods Inf Med 2007 Jan 20;46(4):406-409. [doi: 10.1160/me0406] [Medline: 17694232]

31. Subirana Magdaleno H, Caro Tarragó A, Olona Casas C, Díaz Padillo A, Franco Chacón M, Vadillo Bargalló J, et al. Valoración del impacto de la educación preoperatoria en la colecistectomía laparoscópica ambulatoria. Ensayo prospectivo aleatorizado doble ciego. Cir Esp (Engl Ed) 2018 Feb;96(2):88-95. [doi: 10.1016/j.ciresp.2017.10.002] [Medline: 29224843]

32. Toğaç HK, Yılmaz E. Effects of preoperative individualized audiovisual education on anxiety and comfort in patients undergoing laparoscopic cholecystectomy: randomised controlled study. Patient Educ Couns 2021 Mar;104(3):603-610. [doi: 10.1016/j.pec.2020.08.026] [Medline: 32933794]

33. Udayasankar M, Udupi S, Shenoy A. Comparison of perioperative patient comfort with 'enhanced recovery after surgery (ERAS) approach' versus 'traditional approach' for elective laparoscopic cholecystectomy. Indian J Anaesth 2020;64(4):316. [doi: 10.4103/ija.ija_782_19]

34. Yayla A, Menevşe Ş. Animation education program applied to laparoscopic sleeve gastrectomy patients effect on patient care results: a randomized controlled trial. Clin Nurs Res 2023 Jan;32(1):126-137. [doi: 10.1177/10547738221112754] [Medline: 36000187]

35. Henderson LK, Craig JC, Willis NS, Tovey D, Webster AC. How to write a Cochrane systematic review. Nephrology (Carlton) 2010 Sep;15(6):617-624. [doi: 10.1111/j.1440-1797.2010.01380.x] [Medline: 20883282]

36. Díaz-Cambronero Ó, Mazzinari G, Errando CL, Garutti I, Gurumeta AA, Serrano AB, Reducing the Incidence of Post Operative Residual Curarization Zero investigators. An educational intervention to reduce the incidence of postoperative residual curarisation: a cluster randomised crossover trial in patients undergoing general anaesthesia. Br J Anaesth 2023 Sep;131(3):482-490. [doi: 10.1016/j.bja.2023.02.031] [Medline: 37087332]

37. Harris EP, MacDonald DB, Boland L, Boet S, Lalu MM, McIsaac DI. Personalized perioperative medicine: a scoping review of personalized assessment and communication of risk before surgery. Can J Anaesth 2019 Sep 25;66(9):1026-1037. [doi: 10.1007/s12630-019-01432-6] [Medline: 31240608]

38. Müller A, Hase C, Pommnitz M, de Zwaan M. Depression and suicide after bariatric surgery. Curr Psychiatry Rep 2019 Aug 13;21(9):84. [doi: 10.1007/s11920-019-1069-1] [Medline: 31410656]

39. Mauro MF, Papelbaum M, Brasil MA, Carneiro JR, Coutinho ES, Coutinho W, et al. Is weight regain after bariatric surgery associated with psychiatric comorbidity? A systematic review and meta-analysis. Obes Rev 2019 Oct 19;20(10):1413-1425. [doi: 10.1111/obr.12907] [Medline: 31322316]

40. van der Kruk SR, Zielinski R, MacDougall H, Hughes-Barton D, Gunn KM. Virtual reality as a patient education tool in healthcare: a scoping review. Patient Educ Couns 2022 Jul;105(7):1928-1942. [doi: 10.1016/j.pec.2022.02.005] [Medline: 35168856]

41. Pandrangi VC, Gaston B, Appelbaum NP, Albuquerque FC, Levy MM, Larson RA. The application of virtual reality in patient education. Ann Vasc Surg 2019 Aug;59:184-189. [doi: 10.1016/j.avsg.2019.01.015] [Medline: 31009725]

42. Kim S, Ju MK, Son S, Jun S, Lee SY, Han CS. Development of video-based educational materials for kidney-transplant patients. PLoS One 2020 Aug 3;15(8):e0236750 [FREE Full text] [doi: 10.1371/journal.pone.0236750] [Medline: 32745145]

43. Farag M, Bolton D, Lawrentschuk N. Use of YouTube as a resource for surgical education-clarity or confusion. Eur Urol Focus 2020 May 15;6(3):445-449. [doi: 10.1016/j.euf.2019.09.017] [Medline: 31606471]

44. Lee TC, Kaiser TE, Alloway R, Woodle ES, Edwards MJ, Shah SA. Telemedicine based remote home monitoring after liver transplantation: results of a randomized prospective trial. Ann Surg 2019 Sep;270(3):564-572. [doi: 10.1097/SLA.0000000000003425] [Medline: 31356267]

45. Nandra K, Koenig G, DelMastro A, Mishler EA, Hollander JE, Yeo CJ. Telehealth provides a comprehensive approach to the surgical patient. Am J Surg 2019 Sep;218(3):476-479. [doi: 10.1016/j.amjsurg.2018.09.020] [Medline: 30253859]

46. Eruchalu CN, Bergmark RW, Smink DS, Tavakkoli A, Nguyen LL, Bates DW, et al. Demographic disparity in use of telemedicine for ambulatory general surgical consultation during the COVID-19 pandemic: analysis of the initial public health emergency and second phase periods. J Am Coll Surg 2022 Feb 01;234(2):191-202. [doi: 10.1097/XCS.0000000000000030] [Medline: 35213441]

47. Tom K, Phang PT. Effectiveness of the video medium to supplement preoperative patient education: a systematic review of the literature. Patient Educ Couns 2022 Jul;105(7):1878-1887. [doi: 10.1016/j.pec.2022.01.013] [Medline: 35101307]

48. Wainwright TW. Consensus statement for perioperative care in total hip replacement and total knee replacement surgery: enhanced recovery after surgery (ERAS®) society recommendations. Acta Orthop 2020 Jun 14;91(3):363 [FREE Full text] [doi: 10.1080/17453674.2020.1724674] [Medline: 32056486]

49. Koet LL, Kraima A, Derksen I, Lamme B, Belt EJ, van Rosmalen J, et al. Effectiveness of preoperative group education for patients with colorectal cancer: managing expectations. Support Care Cancer 2021 Sep 02;29(9):5263-5271. [doi: 10.1007/s00520-021-06072-5] [Medline: 33651182]

50. De La Cruz Monroy MF, Mosahebi A. The use of smartphone applications (apps) for enhancing communication with surgical patients: a systematic review of the literature. Surg Innov 2019 Apr 02;26(2):244-259. [doi: 10.1177/1553350618819517] [Medline: 30602332]

51. Timmers T, Janssen L, van der Weegen W, Das D, Marijnissen W, Hannink G, et al. The effect of an app for day-to-day postoperative care education on patients with total knee replacement: randomized controlled trial. JMIR Mhealth Uhealth 2019 Oct 21;7(10):e15323 [FREE Full text] [doi: 10.2196/15323] [Medline: 31638594]

52. Helm JM, Swiergosz AM, Haeberle HS, Karnuta JM, Schaffer JL, Krebs VE, et al. Machine learning and artificial intelligence: definitions, applications, and future directions. Curr Rev Musculoskelet Med 2020 Feb 25;13(1):69-76 [FREE Full text] [doi: 10.1007/s12178-020-09600-8] [Medline: 31983042]
53. Yeung AW, Tosevska A, Klager E, Eibensteiner F, Laxar D, Stoyanov J, et al. Virtual and augmented reality applications in medicine: analysis of the scientific literature. J Med Internet Res 2021 Feb 10;23(2):e25499 [FREE Full text] [doi: 10.2196/25499] [Medline: 33565986]
54. Baniasadi T, Ayyoubzadeh SM, Mohammadzadeh N. Challenges and practical considerations in applying virtual reality in medical education and treatment. Oman Med J 2020 May 19;35(3):e125 [FREE Full text] [doi: 10.5001/omj.2020.43] [Medline: 32489677]
55. Coburn JQ, Freeman I, Salmon JL. A review of the capabilities of current low-cost virtual reality technology and its potential to enhance the design process. J Comput Inf Sci Eng 2017;17(3):031013. [doi: 10.1115/1.4036921]

Abbreviations

EQUATOR: Enhancing the Quality and Transparency of Health Research
ERAS: enhanced recovery after surgery
ICU: intensive care unit
POEI: preoperative education intervention
PRISMA: Preferred Reporting Items for Systematic Reviews and Meta-Analyses
RCT: randomized controlled trial
VAS: Visual Analog Scale

XSL·FO
RenderX

<u>Original Paper</u>

A Novel Digital Health Platform With Health Coaches to Optimize Surgical Patients: Feasibility Study at a Large Academic Health System

Stephen Andrew Esper[1*], MD, MBA; Jennifer Holder-Murray[2*], MD; Katie Ann Meister[1*], BS, CPM; Hsing-Hua Sylvia Lin[3], MS, PhD; David Kojo Hamilton[4], MD; Yram Jan Groff[5], MD; Brian Scott Zuckerbraun[2], MD; Aman Mahajan[1], MD, MBA, PhD

[1]Department of Anesthesiology and Perioperative Medicine, University of Pittsburgh Medical Center, Pittsburgh, PA, United States

[2]Department of Surgery, University of Pittsburgh Medical Center, Pittsburgh, PA, United States

[3]Department of Anesthesiology and Perioperative Medicine, University of Pittsburgh, Pittsburgh, PA, United States

[4]Department of Neurosurgical Surgery, University of Pittsburgh Medical Center, Pittsburgh, PA, United States

[5]Department of Orthopedic Surgery, University of Pittsburgh School of Medicine, Pittsburgh, PA, United States

[*]these authors contributed equally

Corresponding Author:
Stephen Andrew Esper, MD, MBA
Department of Anesthesiology and Perioperative Medicine
University of Pittsburgh Medical Center
A-1305 Scaife Hall
3550 Terrace Street
Pittsburgh, PA, PA/15213
United States
Phone: 1 412 647 2994
Fax: 1 412 647 2993
Email: espersa@upmc.edu

Abstract

Background: Pip is a novel digital health platform (DHP) that combines human health coaches (HCs) and technology with patient-facing content. This combination has not been studied in perioperative surgical optimization.

Objective: This study's aim was to test the feasibility of the Pip platform for deploying perioperative, digital, patient-facing optimization guidelines to elective surgical patients, assisted by an HC, at predefined intervals in the perioperative journey.

Methods: We conducted an institutional review board–approved, descriptive, prospective feasibility study of patients scheduled for elective surgery and invited to enroll in Pip from 2.5 to 4 weeks preoperatively through 4 weeks postoperatively at an academic medical center between November 22, 2022, and March 27, 2023. Descriptive primary end points were patient-reported outcomes, including patient satisfaction and engagement, and Pip HC evaluations. Secondary end points included mean or median length of stay (LOS), readmission at 7 and 30 days, and emergency department use within 30 days. Secondary end points were compared between patients who received Pip versus patients who did not receive Pip using stabilized inverse probability of treatment weighting.

Results: A total of 283 patients were invited, of whom 172 (60.8%) enrolled in Pip. Of these, 80.2% (138/172) patients had ≥1 HC session and proceeded to surgery, and 70.3% (97/138) of the enrolled patients engaged with Pip postoperatively. The mean engagement began 27 days before surgery. Pip demonstrated an 82% weekly engagement rate with HCs. Patients attended an average of 6.7 HC sessions. Of those patients that completed surveys (95/138, 68.8%), high satisfaction scores were recorded (mean 4.8/5; n=95). Patients strongly agreed that HCs helped them throughout the perioperative process (mean 4.97/5; n=33). The average net promoter score was 9.7 out of 10. A total of 268 patients in the non-Pip group and 128 patients in the Pip group had appropriate overlapping distributions of stabilized inverse probability of treatment weighting for the analytic sample. The Pip cohort was associated with LOS reduction when compared to the non-Pip cohort (mean 2.4 vs 3.1 days; median 1.9, IQR 1.0-3.1 vs median 3.0, IQR 1.1-3.9 days; mean ratio 0.76; 95% CI 0.62-0.93; *P*=.009). The Pip cohort experienced a 49% lower risk of 7-day readmission (relative risk [RR] 0.51, 95% CI 0.11-2.31; *P*=.38) and a 17% lower risk of 30-day readmission (RR

0.83, 95% CI 0.30-2.31; *P*=.73), though these did not reach statistical significance. Both cohorts had similar 30-day emergency department returns (RR 1.06, 95% CI 0.56-2.01, *P*=.85).

Conclusions: Pip is a novel mobile DHP combining human HCs and perioperative optimization content that is feasible to engage patients in their perioperative journey and is associated with reduced hospital LOS. Further studies assessing the impact on clinical and patient-reported outcomes from the use of Pip or similar DHPs HC combinations during the perioperative journey are required.

Introduction

The annual surgical volume in the United States is estimated at 48.4 million procedures [1]. Though heart disease and stroke may be the 2 leading causes of worldwide mortality (25% or 15 million deaths) [2,3], before the SARS-CoV-2 pandemic, postoperative surgical mortality was the third leading contributor to death in the United States [2]. Furthermore, the occurrence of postoperative 30-day complications is expected to rise to 15% among all patients and cost over US $11,000 per case, or US $31.35 billion nationally, on an annual basis [4,5]. Improving surgical quality of care to reduce mortality, complications, readmissions, and emergency department (ED) visits represents an enormous opportunity for the health care system. To reduce surgical complications and improve postoperative outcomes, focus has shifted to optimizing patients preoperatively and postoperatively through strategies such as prehabilitation, improvement in medical comorbidity, and enhanced recovery after surgery protocols [6]. Because mobile and wireless technologies have become increasingly accessible and capable on a global scale [7], digitization of protocols and other health interventions is being developed as a means to improve quality of care while reducing cost.

The field of digital health has grown over the past several years with advances in digital health platforms (DHPs) or telemedicine services, which have allowed deployment in select patient populations to improve chronic health conditions [8]. Several mobile apps have been developed and used as tools to help provide perioperative instructions as well as protocol guidance for patients. Feasibility studies have shown these DHP are convenient for patients to use in orthopedic surgery [9,10] and gastrointestinal surgery [11-13]. Yet, outcomes results have been mixed [14,15] or not yet studied to date. Furthermore, the DHP content is often narrow and applied to one surgery type or a specific problem, such as activity or pain management, rather than more holistic prehabilitation and curated to each patient's needs based on patient comorbidity, activity level or ability, or nutritional status. Additionally, these DHPs did not use a one-on-one health coach (HC) in addition to the DHP to assist patients in achieving their goals. Finally, there continues to be a significant unmet need within health care to provide patients undergoing surgery with high-quality education, optimization, and care coordination throughout the complex preoperative and postoperative journey. Our hospital desired to pilot an integrated DHP with human digital HCs to improve patient preoperative optimization, surgical care coordination, and outcomes. To address this need, we partnered with a novel perioperative DHP company, Pip Care, to create digitized perioperative patient-facing optimization guidelines and surgical instructions for our surgical population. Pip simplifies the patient's health care plan into definable, easy-to-understand, and complete daily tasks and uses regular HC contact to improve outcomes, thus setting Pip apart from other DHPs. The aim of this study was to test the feasibility and acceptability of the novel Pip platform in deploying perioperative patient-facing optimization guidelines to elective surgical patients both digitally and with the assistance of an HC at predefined intervals in the perioperative journey and to report clinical outcomes and patient satisfaction with the use of Pip.

Methods

Overview

We partnered with Pip Care to develop perioperative content and test the deployment of Pip perioperatively. Pip is a HIPAA (Health Insurance Portability and Accountability Act)-compliant, personalized, and interactive DHP that functions on both iOS (Apple Inc) and Android (Google Inc) operating systems.

Design of Clinical Pathways and Pip Functionality

A multidisciplinary team in perioperative care at our academic medical center from anesthesiology, surgery, and nursing defined the pathway content and patient tasks to be digitized on the Pip platform. These perioperative clinical pathways included preoperative nutrition, preoperative fitness, smoking cessation, preparation for surgery, day-before surgery planning, home preparation, and recovery after surgery. Patients were digitally assigned the appropriate clinical pathways by the human HC following the initial HC-patient intake and the HC's review of the patient's comorbidities from the electronic medical record. The tasks were prompted to the patient at appropriate intervals. Certified human HCs employed by Pip Care received education regarding the clinical pathways and were trained to interact with the electronic medical record for data collection and communication. HCs were responsible for motivating patients to reach their pre- and postsurgery goals through at least weekly one-on-one video or audio sessions; during these sessions, HCs would also answer any questions, provide educational content, track patient-reported outcomes (PROs), communicate patient progress to the provider, and facilitate referrals and resources if needed, in coordination with the perioperative clinical team members (Table 1). In addition to HC follow-up, patients were invited to explore a host of educational multimedia resources on disease processes and why optimization of said diseases is important before surgery.

Pip contains 4 key features, which are represented by separate pages within the DHP user experience. The first is Pip My Plan, which displays the assigned personalized care plans and tasks by their HC (Figure 1). The second is Pip Appointments. Patients were asked to schedule weekly digital HC sessions through the Appointments page. The HC also populated the patient's surgery-related appointments into this section for easy patient viewing (Figure 2). Third, patients have access to unlimited engagement with their HC through the Pip Messages page (Figure 3). Finally, patients have further unlimited access to a library of health system-approved education content, including articles and videos, to assist with their surgery preparation and recovery (Figure 3).

Table 1. Pip health coach (HC) tasks.

Category and tasks	Task description
Referral management	
Review the EMR[a] Pip List for newly added patients.	HC reviews the EMR to identify and validate referred patients.
Referred patient data transfer	HC transcribes the appropriate patient information into the Pip database.
Pilot enrollment and activation	
Execute the enrollment conversion plan.	HC executes a time-cadence enrollment conversion plan until the patient has enrolled in the pilot study or until the enrollment conversion plan ends.
Execute the patient activation conversion plan.	HC executes a time-cadence activation conversion plan until the patient has scheduled an "Initial HC Session" or until the activation conversion plan ends.
Surgery coaching and care plan management	
Weekly health coaching sessions.	For an estimated 4 weeks before surgery and 4 weeks postsurgery, HC conducts 30-minute weekly coaching sessions with patients to assist with surgery preparation and recovery.
Coaching session documentation	HC documents "encounter notes" from each coaching session.
Coaching session scheduling	HC schedules the subsequent coaching session.
Midweek patient check-in	In between weekly sessions, the HC sends at least 1 message (in-app or SMS text message) to the patient.
Patient communication through the in-app message	HC responds to the patients' messages when they are received.
Distribution of surgery-related educational materials	HC sends patients applicable educational content on best practices for surgery preparation and recovery.
Patient care plan assignment and management	HC assigns and manages the patient's care plans, including fitness, nutrition, smoking cessation, and discharge planning.
Provider communication	
Weekly patient progress report sent through EMR Encounter Note	HC's encounter note in the EMR is sent to the clinical provider, detailing the patient's status and adherence to protocols.
EMR InBasket communication	When an HC receives an out-of-scope question from a patient or learns of an escalated clinical issue, the HC messages the provider through EMR InBasket to escalate the clinical issue.
Provider synchronization calls	HC participates in daily and weekly synchronization calls with the provider team to ensure good communication and proper workflows.
Care coordination	
Surgery-related appointments	HC reviews the EMR and ensures all surgery-related clinical appointments are properly displayed within the Pip app. The HC encourages attendance at these appointments through messaging and during coaching sessions.
Facilitating health system resources for patients	HC facilitates health system-specific surgery-related resources for the patient as needed.
Patient-reported outcome and satisfaction data collection	
Collecting patient satisfaction surveys	HC sends an anonymous patient satisfaction survey to patients.
Collecting PROs[b]	HC collects PROs upon the patient's completion of the pilot program.
Service recovery	
Digital platform trouble shooting	HC assists with any issues with the technology.

[a]EMR: electronic medical record.

[b]PRO: patient-reported outcome.

XSL•FO

RenderX

Figure 1. Screenshots of Pip with personalized protocols and daily tasks in My Plan.
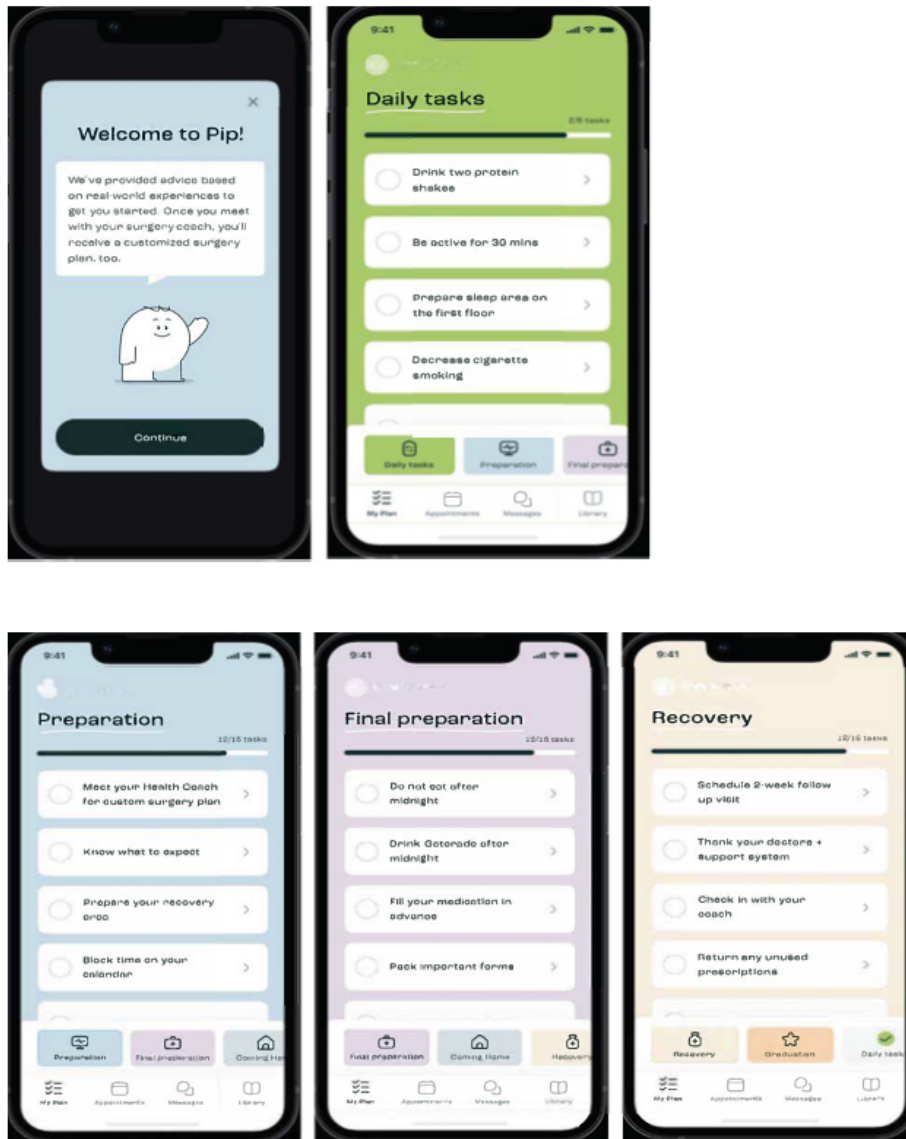

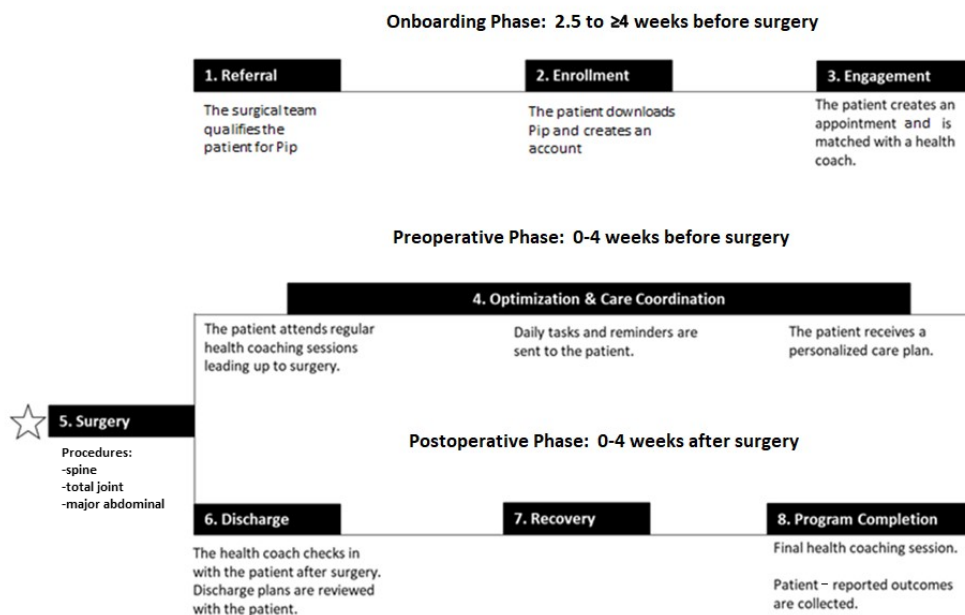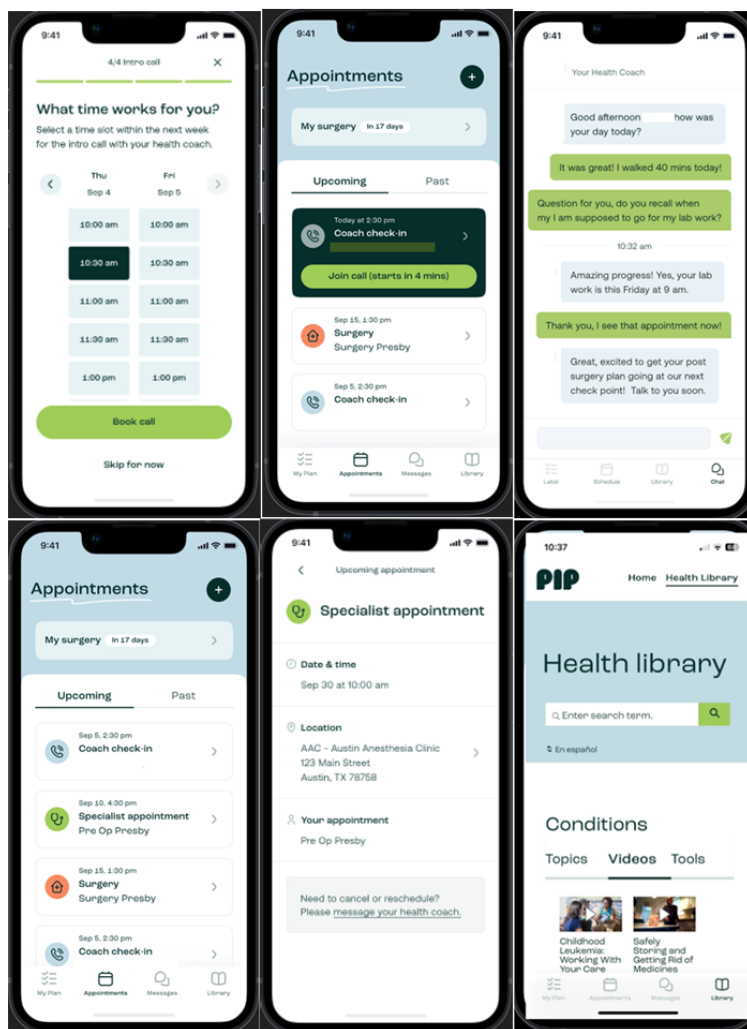**Figure 2.** Pip patient engagement map. HC: health coach.

Figure 3. Screenshot examples of the Pip Appointments section, messaging, and entry into the Pip Library.

Feasibility Study

This study is an institutional review board/quality improvement review committee–approved (ID 3949) descriptive and prospective feasibility study of patients scheduled for elective abdominal, spine (cervical, lumbar, thoracic, and combined), and total joint replacement (hip or knee) surgery, invited to enroll in Pip from 2.5 to 4 weeks preoperatively through 4 weeks postoperatively at a single academic medical center from November 22, 2022, to March 27, 2023. Inclusion criteria were being aged 18 years or older; ability to speak and understand English; scheduled elective abdominal, spine, or joint replacement surgery; having more than 1 comorbidity linked to increased surgery risk (eg, type 2 diabetes, being aged 70 years or older, having a BMI greater than 40 kg/m^2, high blood pressure, and smoking history); no recent hospitalization for medical comorbidity that may impact surgical timing, such as heart failure (in order to ensure surgical date was likely); daily access to a tablet or smartphone; and technological literacy (ability to navigate digital devices with oversight or perioperative team assistance). Exclusion criteria include surgery not scheduled, canceled or delayed, or a change in scheduled surgery type.

Patients were recruited continuously from our perioperative clinic until the desired pilot sample size of approximately 150 patients was reached. All patients received our standard perioperative risk assessment, optimization, and educational content from our perioperative clinic. After enrollment, patients downloaded and enrolled in Pip. Patients scheduled their first digital one-on-one session with the HC through the Pip platform after enrollment, and this first HC visit was typically scheduled within 1 week or less. HC visits were offered weekly preoperatively and weekly following hospital discharge. If at any time the patient desired to leave the study, they were able to withdraw (Figure 2).

The number of patients who were invited, enrolled, activated, and completed the program was collected. The number of health coaching sessions attended and the time from enrollment to surgery were collected. Patient-specific characteristics included age, institutional perioperative risk score (low being less than 2%, intermediate being between 2% and less than 5%, and high being 5% or more risk of mortality or major adverse cardiac or cerebrovascular events) [16], type of surgery, length of stay (LOS), readmission, and ED visits. Primary end points include patient satisfaction, patient engagement, and Pip HC evaluations. We used industry benchmarks to compare our DHP enrollment rate [17,18], surgery completion with enrollment [18], and

postsurgery engagement rates [17,18]. Patients' overall satisfaction was assessed by the topline patient satisfaction surveys with score ratings from 1 to 5, with 1 denoting the lowest satisfaction and 5 denoting the highest satisfaction [19]. Pip HCs were evaluated based on a scaled numerical response to the question, "How much do you agree with the statement: My Pip Health Coach Helped Me Prepare for and Recover from Surgery?" using a score rating scale of 1 to 5, with 1 denoting "strongly disagree" and 5 denoting "strongly agree." The Pip experience was evaluated for acceptability using the net promoter score with the question, "Using a scale of 1 to 10, how likely are you to recommend Pip to a friend or colleague?" with 1 denoting "least likely" and 10 denoting "most likely."

Secondary end points included LOS, 7- and 30-day readmission rates, and ED use within 30 days. In order to evaluate the effect of Pip, patients receiving the Pip program were compared with a non-Pip group of patients. This control group of patients included patients who were aged 18 years or older and underwent elective surgery of the same type from January 1, 2022, to December 31, 2022.

Statistical Analysis

The primary end points are descriptive. Secondary end points required further statistical analysis. Continuous variables were summarized using the mean (SD) or median (IQR) when appropriate. Categorical variables were summarized by frequencies and percentages. The chi-square test was used for differences in proportions for categorical variables, and the Student t test or nonparametric Kruskal-Wallis test was used to determine the differences in the distribution of continuous data between the Pip and non-Pip groups. Stabilized inverse probability of treatment weighting (SIPTW) was created to reduce selection bias and balance the patient characteristics (ie, age, procedures, and perioperative risk score) in the Pip and non-Pip groups [20,21]. A marginal structural model with log-linked gamma distribution and SIPTW was used to estimate the mean ratios of the LOS between the Pip and non-Pip groups.

Marginal structural models with log-binomial distribution and SIPTW were used to estimate the relative risk of 7-day hospital readmission, 30-day hospital readmission, and 30-day ED use [21]. All tests were two-sided and a P value of less than .05 was used to indicate statistical significance. SAS (version 9.4; SAS Institute) was used for statistical analyses.

Ethical Considerations

The study was granted a waiver of consent as the risk to the patient was considered to be minimal and was considered to be a quality improvement study. All patient participation was voluntary, and no patient received compensation.

Results

Engagement Outcomes

Out of 283 patients invited to participate in Pip, 172 (60.8%) were enrolled, compared to industry benchmarks (5%-30%). A total of 5 patients who enrolled were excluded from this analysis due to surgery delay, cancellation, or alternative surgery scheduled. Of those enrolled, 83.1% (143/172) had ≥1 HC session. Of the patients who had ≥1 HC session, 97.2% (138/142) proceeded to surgery, an improvement compared to industry benchmarks (90%-93%) [17,18]. After surgery, 70.3% (97/138) patients engaged with Pip postoperatively, compared to the industry benchmarks (31%-52%; Figure 4). Pip demonstrated an 82% weekly engagement rate, defined as repeat attendance at HC sessions. There was an average of 27 (range 7-108) days of lead time from enrollment to surgery, and patients attended an average of 6.7 (range 3-19) HC sessions. Pip received a total of 95 patient satisfaction survey submissions. Patients reported an overall high level of satisfaction based on the topline survey (mean 4.8/5; n=95; Table 2). Patients strongly agree that HC helped them throughout the perioperative process based on the Pip HC evaluation (mean 4.97/5; n=33). To measure acceptability, the net promotor score rating score was obtained; of the 33 respondents, the mean score was 9.7 out of 10.

Figure 4. Pip patient engagement map. *Data set does not include 2 patient referrals who were out of scope of pilot parameters. ** Exclusions to analysis are as follows: patient did not need surgery (n=1); patients referred for alternative lower-risk therapy (n=2); surgery delayed and patient rescheduled (n=1); surgery delayed and Pip could not access the patient's chart (n=1).
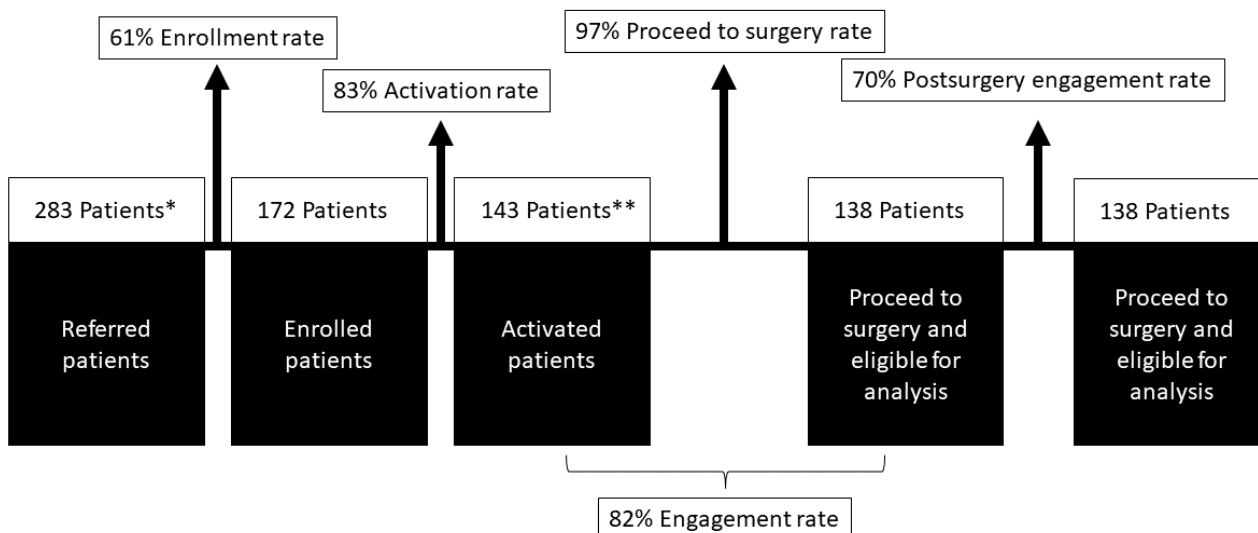
Table 2. Aggregate patient satisfaction scores (average score rating was 4.8 out of 5).

Score	Surveys completed (n=95), n (%)
1	0 (0)
2	1 (1)
3	1 (1)
4	16 (17)
5	77 (81)

Clinical Outcomes

There were a total of 367 patients in the non-Pip group and 138 patients in the Pip group. After creating SIPTW based on age, procedures, and perioperative risk score, a total of 268 patients in the non-Pip group and 128 patients in the Pip group had appropriate overlapping distributions of SIPTW for the analytic sample. Before SIPTW, age and preoperative risk score were shown to be significantly different between the Pip and non-Pip groups (Table S1 in Multimedia Appendix 1). Baseline patient characteristics weighted by SIPTW showed a balanced age, procedure type, and preoperative risk score between the 2 groups

(Table 3). The Pip cohort was associated with both mean and median reductions in LOS when compared to the non-Pip cohort (mean 2.4 vs 3.1; median 1.9 IQR 1.0-3.1 vs median 3.0, IQR 1.1-3.9). Pip was significantly associated with a 24% reduction in postoperative LOS (mean ratio 0.76; 95% CI 0.62-0.93; P=.009 Table 4). Pip care was associated with a 49% lower risk of 7-day readmission (relative risk [RR] 0.51; 95% CI 0.11-2.31; P=0.38) and a 17% lower risk of 30-day readmission (RR 0.83; 95% CI 0.30-2.31; P=.73), though not statistically significant. Pip and non-Pip groups had similar risk in 30-day ED returns (RR 1.06; 95% CI 0.56-2.01; P=.85).

Table 3. Weighted patient characteristics by Pip versus non-Pip.

Variable	Non-Pip (n=268; 68%)	Pip (n=128; 32%)	P value
Age (years)			.85
Mean (SD)	63.8 (13.1)	63.6 (10.7)	
Median (IQR)	66 (56-73)	65 (59-71)	
Minimum-maximum	19-88	20-84	
Sex, n (%)			.14
Female	155 (57.8)	64 (50)	
Male	113 (42.2)	64 (50)	
Race, n (%)			.78
White	235 (87.7)	114 (89.1)	
Black	25 (9.3)	11 (8.6)	
Other	4 (1.5)	3 (2.3)	
Unknown or declined	4 (1.5)	1 (0.78)	
Risk level, n (%)			.69
Low	224 (83.6)	109 (85.2)	
Intermediate	40 (14.9)	16 (12.5)	
High	4 (1.5)	3 (2.3)	
Procedure, n (%)			.99
Major abdominal	31 (11.6)	15 (11.7)	
Spine	69 (25.7)	35 (27.3)	
TJR[a] hip	75 (28)	36 (28.1)	
TJR knee	93 (34.7)	42 (32.8)	

[a]TJR: total joint replacement.

Table 4. Comparison of secondary end points between non-Pip and Pip patients using marginal structural models with stabilized inverse probability of treatment weighting (SIPTW).

Secondary end points	Non-Pip (n=268; 68%)	Pip (n=128; 32%)	P value
Length of stay (days)			.009
Mean (SD)	3.1 (2.8)	2.4 (2.4)	
Median (IQR)	2.9 (1.1-3.9)	1.9 (1.0-3.1)	
Minimum-maximum	0-27.8	0-14.2	
Mean ratio (95% CI)	Reference	0.76 (0.62-0.93)	
7-day readmission			.38
Patients, n (%)	9 (3.4)	2 (1.7)	
Relative risk (95% CI)	Reference	0.51 (0.11-2.31)	
30-day readmission			.73
Patients, n (%)	13 (4.9)	5 (4.1)	
Relative risk (95% CI)	Reference	0.83 (0.30-2.31)	
30-day emergency department return			.85
Patients, n (%)	26 (9.7)	13 (10.3)	
Relative risk (95% CI)	Reference	1.06 (0.56-2.01)	

Discussion

Primary Result and Comparison With Previous Work

Our results demonstrate that Pip, a novel mobile DHP that combines both human HCs and technology, is feasible to use to engage patients during their perioperative journey. Pip engagement was also associated with reduced hospital LOS. Of the patients who attended ≥1 HC session, over two-thirds completed the program, which is far better than industry benchmarks. As the mean age of our Pip cohort was 63 (range 20-84) years, this demonstrates great engagement and feasibility across many ages.

There are multiple DHPs that have been developed in recent years, some focusing on chronic medical conditions or symptom monitoring [8,22]. There are also other mobile DHPs that are designed to provide enhanced recovery after surgery protocol guidance, presurgical instructions, and patient adherence to said protocols to help improve outcomes for both patient and hospital [13,23-25]. However, this is one of the first perioperative DHPs to involve a human-HC interaction to help allay patients' anxiety, alleviate clinical and administrative burden, and digitize perioperative protocols and instructions, not only through the preoperative period but also in the postoperative setting.

Our primary outcomes focused on human-technology and human-human engagement [26], that is, how the user interacts with both the technology and the emotional response to the human interaction. The excellent short-term user experience patient satisfaction scores and net promotor scores demonstrate high patient satisfaction and the commercializability of the product. Over 95% (93/95) of patients were satisfied with Pip and would recommend it. Pip generated impressive patient satisfaction scores when discussing patient-HC interaction, and nearly all respondents agreed that they would refer a friend or colleague going through surgery to use Pip. Furthermore, the

patient capture rate and DHP use are far in excess of industry benchmarks. As 70% (97/138) of the patients who proceeded to surgery completed the program, this is also an advantage to health systems for cost reduction with shorter LOS and decreased complications with improved optimization.

Positive comments on the use of Pip in the perioperative journey supported that both the HC and the DHP, in concert with the HC, helped to relieve anxiety, hold patients accountable using encouragement, and empower patients to take responsibility for their care. These comments reflect observations that high-level engagement, representing a partnership for shared leadership, is very important [27]. Furthermore, the patients' desire to be not only heard (as a token of involvement) but listened to (reflecting a deeper conversation addressing the core issues at the center of the patient's thoughts) is essential to continued patient engagement with the platform [28].

An interesting finding was the significant LOS reduction with Pip use. While impressive, we acknowledge that this is a small cohort and the study was not powered for this outcome. Nevertheless, using a marginal structural model with SIPTW, the sample size is preserved close to the original data and produces an appropriate estimation of the main intervention effect while maintaining an appropriate type I error rate. Pip was significantly associated with a 24% reduction in postoperative LOS (mean ratio 0.76; 95% CI 0.62-0.93), and Pip was associated with 49% and 17% lower risk in readmissions at 7 and 30 days (though not statistically significant). Though we have matched for age, procedure, and perioperative risk score and feel that the likely effect is the Pip intervention, further studies powered for these outcomes are necessary. As all patients in the Pip and standard of care cohorts attended our perioperative risk stratification and optimization clinic, these findings may be even more pronounced when a robust perioperative clinic is not readily available in smaller health systems or when patients have limited access to care.

Furthermore, we feel that the personalized contact from the HC offers advantages over other content-only DHPs. The DHP and HC combination, personalized optimization protocols, and high satisfaction correlate with positive patient outcomes. Further studies examining the type and frequency of Pip DHP or HC interaction based on patient comorbidity would offer interesting insights into more widespread deployment of the DHP and HC resources for those most likely to benefit.

Limitations

This study has several limitations. Because all patients were computer literate and had ready access to smartphones, there may have been a participation bias that influenced this feasibility study. Adding a web-based interface or the ability to add a caregiver could reduce the technological barrier for some patients. Additionally, those patients who chose to participate in Pip may have contributed to selection bias for patients who are more motivated to optimize before surgery. Our patient satisfaction data are limited to descriptive statistics, and further information will be collected in the future. Additionally, the satisfaction question assessing the HC was framed positively, and this may have skewed the patient rating. Regarding secondary end points, while the LOS reduction is significant and the readmission rate reduction trends reasonably, this study was neither designed nor powered for these outcomes. Additionally, because many referrals took place within the health system network, there may have been other factors contributing to these outcomes. Further study is required with a larger cohort designed to examine both clinical outcomes and PROs.

Conclusions

In summary, Pip is a novel mobile health care digital platform that combines human HCs and preoperative optimization content that is feasible to engage surgical patients during their perioperative journey, with high patient enrollment and very high engagement with the HCs. Patient satisfaction was high for those participating in Pip. When compared to a similar cohort without Pip, surgical patients that participated in Pip experienced a reduced LOS in our feasibility study. Further studies are required to better assess the clinical and PRO impacts of the use of Pip or similar DHPs combined with HCs during the perioperative journey, as the use of an HC may offer improved patient-centered outcomes.

Multimedia Appendix 1
Baseline characteristics and outcomes before weighting by Pip versus non-Pip.
[DOCX File , 16 KB - periop_v7i1e52125_app1.docx]

References

1. Hall MJ, Schwartzman A, Zhang J, Liu X. Ambulatory surgery data from hospitals and ambulatory surgery centers: United States, 2010. Natl Health Stat Report 2017(102):1-15 [FREE Full text] [Medline: 28256998]
2. Nepogodiev D, Martin J, Biccard B, Makupe A, Bhangu A, National Institute for Health Research Global Health Research Unit on Global Surgery. Global burden of postoperative death. Lancet 2019;393(10170):401 [FREE Full text] [doi: 10.1016/S0140-6736(18)33139-8] [Medline: 30722955]
3. Mahajan A, Esper SA, Cole DJ, Fleisher LA. Anesthesiologists' role in value-based perioperative care and healthcare transformation. Anesthesiology 2021;134(4):526-540 [FREE Full text] [doi: 10.1097/ALN.0000000000003717] [Medline: 33630039]
4. Corey KM, Kashyap S, Lorenzi E, Lagoo-Deenadayalan SA, Heller K, Whalen K, et al. Development and validation of machine learning models to identify high-risk surgical patients using automatically curated electronic health record data (Pythia): a retrospective, single-site study. PLoS Med 2018;15(11):e1002701 [FREE Full text] [doi: 10.1371/journal.pmed.1002701] [Medline: 30481172]
5. Healey MA, Shackford SR, Osler TM, Rogers FB, Burns E. Complications in surgical patients. Arch Surg 2002;137(5):611-617; discussion 617 [FREE Full text] [doi: 10.1001/archsurg.137.5.611] [Medline: 11982478]
6. Esper SA, Holder-Murray J, Subramaniam K, Boisen M, Kenkre TS, Meister K, et al. Enhanced recovery protocols reduce mortality across eight surgical specialties at academic and university-affiliated community hospitals. Ann Surg 2023;277(1):101-108. [doi: 10.1097/SLA.0000000000004642] [Medline: 33214486]
7. Michard F, Sessler DI. Ward monitoring 3.0. Br J Anaesth 2018;121(5):999-1001 [FREE Full text] [doi: 10.1016/j.bja.2018.07.032] [Medline: 30336872]

8.   Lee JA, Choi M, Lee SA, Jiang N. Effective behavioral intervention strategies using mobile health applications for chronic disease management: a systematic review. BMC Med Inform Decis Mak 2018;18(1):12 [FREE Full text] [doi: 10.1186/s12911-018-0591-0] [Medline: 29458358]

9.   Higgins J, Chang J, Hoit G, Chahal J, Dwyer T, Theodoropoulos J. Conventional follow-up versus mobile application home monitoring for postoperative anterior cruciate ligament reconstruction patients: a randomized controlled trial. Arthroscopy 2020;36(7):1906-1916. [doi: 10.1016/j.arthro.2020.02.045] [Medline: 32268161]

10. Scheper H, Derogee R, Mahdad R, van der Wal RJP, Nelissen RGHH, Visser LG, et al. A mobile app for postoperative wound care after arthroplasty: ease of use and perceived usefulness. Int J Med Inform 2019;129:75-80. [doi: 10.1016/j.ijmedinf.2019.05.010] [Medline: 31445292]

11. Low CA, Danko M, Durica KC, Kunta AR, Mulukutla R, Ren Y, et al. A real-time mobile intervention to reduce sedentary behavior before and after cancer surgery: usability and feasibility study. JMIR Perioper Med 2020;3(1):e17292 [FREE Full text] [doi: 10.2196/17292] [Medline: 33393915]

12. van der Linden MJW, Nahar van Venrooij LMW, Verdaasdonk EGG. Personal devices to monitor physical activity and nutritional intake after colorectal cancer surgery: feasibility study. JMIR Perioper Med 2022;5(1):e40352 [FREE Full text] [doi: 10.2196/40352] [Medline: 36512385]

13. Symer MM, Abelson JS, Milsom J, McClure B, Yeo HL. A mobile health application to track patients after gastrointestinal surgery: results from a pilot study. J Gastrointest Surg 2017;21(9):1500-1505. [doi: 10.1007/s11605-017-3482-2] [Medline: 28685388]

14. Low CA, Danko M, Durica KC, Vega J, Li M, Kunta AR, et al. A real-time mobile intervention to reduce sedentary behavior before and after cancer surgery: pilot randomized controlled trial. JMIR Perioper Med 2023;6:e41425 [FREE Full text] [doi: 10.2196/41425] [Medline: 36633893]

15. Morgan JK, Rawlins CR, Walther SK, Harvey A, O'Donnell A, Greene M, et al. A mobile app for postoperative pain management among older veterans undergoing total knee arthroplasty: mixed methods feasibility and acceptability pilot study. JMIR Perioper Med 2023;6:e50116 [FREE Full text] [doi: 10.2196/50116] [Medline: 37851497]

16. Mahajan A, Esper S, Oo TH, McKibben J, Garver M, Artman J, et al. Development and validation of a machine learning model to identify patients before surgery at high risk for postoperative adverse events. JAMA Netw Open 2023;6(7):e2322285 [FREE Full text] [doi: 10.1001/jamanetworkopen.2023.22285] [Medline: 37418262]

17. Hutchings R, Sherlaw-Johnson C. Supporting patient engagement with digital health care innovations: lessons from the Care City test bed. Nuffieldtrust. 2022. URL: https://www.nuffieldtrust.org.uk/sites/default/files/2022-04/1651161363_supporting-patient-engagement-web.pdf [accessed 2024-02-07]

18. Taylor S. How digital health programs can spark employee engagement and utilization. Employer Benefit News. 2021. URL: https://tinyurl.com/he4vr7bm [accessed 2024-02-07]

19. Glossary of terms. Roper Center, Cornell University. 2024. URL: https://ropercenter.cornell.edu/quick-answers/glossary-terms [accessed 2024-02-07]

20. Xu S, Ross C, Raebel MA, Shetterly S, Blanchette C, Smith D. Use of stabilized inverse propensity scores as weights to directly estimate relative risk and its confidence intervals. Value Health 2010;13(2):273-277 [FREE Full text] [doi: 10.1111/j.1524-4733.2009.00671.x] [Medline: 19912596]

21. Naimi AI, Cole SR, Kennedy EH. An introduction to g methods. Int J Epidemiol 2017;46(2):756-762 [FREE Full text] [doi: 10.1093/ije/dyw323] [Medline: 28039382]

22. Vegesna A, Tran M, Angelaccio M, Arcona S. Remote patient monitoring via non-invasive digital technologies: a systematic review. Telemed J E Health 2017;23(1):3-17 [FREE Full text] [doi: 10.1089/tmj.2016.0051] [Medline: 27116181]

23. Pronk Y, Peters MCWM, Sheombar A, Brinkman JM. Effectiveness of a mobile ehealth app in guiding patients in pain control and opiate use after total knee replacement: randomized controlled trial. JMIR Mhealth Uhealth 2020;8(3):e16415 [FREE Full text] [doi: 10.2196/16415] [Medline: 32167483]

24. Pecorelli N, Fiore JF, Kaneva P, Somasundram A, Charlebois P, Liberman AS, et al. An app for patient education and self-audit within an enhanced recovery program for bowel surgery: a pilot study assessing validity and usability. Surg Endosc 2018;32(5):2263-2273. [doi: 10.1007/s00464-017-5920-3] [Medline: 29098431]

25. Pan S, Rong LQ. Mobile applications in clinical and perioperative care for anesthesia: narrative review. J Med Internet Res 2021;23(9):e25115 [FREE Full text] [doi: 10.2196/25115] [Medline: 34533468]

26. Oertel C, Castellano G, Chetouani M, Nasir J, Obaid M, Pelachaud C, et al. Engagement in human-agent interaction: an overview. Front Robot AI 2020;7:92 [FREE Full text] [doi: 10.3389/frobt.2020.00092] [Medline: 33501259]

27. Carman KL, Dardess P, Maurer M, Sofaer S, Adams K, Bechtel C, et al. Patient and family engagement: a framework for understanding the elements and developing interventions and policies. Health Aff (Millwood) 2013;32(2):223-231 [FREE Full text] [doi: 10.1377/hlthaff.2012.1133] [Medline: 23381514]

28. Bombard Y, Baker GR, Orlando E, Fancott C, Bhatia P, Casalino S, et al. Engaging patients to improve quality of care: a systematic review. Implement Sci 2018;13(1):98 [FREE Full text] [doi: 10.1186/s13012-018-0784-z] [Medline: 30045735]

Abbreviations

DHP: digital health platform
ED: emergency department
HC: health coach
HIPAA: Health Insurance Portability and Accountability Act
LOS: length of stay
PRO: patient-reported outcome
RR: relative risk
SIPTW: stabilized inverse probability of treatment weighting

Original Paper

Postsurgical Pain Risk Stratification to Enhance Pain Management Workflow in Adult Patients: Design, Implementation, and Pilot Evaluation

Matthias Görges[1,2], PhD; Jonath Sujan[2], MEng; Nicholas C West[2], MSc; Rama Syamala Sreepada[1,2], PhD; Michael D Wood[1,2], PhD; Beth A Payne[2,3], PhD; Swati Shetty[4], BSc, MD; Jean P Gelinas[5,6], MD; Ainsley M Sutherland[1,7], MD, PhD

[1]Department of Anesthesiology, Pharmacology & Therapeutics, The University of British Columbia, Vancouver, BC, Canada

[2]Research Institute, BC Children's Hospital, Vancouver, BC, Canada

[3]School of Population and Public Health, The University of British Columbia, Vancouver, BC, Canada

[4]MD Undergraduate Program, The University of British Columbia, Vancouver, BC, Canada

[5]Department of Anesthesiology & Pain Medicine, University of Alberta, Edmonton, AB, Canada

[6]Department of Anesthesiology, Surrey Memorial Hospital, Surrey, BC, Canada

[7]Department of Anesthesiology, St. Paul's Hospital, Vancouver, BC, Canada

Corresponding Author:
Matthias Görges, PhD
Department of Anesthesiology, Pharmacology & Therapeutics
The University of British Columbia
Rm V3-324, 950 West 28th Avenue
Vancouver, BC, V5Z 4H4
Canada
Phone: 1 6048752000 ext 5616
Email: mgoerges@bcchr.ca

Abstract

Background: Exposure to opioids after surgery is the initial 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 (1) a digital health platform leveraging patient-survey-reported risk factors and (2) a postsurgical pain risk stratification algorithm to personalize perioperative care by integrating several commercially available digital health solutions into a combined platform. Development was reduced in scope by the COVID-19 pandemic.

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

Methods: A POQI platform prototype was implemented in a quality improvement initiative at a Canadian tertiary care center and evaluated from January to September 2022. After surgical booking, a preliminary risk stratification algorithm was applied to health history questionnaire responses. The estimated risk guided the patient assignment 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 use of >90 morphine milligram equivalents per day was the outcome used to assess algorithm performance. Data were summarized and compared between the low- and high-risk groups. POQI use was assessed by completed surveys on postoperative days 7, 14, 30, 60, 90, and 120. Semistructured patient and clinician interviews provided qualitative feedback on the platform.

Results: Overall, 276 eligible patients were admitted for colorectal procedures. The risk algorithm stratified 203 (73.6%) as the low-risk group and 73 (26.4%) as the high-risk group. Among the 214 (77.5%) patients with available data, high-risk patients were younger than low-risk patients (age: median 53, IQR 40-65 years, vs median 59, IQR 49-69 years, median difference five years, 95% CI 1-9; *P*=.02) and were more often female patients (45/73, 62% vs 80/203, 39.4%; odds ratio 2.5, 95% CI 1.4-4.5; *P*=.002). The risk stratification was reasonably specific (true negative rate=144/200, 72%) but not sensitive (true positive rate=10/31, 32%). Only 39.7% (85/214) patients completed any postoperative quality of recovery questionnaires (only 14, 6.5%

patients beyond 60 days after surgery), and 22.9% (49/214) completed a postdischarge medication survey. Interviewed participants welcomed the initiative but noted usability issues and poor platform education.

Conclusions: An initial POQI platform prototype was deployed operationally; the risk algorithm had reasonable specificity but poor sensitivity. There was a significant loss to follow-up in postdischarge survey completion. Clinicians and patients appreciated the potential impact of preemptively addressing opioid exposure but expressed shortcomings in the platform's design and implementation. Iterative platform redesign with additional features and reevaluation are required before broader implementation.

Introduction

Background

The ongoing opioid overdose epidemic has contributed to unprecedented and unnecessary deaths, with an estimated 100,306 deaths from prescription and illegal opioid use in the United States in the 12 months before April 2021 [1] and 5360 deaths in Canada in the first 9 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 United States) [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. Postsurgical 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 multimodal analgesia to decrease perioperative opioid exposure and prevent subsequent persistent opioid use [3].

Perioperative health care is being optimized through enhanced recovery after surgery (ERAS) pathways [4-6], multimodal analgesic plans [5,7,8], and regional anesthesia techniques [9]. Further opportunities to improve postsurgical pain trajectories are offered by prehabilitation programs [10-12], our developing understanding of the risks of persistent postsurgical 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 postsurgical 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, where opioid use disorder continues to be one of the 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 of people who receive a high dose (>90 morphine milligram equivalents [MME]/day) increasing during the period from 2013 to 2017 [18]; patients with opioid overdose 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, health care organizations, and university partners. It aimed to develop and implement a postsurgical pain risk stratification algorithm by integrating several commercially available digital health solutions into a combined POQI digital health platform for prehabilitation and postsurgical care planning. The COVID-19 pandemic adversely impacted the ability to engage clinicians and patients in co-designing and testing the solution iteratively. Hence, the project faced significant delays, and the scope of the POQI platform development was reduced. Specifically, planned features for 2-way communication and personalization of educational information for patients were not included in the prototype tested in this study.

Objectives

The specific objectives of the pilot deployment of the POQI platform were to assess (1) the screening performance of the risk stratification algorithm to facilitate subsequent risk score optimization and (2) the use, 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 (PHC's) St. Paul's Hospital in Vancouver, British Columbia, Canada. The target users were clinicians and patients. The patient population for pilot-testing had undergone a designated set of colorectal surgeries; this population was selected because the colorectal surgical clinic was an early adopter of an electronic health history questionnaire (HHQ) upon which the platform expanded. As a result of this initiative, the Department of Anesthesiology and Pain Medicine at 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 Hospital patients after the study concluded.

The POQI platform incorporated an algorithm [20] that classified patients as low risk or high risk for persistent postsurgical pain and long-term opioid use. Clinicians used this classification to assign patients to low-risk or high-risk pathways for personalized prehabilitation, patient education, and care planning. Specifically, patients were told that there were resources that they could use to learn about pain and nonpharmacologic strategies for pain management 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 use. The clinician and patient user experiences were evaluated using mixed methods.

Ethical Considerations

The University of British Columbia PHC Research Ethics Board determined this work to be a quality improvement project (reviewed on October 13, 2020), for which they do not require ethical review under Article 2.5 of the Canadian Tri-Council Policy Statement [21]. Hence, this project was run as a quality improvement pilot project governed by 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 [22].

The POQI Digital Health Platform

Development of the POQI platform combined existing technologies from 3 industry partners (Figure 1): a preoperative survey and POQI platform for low-risk patients (POQI-L), supplied by Thrive Health; a POQI platform for high-risk patients (POQI-H), supplied by Careteam Technologies; and a data broker, supplied by Excelar Technologies (also incorporating Xerus Medical from 2021). 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 Hospital). 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 (1) additional iterations of user testing and design refinement; (2) additional features, such as 2-way communication between patients and clinicians; and (3) personalization of educational materials to meet patients' needs optimally.

Figure 1. Workflow in the perioperative 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. PHN: personal health number; PII: personally identifiable information; POQI-H: POQI platform for high-risk patients; POQI-L: POQI platform for low-risk patients; QoR: quality of recovery.
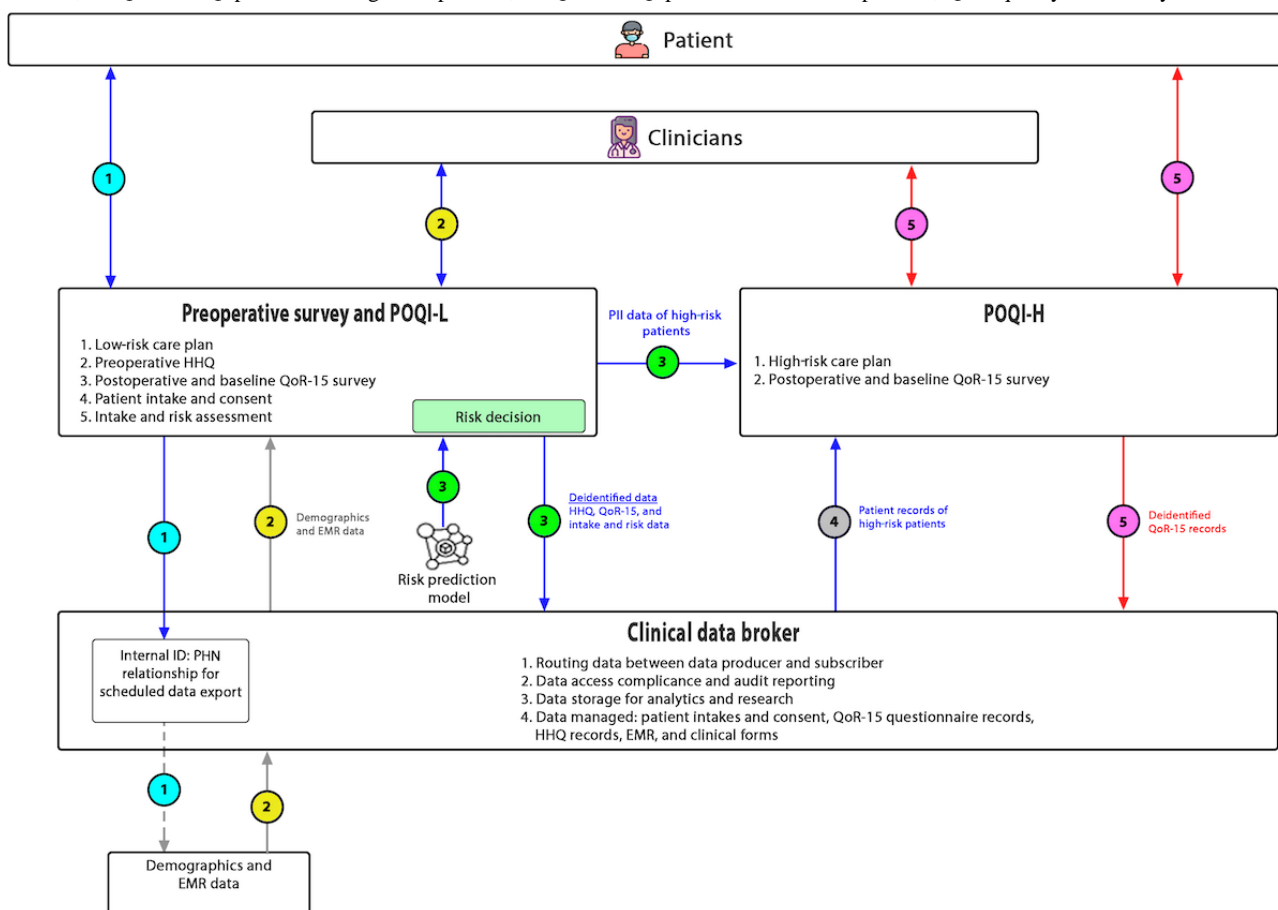
The prototype POQI platform allowed for the collection of patient-specific data, including a presurgical HHQ (questions selected as risk factors for modeling are presented in Multimedia Appendix 1) and patient-reported outcome measures (PROMs) at baseline. Furthermore, data were collected postoperatively using quality of recovery-15 (QoR-15) questionnaires [23] and additional PROM surveys to collect self-reported medication use and pain (scores). The platform was linked to an automated export from the Cerner electronic medical record (EMR) system (Cerner Corp), which allowed for collecting surgery details and oral and intravenous opioid use data from inpatient medication administration records.

Initial HHQ data were used to stratify patients for risk of persistent postsurgical pain and opioid use, using a previously

developed risk score, which was based on the data collected from 122 patients who underwent colorectal surgery; 22 (18%) of them had high postoperative opioid use, 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 groups using a point-based prediction model that considered 11 risk factors with different weights [20]: substance use disorder (risk score weight=5); current prescription of opioid (risk score weight=5), benzodiazepine (risk score weight=4), or antidepressant (risk score weight=4); recreational drug use (risk score weight=4); history of chronic pain (risk score weight=4), anxiety or panic attacks (risk score weight=2), depression (risk score weight=2), or poorly controlled pain after surgery (risk score weight=2); female sex (risk score weight=2); and age <40 years (risk score weight=1; refer to relevant HHQ questions in Multimedia Appendix 1). The algorithm flagged a patient as high risk if the risk score was >7 out of 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. In addition, clinicians could use their clinical judgment to manually onboard patients directly to POQI-H after the St. Paul's Hospital Transitional Pain Clinic consultation, 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 (refer to the *Study Design and Approval* section for details). Some high-risk patients were also seen preoperatively in St. Paul's Hospital Transitional Pain Clinic for prehabilitation, education, and pain management planning when the responsible clinician deemed it appropriate. Postoperatively, high-risk patients were flagged by St. Paul's Hospital Transitional Pain Clinic providers for closer follow-up by the Acute Pain Service clinicians in the hospital.

Regardless of the risk categorization, patients who used a significant quantity of opioids postoperatively (>90 MME) were also followed by St. Paul's Hospital Transitional Pain Service for optimization of their postdischarge 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 >90 MME per day be weaned to the lowest effective dose, potentially including discontinuation [24].

Participants and Recruitment

Pilot use of the POQI platform was initiated at St. Paul's Hospital in December 2021 and formally adopted on January 1, 2022. The target population for pilot-testing included patients undergoing a designated set of colorectal surgeries during the active enrollment period (Multimedia Appendix 2) and excluded patients who underwent screening and minimally invasive diagnostic procedures such as endoscopies. Patients who had a surgery that was not included in the designated set or had undergone procedures with a surgical time of <20 minutes were excluded. Furthermore, patients who underwent surgery before January 1, 2022, were 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 perioperative quality improvement platform as piloted at St. Paul's Hospital. This figure 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 whether patients require enhanced follow-up after discharge. A poor patient-reported outcome measure (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 if they were still taking opioids beyond postoperative day 7. HHQ: health history questionnaire; MOA: medical office assistant; OR: operating room.
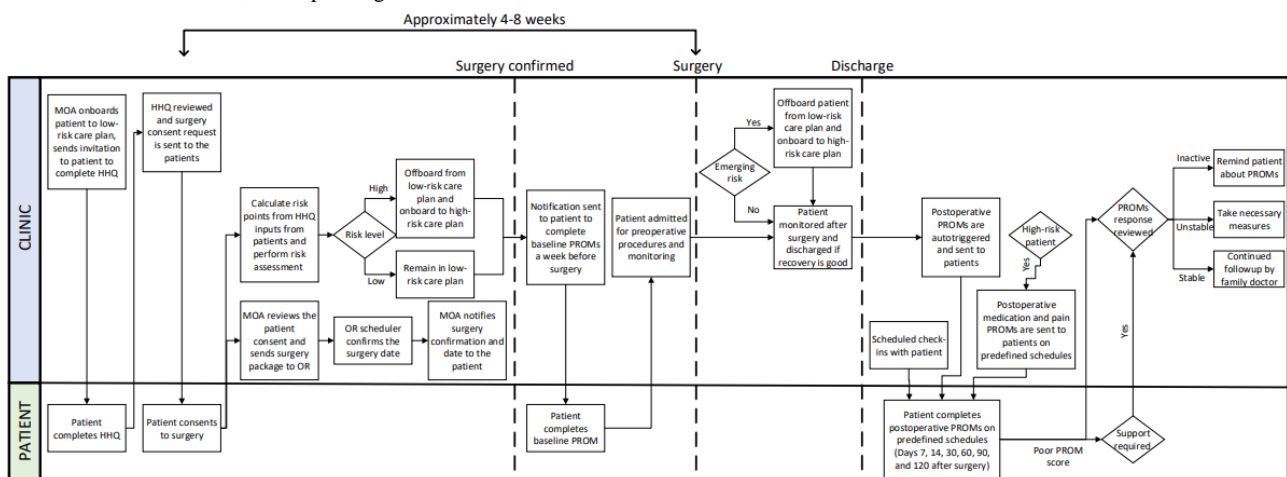
Data Collection and Management

The patient-specific data, including preoperative baseline HHQ, 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 use data from the medication administration record were extracted 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 and the ThriveID, assigned at the initial onboarding for HHQ completion. Data for this evaluation were aggregated and deidentified (Figure 2). The deidentified data sets were then exported to the research team for analysis.

Outcomes

Risk Stratification

To evaluate the risk stratification, we elected to focus on inpatient opioid use. 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. Therefore, the primary outcome used to evaluate the accuracy of the risk stratification was based on inpatient daily opioid use, using a threshold of >90 MME per day to indicate high opioid use, in line with the recommendations for opioid therapy and chronic noncancer pain [24]. 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 intravenous 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 intravenous and oral administration were then summed for every patient over a 24-hour period, starting at 6 AM and ending at 6 AM the following day.

EMR 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; that is, on the day of surgery, only opioids administered after the surgery up to 6 AM the following day were included for the MME/day calculation.

Use, Utility, and Perceived Benefit

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

Use 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 1 postoperative QoR-15 survey, at least 1 PROM survey, and their postoperative data collection period up to the 90-day mark.

Utility and perceived benefit were evaluated through a series of semistructured interviews with both patients and clinicians via Zoom (Zoom Video Communications). To obtain a representative sample, a randomly selected group of 10 patients deemed high risk for significant postsurgical pain and a random group of 10 patients deemed low risk for significant postsurgical pain were contacted approximately 1 week after hospital discharge and invited to participate. For clinicians, we included anesthesiologists and nurses in St. Paul's Hospital Transitional Pain Clinic and aimed for a sample of 5 clinicians.

Brief (approximately 10-15 minutes) interviews focused on three domains: (1) experience with the platform technologies, (2) perceived benefit of the platform for the health care experience, and (3) 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).

Additional Secondary Outcomes

Additional secondary outcomes included emergent readmissions; pain scores over the first 3 postoperative days; and continued opioid use 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 data sets for patients with prior surgery. We confirmed that the admission time in the new visit was after the discharge time following the surgery. As inpatients could have had nonemergent 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 data set 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 (refer to *The POQI Digital Health Platform* section), 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 use 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 nonparametric statistical tests: the Fisher exact test for counts and the Mann-Whitney U test for continuous data. A logistic regression of all risk factors for high in-hospital opioid use was performed to generate adjusted odds ratios (ORs), reported with 95% CIs. Analyses were performed using Python (version 3.10; Python Software Foundation):

Pandas (version 1.5.0; Wes McKinney), SciPy (version 1.9.3; Enthought), and NumPy (version 1.23.3) were used for data cleaning, processing, and analysis; Matplotlib (version 3.6.0) was used to generate plots; and Openpyxl (version 3.0.10) was used to create analysis reports. R software (version 4.2.2; The R Foundation) 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 enrollment labels) and the outcome, that is, high (>90 MME/day) and low (≤90 MME/day) opioid use. 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 use by patients on postoperative days 0 to 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 Hospital between January 01, 2022, and September 30, 2022, and completed the HHQ before surgery (Figure 3). The denominators vary in the result 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; HHQ: health history questionnaire; MAR: medication administration record; QoR: quality of recovery.
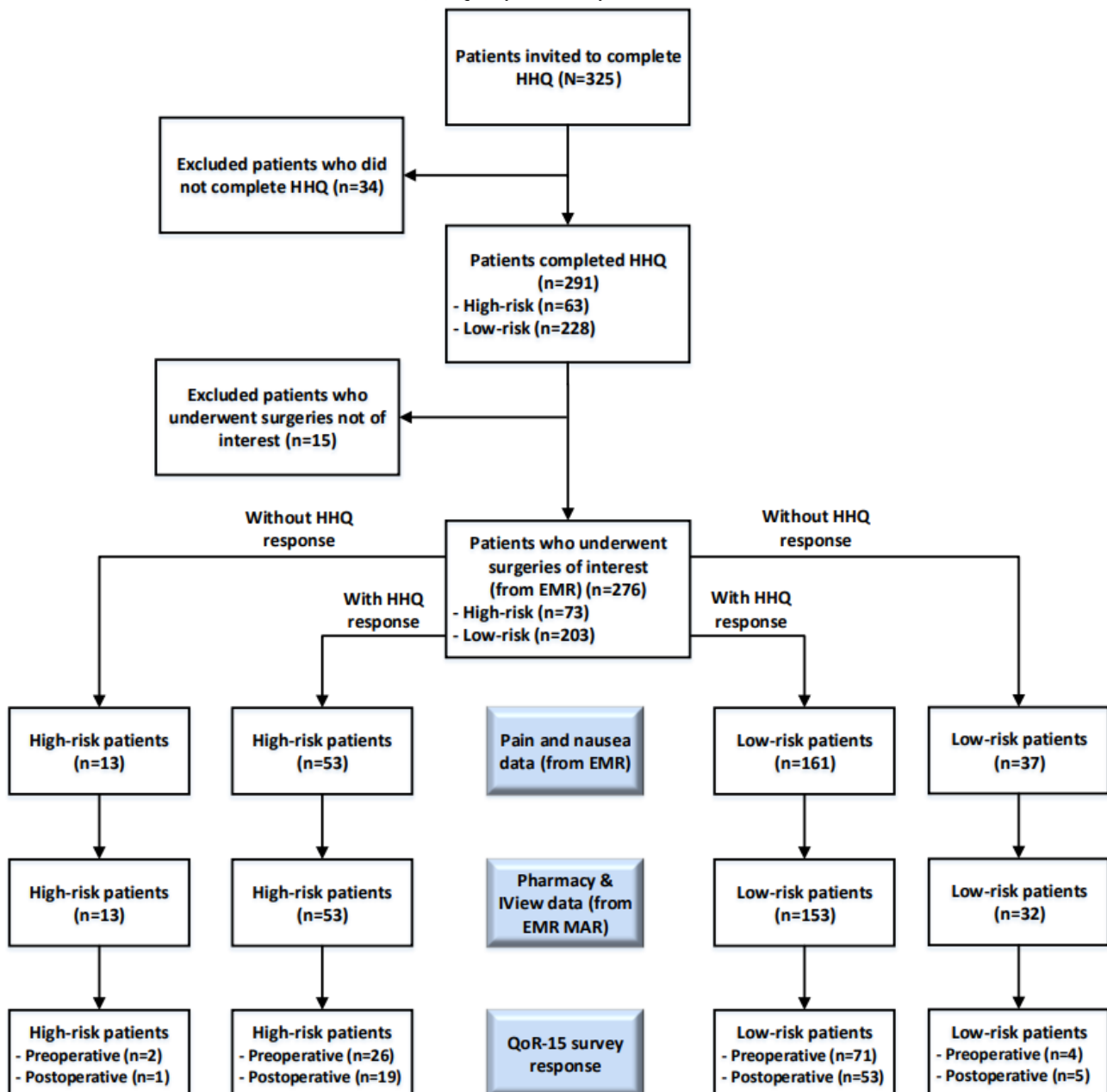
Risk Stratification Characteristics

Of the 276 patients, the risk stratification algorithm identified 203 (73.6%) patients as low risk and 73 (26.4%) 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 substantial differences in risk factors between the high-risk and low-risk groups were history of depression (OR 29.4, 95% CI 9.2-125; risk score weight=2), antidepressant prescription (OR 23.4, 95% CI 7.9-85.2; risk score weight=4), current opioid prescription (OR 20.4, 95% CI 4.2-196.4; risk score weight=5), and history of chronic pain (OR 19.4, 95% CI 6.9-63.3; risk score weight=4; Table 1).

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

Risk factor	Total sample (N=214), n (%)	Low-risk group (n=161), n (%)	High-risk group (n=53), n (%)	Odds ratio (95% CI)
Substance use disorder	9 (4.2)	3 (1.9)	6 (11.3)	6.6 (1.4-42.6)
Current opioid prescription	13 (6.1)	2 (1.2)	11 (20.8)	20.4 (4.2-196.4)
Benzodiazepine prescription	9 (4.2)	3 (1.9)	6 (11.3)	6.6 (1.4-42.6)
Antidepressant prescription	28 (13.1)	5 (3.1)	23 (43.4)	23.4 (7.9-85.2)
Recreational drug use	29 (13.6)	10 (6.2)	19 (35.8)	8.3 (3.3-22.0)
History of chronic pain	29 (13.6)	6 (3.7)	23 (43.4)	19.4 (6.9-63.3)
History of anxiety	46 (21.5)	18 (11.2)	28 (52.8)	8.8 (4.0-19.7)
History of depression	27 (12.6)	4 (2.5)	23 (43.4)	29.4 (9.2-125.0)
History of poorly controlled pain	26 (12.1)	11 (6.8)	15 (28.3)	5.3 (2.1-14.0)
Female sex	90 (42.1)	59 (36.6)	31 (58.5)	2.4 (1.2-4.8)
Age (<40 years)	32 (15.0)	20 (12.4)	12 (22.6)	2.1 (0.8-4.9)

High-risk patients were younger than low-risk patients (age: median 53, IQR years, vs median 59, IQR years, median difference [MD] 5 years, 95% CI 1-9; P=.02) and were more often female (45/73, 62%, vs 80/203, 39.4%; OR 2.5, 95% CI 1.4-4.5; P=.002; Table 2). Furthermore, high-risk patients reported lower baseline (preoperative) QoR scores (median 122, IQR 91-136, vs median 131, IQR 116-140, MD 12, 95% CI 2-23; P=.02).

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

	Total sample (N=276)	Low-risk group (n=203)	High-risk group (n=73)	P value	Median difference (95% CI)	Odds ratio (95% CI)
Age (y), median (IQR)	59 (47-68)	59 (49-69)	53 (40-65)	.02	5 (1 to 9)	—[a]
Sex, n (%)				.002	—	2.5 (1.4 to 4.5)
Male	151 (54.7)	123 (60.6)	28 (38.4)			
Female	125 (45.3)	80 (39.4)	45 (61.6)			
Surgery type, n (%)				.15	—	1.5 (0.9 to 2.8)
Closed	183 (66.3)	140 (69.0)	43 (58.9)			
Open	93 (33.7)	63 (31.0)	30 (41.1)			
Time to surgery (days), median (IQR)[b]	30 (18-68)	29 (16-54)	34 (19-86)	.21	–4.9 (–13.3 to 2.7)	—
Length of surgery (hours), median (IQR)	2.1 (1.2-3.1)	2.1 (1.1-3.0)	1.9 (1.2-3.3)	.85	0.0 (–0.3 to 0.4)	—
Preoperative QoR-15[c] score, median (IQR)[d]	129 (104-139)	131 (116-140)	122 (91-136)	.02	12 (2 to 23)	—

[a]Not applicable.

[b]Data available: total, n=267; low-risk patients, n=195; high-risk patients, n=75. This indicates the number included in the analysis (eg, surgical decision time is not available for all patients).

[c]QoR-15: quality of recovery-15.

[d]Data available: total, n=110; low-risk patients, n=77; high-risk patients, n=33. This indicates the number included in the analysis.

Postoperative Outcomes

Overall inpatient opioid use was not significantly different between the 2 risk groups, with a median of 20 IQR (10-45) MME/day in low-risk cases versus a median of 25 IQR (10-50) MME/day in high-risk cases (MD –2, 95% CI –5 to 0; P=.10; Table 3). Similarly, no significant difference was observed in opioid use across the recovery profile of low- versus high-risk patients over the first 10 postoperative days (Figure 4). Our risk factors were not strong predictors for high MME/day: none of the ORs from logistic regression were significant (ie, 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 use in patients with patient-controlled analgesia or oral opioid medications (n=231)[a].

	Total (n=231)	Low-risk group (n=165)	High-risk group (n=66)	P value	Median difference (95% CI)	Odds ratio (95% CI)
MME[b]/day (mg), median (IQR)	24 (10-47)	20 (10-45)	25 (10-50)	.10	–2 (–5 to 0)	—[c]
Total MME (mg), median (IQR)	48 (15-145)	43 (15-130)	65 (18-237)	.09	–10 (–38 to 1)	—
Patients using >90 MME/day, n (%)	31 (13.4)	21 (12.7)	10 (15.1)	.67	—	1.2 (0.5 to 2.9)

[a]Some patients, not included here, had continuous opioid infusion only or no opioid medications.

[b]MME: morphine milligram equivalent.

[c]Not applicable.

XSL•FO

RenderX

Figure 4. Box plots of morphine milligram equivalents (MME) per day comparing high-risk and low-risk patients.
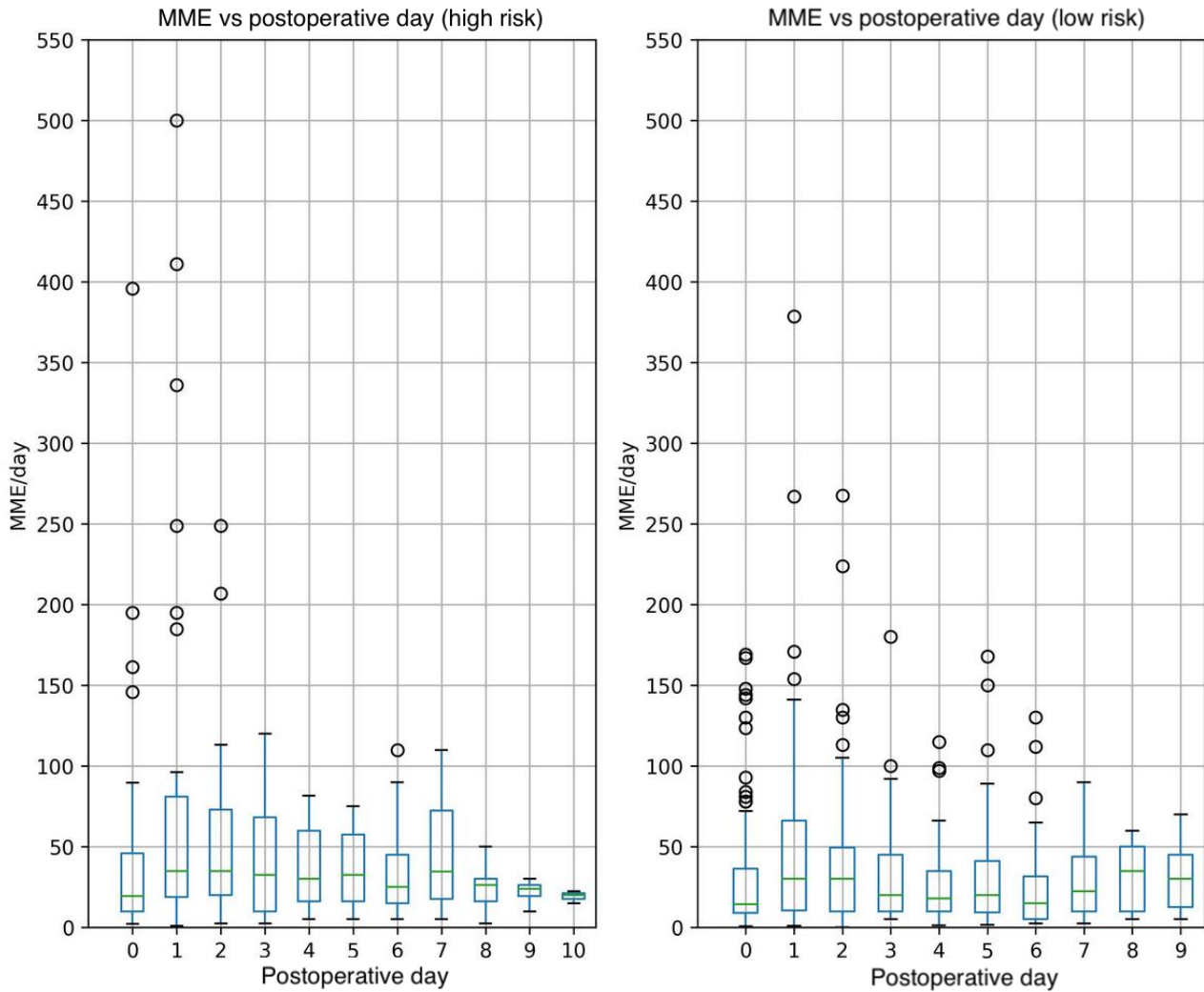
Table 4. Risk factor distribution among cohort and outcome groups, with the odds ratios for patients using >90 morphine milligram equivalent (MME) per day for which the presurgical health history questionnaire details were available. The adjusted odds ratios from the derivation cohort [20] are provided for reference.

Risk factor	Total sample (n=201), n (%)	≤90 MME/day (n=177), n (%)	>90 MME/day (n=24), n (%)	Unadjusted odds ratio (95% CI)	Adjusted odds ratio (95% CI)[a]	Adjusted odds ratio in the derivation cohort [20] (95% CI)
Substance use disorder	9 (4.5)	7 (4.0)	2 (8.3)	2.2 (0.2-12.6)	1.8 (0.2-9.5)	1.6 (1.0-2.3)
Current opioid prescription	12 (6.0)	9 (5.1)	3 (12.5)	2.6 (0.4-11.8)	2.9 (0.5-12.4)	1.1 (0.7-1.6)
Benzodiazepine prescription	9 (4.5)	8 (4.5)	1 (4.2)	0.9 (0.0-7.4)	0.6 (0.0-4.4)	1.0 (0.8-1.3)
Antidepressant prescription	28 (13.9)	23 (13.0)	5 (20.8)	1.8 (0.5-5.5)	1.6 (0.4-6.2)	1.2 (0.7-1.8)
Recreational drug use	28 (13.9)	25 (14.1)	3 (12.5)	0.9 (0.2-3.2)	0.7 (0.1-2.5)	1.1 (0.6-1.7)
History of chronic pain	28 (13.9)	24 (13.6)	4 (16.7)	1.3 (0.3-4.3)	0.9 (0.2-3.1)	1.6 (1.0-2.6)
History of anxiety	44 (21.9)	35 (19.8)	9 (37.5)	2.4 (0.9-6.5)	2.5 (0.8-7.3)	0.8 (0.5-1.2)
History of depression	26 (12.9)	22 (12.4)	4 (16.7)	1.4 (0.3-4.8)	0.8 (0.2-3.2)	0.9 (0.6-1.3)
History of poorly controlled pain	25 (12.4)	23 (13.0)	2 (8.3)	0.6 (0.1-2.8)	0.5 (0.1-2.1)	1.1 (0.6-1.7)
Female sex	82 (40.8)	72 (40.7)	10 (41.7)	1.0 (0.4-2.7)	0.8 (0.3-2.0)	1.0 (0.6-1.6)
Age (<40 years)	30 (14.9)	26 (14.7)	4 (16.7)	1.2 (0.3-3.9)	1.2 (0.3-4.0)	1.0 (0.9-1.0)
Open surgery	__[b]	—	—	—	—	1.2 (0.7-2.0)

[a]Values derived from multivariate logistic regression, including all other risk factors.

[b]Not applicable.

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 the low-risk group than in the high-risk group (MD 11, 95% CI 4-19; *P*=.002; Table 5).

Table 5. Postoperative outcomes.

	Total (n=231)	Low-risk group (n=165)	High-risk group (n=66)	*P* value	Median difference (95% CI)	Odds ratio (95% CI)
Total readmissions, n (%)	75 (32.5)	51 (30.9)	24 (36.4)	.22	__[a]	1.5 (0.8 to 2.7)
Emergent readmissions (within 30 days of surgery), n (%)	20 (8.7)	13 (7.8)	7 (10.6)	.43	—	1.5 (0.5 to 4.4)
Emergent readmissions (30 to 180 days following surgery), n (%)	7 (3.0)	4 (2.4)	3 (4.5)	.39	—	2.1 (0.3 to 12.9)
Length of hospital stay (days), median (IQR)	4 (2-6)	4 (2-6)	5 (1-7)	.56	0 (–1 to 0)	—
Overall postoperative QoR-15[b] score, median (IQR)[c]	118 (100-133)	121 (107-134)	108 (89-128)	.002	11 (4 to 19)	—

[a]Not applicable.

[b]QoR-15: quality of recovery-15.

[c]Data available: total, n=85; low-risk patients, n=59; high-risk patients, n=26. This indicates the number included in the analysis.

Risk Stratification Performance

In terms of performance, with an incidence of opioid use of >90 MME/day as the primary outcome, the pilot risk stratification algorithm was reasonably specific (true negative rate=144/200, 72%) but not sensitive (true positive rate=10/31, 32%). These equate to a high false negative rate of 68% (21/31), with a false positive rate of 28% (56/200), a positive likelihood of 1.15, and a negative likelihood of 0.94.

Postoperative Use of the POQI Platform

Data are available for 214 (77.5%) of the 276 patients who completed the HHQ and were risk stratified by the POQI platform (low-risk patients: 161/203, 79.3%; high-risk patients: 53/73, 73%). Of the 276 patients, 85 (30.8%) completed any

postoperative QoR-15 questionnaire (low-risk patients: 59/203, 29.1%; high-risk patients: 26/73, 36%). Similarly, 31 (15.3%) of the 203 low-risk patients and 3 (4.1%) of the 73 high-risk patients reported any postoperative opioid use (Table 6).

Table 6. Postoperative use of the perioperative quality improvement (POQI) platform.

	Total sample (n=276)	Low-risk group (n=203)	High-risk group (n=73)	P value	Median difference (95% CI)	Odds ratio (95% CI)
Data available from preoperative HHQ[a], n (%)	214 (77.5)	161 (79.3)	53 (72.6)	.26	__[b]	0.7 (0.4 to 1.4)
Completed at least 1 postoperative questionnaire, n (%)	85 (30.8)	59 (29.1)	26 (35.6)	.62	—	0.9 (0.4 to 1.7)
Length of follow-up post-surgery (days), median (IQR)[c]	25 (11-54)	24 (11-53)	29 (11-57)	.80	–1 (–9 to 10)	—
Completed follow-up questionnaires at POD[d] 31 to 60, n (%)	15 (5.4)	11 (5.4)	4 (5.5)	.99	—	1.0 (0.3 to 4.4)
Completed follow-up questionnaires beyond POD 90, n (%)	3 (1.1)	0 (0)	3 (4.1)	.57	—	0 (0 to 6.8)
Patients reporting postoperative medication use, n (%)	34 (12.3)	31 (15.3)	3 (4.1)	.01	—	4.2 (1.2 to 22.1)

[a]HHQ: health history questionnaire.

[b]Not applicable.

[c]Data available: total, n=85; low-risk patients, n=59; high-risk patients, n=26. This indicates the number included in the analysis.

[d]POD: postoperative day.

Qualitative Interviews

We conducted feedback interviews with 3 (15%) patients (2 POQI-L users and 1 POQI-H user) of the 20 invited patients; most patients (17/20, 85%) approached declined to participate in this portion of the study. We interviewed all 4 clinicians (anesthesiologists and nurses who used both platforms) involved in the platform deployment in St. Paul's Hospital Transitional Pain Clinic.

Perceived Benefit of the Platforms for the Health Care Experience

Patients recognized that the POQI-L had improved their health care experience by making them mindful of their behavior, 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 health care 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:

> [T]his will help me keep track of things and have some kind of two-way communication

However, they did not feel that the 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. However, they recognized potential patient benefits, including access to educational information:

> [F]or the patients, there is good access to many resources.

> [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, although this may have resulted from poor communication of the purpose of the application and potential benefits for them:

> I'm not sure what that tool is trying to be. [POQI-L user]

> [...] I didn't feel like I had much guidance in using [it]. [POQI-H user]

Furthermore, there was a lack of clarity in instructions for using both platforms; for example, the POQI-L users expressed frustration about redundant emails or SMS text messages, which were unclear about "what was supposed to be completed and when," and the POQI-H user said as follows:

> 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 2 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 postsurgical pain.

Similarly, usability issues during the initial deployment contributed to attrition among clinical users; for example, 1 clinician admitted that they had not signed patients up on the POQI-H for 4 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 as follows:

[I] 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, a clinician stated as follows:

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 Findings

A pragmatic risk prediction algorithm was used to categorize 276 patients who underwent colorectal surgery into high-risk or low-risk groups 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=14/200, 72%) but not sensitive (true positive rate=10/31, 32%). Furthermore, the risk categorization was 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 (77.5%) of the 276 patients, but there was a significant loss to follow-up with postoperative surveys, including QoR-15, completed by only 85 (39.7%) of the 214 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 multimodal pain management techniques and patient preparation or education to reduce reliance on opioids (both in-hospital and postdischarge opioid use) during recovery from surgery. 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 postsurgical pain is associated with younger age, female sex, and preoperative pain [25], which are consistent with the characteristics observed in the patients classified as high risk by our algorithm (Table 2). Furthermore, a recent multicenter study in the United States identified preoperative opioid use as the most significant predictor of prolonged opioid use after surgery [26]. 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 patients in the postsurgical period, including web-based tools and mobile apps, can support tracking various postoperative outcomes, including prescription drug use. Although the development of perioperative eHealth or mobile health solutions for telemonitoring is still maturing [27], these technologies show promise as not only their implementation is feasible but they can also streamline clinical workflow and improve patient outcomes [28,29]. Web-based patient portals integrated with the EMR can improve patient satisfaction, enable more effective health care use [30], and improve outcomes such as glycemic control in patients with diabetes [31]. 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 [32]; using apps can also have a positive impact [33]. Perioperative solutions must be designed with frequent and meaningful clinician and patient input and evaluated in large, robust clinical trials [27,29]. Particular attention is needed when developing and evaluating tools for vulnerable populations, such as patients with chronic pain issues and older patients, although a recent systematic review reported generally positive results from 7 studies on patients aged ≥65 years [34]. In contrast, our population was relatively younger, with a median age of 59 (IQR) (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 3 months [33].

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 benefited from the POQI-H platform. None of our 11 patient-reported preoperative risk factors had a significant adjusted OR for high in-hospital opioid use (>90 MME/day), in which the 95% CI range excluded 1 (Table 4). This indicates that by themselves, none of the risk factors would have predicted high postoperative opioid use 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 [24], 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 postsurgical outcomes, with generally positive findings in a recent systematic review [35]. Such technology has been used to predict prolonged opioid use after orthopedic surgery [36] or estimate the risk of an adverse outcome within 30 days of an opioid dispensation [37]. 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 predefined 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 [37].

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 that we encountered and the lessons learned during our implementation can benefit other research, specifically clinical and industry teams endeavoring 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 [38], to confirm that the design addresses patient and provider needs and delivers meaningful benefits to patient care and health care practice.

Next, when including a research component in health care system technical development and implementation, it is essential to ensure that research end points 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 [39,40]. 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 [41]: process metrics, patient trajectories, and benchmarking tools will enable clinicians to learn from

their patients. PROMs and patient-reported experience measures [42] 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

In addition to the implementation issues already discussed, we must acknowledge many limitations in the data that we have presented. First, restrictions to hospital access due to the COVID-19 pandemic 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.

Second, 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 bidirectional 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.

Third, 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 or authorized access through the British Columbia Health Gateway was a project goal, and implementation was explored. However, it was found to be impossible 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 center (including only 24, 11.9% of the 201 patients who used opioids >90 MME/day) and missing follow-up outcomes from many patients designated as high risk for significant postsurgical pain and opioid use. This is partly due to low engagement during the COVID-19 pandemic and

challenges in achieving the project's objectives within a limited funding period. Similarly, we planned to recruit 10 patients from the POQI-L group, 10 from the POQI-H group, and 5 clinicians to participate in semistructured interviews. However, we only obtained feedback from 3 patients (2 POQI-L users and 1 POQI-H user) and 4 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 the COVID-19 pandemic. On the other hand, the COVID-19 pandemic 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 Hospital, 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 prehabilitation while overcoming potential resource constraints.

Conclusions

Our POQI platform categorized patients who underwent colorectal surgery into high-risk or low-risk groups 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. However, a significant loss in follow-up with postdischarge 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 redesign and evaluation before wider implementation is desirable.

Conflicts of Interest

JPG is a consultant for Excelar Technologies. All other authors declare no other conflicts of interest.

Multimedia Appendix 1
Risk factors and relevant questions from health history questionnaire.
[DOCX File , 25 KB - periop_v7i1e54926_app1.docx]

Multimedia Appendix 2
List of included colorectal surgeries in pilot implementation.
[DOCX File , 24 KB - periop_v7i1e54926_app2.docx]

Multimedia Appendix 3
Morphine milligram equivalent conversion factors.
[DOCX File , 21 KB - periop_v7i1e54926_app3.docx]

Multimedia Appendix 4
Interview guides.
[DOCX File , 25 KB - periop_v7i1e54926_app4.docx]

References

XSL•FO

RenderX

1. Drug overdose deaths in the U.S. top 100,000 annually. CDC/National Center for Health Statistics. 2021 Nov 17. URL: https://www.cdc.gov/nchs/pressroom/nchs_press_releases/2021/20211117.htm [accessed 2023-04-24]

2. Opioid- and stimulant-related harms in Canada. Public Health Agency of Canada. 2024 Mar 27. URL: https://health-infobase.canada.ca/substance-related-harms/opioids-stimulants/ [accessed 2023-04-24]

3. Soffin EM, Lee BH, Kumar KK, Wu CL. The prescription opioid crisis: role of the anaesthesiologist in reducing opioid use and misuse. Br J Anaesth 2019 Jun;122(6):e198-e208 [FREE Full text] [doi: 10.1016/j.bja.2018.11.019] [Medline: 30915988]

4. Elhassan A, Elhassan I, Elhassan A, Sekar KD, Cornett EM, Urman RD, et al. Perioperative surgical home models and enhanced recovery after surgery. J Anaesthesiol Clin Pharmacol 2019 Apr;35(Suppl 1):S46-S50 [FREE Full text] [doi: 10.4103/joacp.JOACP_47_18] [Medline: 31142959]

5. Beverly A, Kaye AD, Ljungqvist O, Urman RD. Essential elements of multimodal analgesia in enhanced recovery after surgery (ERAS) guidelines. Anesthesiol Clin 2017 Jun;35(2):e115-e143. [doi: 10.1016/j.anclin.2017.01.018] [Medline: 28526156]

6. King AB, Alvis BD, McEvoy MD. Enhanced recovery after surgery, perioperative medicine, and the perioperative surgical home: current state and future implications for education and training. Curr Opin Anaesthesiol 2016 Dec;29(6):727-732. [doi: 10.1097/ACO.0000000000000394] [Medline: 27652514]

7. Huang CC, Sun WZ, Wong CS. Prevention of chronic postsurgical pain: the effect of preventive and multimodal analgesia. Asian J Anesthesiol 2018 Sep;56(3):74-82. [doi: 10.6859/aja.201809_56(3).0002] [Medline: 30583329]

8. Pozek JP, Beausang D, Baratta JL, Viscusi ER. The acute to chronic pain transition: can chronic pain be prevented? Med Clin North Am 2016 Jan;100(1):17-30. [doi: 10.1016/j.mcna.2015.08.005] [Medline: 26614716]

9. Curatolo M. Regional anesthesia in pain management. Curr Opin Anaesthesiol 2016 Oct;29(5):614-619. [doi: 10.1097/ACO.0000000000000353] [Medline: 27137511]

10. Moorthy K, Wynter-Blyth V. Prehabilitation in perioperative care. Br J Surg 2017 Jun;104(7):802-803. [doi: 10.1002/bjs.10516] [Medline: 28300279]

11. Minnella EM, Carli F. Prehabilitation and functional recovery for colorectal cancer patients. Eur J Surg Oncol 2018 Jul;44(7):919-926. [doi: 10.1016/j.ejso.2018.04.016] [Medline: 29754828]

12. Wynter-Blyth V, Moorthy K. Prehabilitation: preparing patients for surgery. BMJ 2017 Aug 08;358:j3702. [doi: 10.1136/bmj.j3702] [Medline: 28790033]

13. Hah JM, Bateman BT, Ratliff J, Curtin C, Sun E. Chronic opioid use after surgery: implications for perioperative management in the face of the opioid epidemic. Anesth Analg 2017 Nov;125(5):1733-1740 [FREE Full text] [doi: 10.1213/ANE.0000000000002458] [Medline: 29049117]

14. Stark N, Kerr S, Stevens J. Prevalence and predictors of persistent post-surgical opioid use: a prospective observational cohort study. Anaesth Intensive Care 2017 Nov;45(6):700-706. [doi: 10.1177/0310057X1704500609] [Medline: 29137580]

15. Sun EC, Darnall BD, Baker LC, Mackey S. Incidence of and risk factors for chronic opioid use among opioid-naive patients in the postoperative period. JAMA Intern Med 2016 Sep 01;176(9):1286-1293 [FREE Full text] [doi: 10.1001/jamainternmed.2016.3298] [Medline: 27400458]

16. Macrae WA. Chronic pain after surgery. Br J Anaesth 2001 Jul;87(1):88-98 [FREE Full text] [doi: 10.1093/bja/87.1.88] [Medline: 11460816]

17. Kehlet H, Jensen TS, Woolf CJ. Persistent postsurgical pain: risk factors and prevention. Lancet 2006 May 13;367(9522):1618-1625. [doi: 10.1016/S0140-6736(06)68700-X] [Medline: 16698416]

18. Yefet LS, Bone JN, Courtemanche R, Lauder G, Courtemanche DJ. Opioid prescribing patterns in British Columbia from 2013 to 2017: a population-based study. B C Med J 2021;63(8):336-342 [FREE Full text]

19. Edwards NY, Sutherland AM, Caters L, Kim LS, Chan S, Shetty S, et al. Opioid overdose following surgery or pain treatment: a missed opportunity for intervention. BC Med J 2023;65(1):19-25 [FREE Full text]

20. Sreepada R, Sutherland A, Shams B, Soriano G, Perrett E, Chowdhury N, et al. Development of a simple risk prediction model for excessive postoperative opioid utilization in inpatients. Anesth Analg 2021 Mar 01;132(3S Suppl 1):52-53. [doi: 10.1213/ANE.0000000000005509]

21. TCPS 2 (2022) – chapter 2: scope and approach. The Panel on Research Ethics, Canada. URL: https://ethics.gc.ca/eng/tcps2-eptc2_2022_chapter2-chapitre2.html [accessed 2024-04-29]

22. Ogrinc G, Davies L, Goodman D, Batalden P, Davidoff F, Stevens D. SQUIRE 2.0 (standards for QUality Improvement reporting excellence): revised publication guidelines from a detailed consensus process. BMJ Qual Saf 2016 Dec;25(12):986-992 [FREE Full text] [doi: 10.1136/bmjqs-2015-004411] [Medline: 26369893]

23. Stark PA, Myles PS, Burke JA. Development and psychometric evaluation of a postoperative quality of recovery score: the QoR-15. Anesthesiology 2013 Jun;118(6):1332-1340 [FREE Full text] [doi: 10.1097/ALN.0b013e318289b84b] [Medline: 23411725]

24. Busse JW, Craigie S, Juurlink DN, Buckley DN, Wang L, Couban RJ, et al. Guideline for opioid therapy and chronic noncancer pain. CMAJ 2017 May 08;189(18):E659-E666 [FREE Full text] [doi: 10.1503/cmaj.170363] [Medline: 28483845]

25. Andreoletti H, Dereu D, Combescure C, Rehberg B. A systematic review and meta-analysis of three risk factors for chronic postsurgical pain: age, sex and preoperative pain. Minerva Anestesiol 2022 Oct;88(10):827-841. [doi: 10.23736/S0375-9393.22.16489-8] [Medline: 35766955]

26. Kuck K, Naik BI, Domino KB, Posner KL, Saager L, Stuart AR, Multicenter Perioperative Outcomes Group Enhanced Observation Study Investigator Group for the Multicenter Perioperative Outcomes Group Enhanced Observation Study Collaborator Group. Prolonged opioid use and pain outcome and associated factors after surgery under general anesthesia: a prospective cohort association multicenter study. Anesthesiology 2023 May 01;138(5):462-476 [FREE Full text] [doi: 10.1097/ALN.0000000000004510] [Medline: 36692360]

27. Haveman ME, Jonker LT, Hermens HJ, Tabak M, de Vries JP. Effectiveness of current perioperative telemonitoring on postoperative outcome in patients undergoing major abdominal surgery: a systematic review of controlled trials. J Telemed Telecare 2024 Feb;30(2):215-229. [doi: 10.1177/1357633X211047710] [Medline: 34723689]

28. van der Meij E, Anema JR, Otten RH, Huirne JA, Schaafsma FG. The effect of perioperative E-Health interventions on the postoperative course: a systematic review of randomised and non-randomised controlled trials. PLoS One 2016;11(7):e0158612 [FREE Full text] [doi: 10.1371/journal.pone.0158612] [Medline: 27383239]

29. De La Cruz Monroy MF, Mosahebi A. The use of smartphone applications (Apps) for enhancing communication with surgical patients: a systematic review of the literature. Surg Innov 2019 Apr;26(2):244-259. [doi: 10.1177/1553350618819517] [Medline: 30602332]

30. Graham TA, Ali S, Avdagovska M, Ballermann M. Effects of a web-based patient portal on patient satisfaction and missed appointment rates: survey study. J Med Internet Res 2020 May 19;22(5):e17955 [FREE Full text] [doi: 10.2196/17955] [Medline: 32427109]

31. Alturkistani A, Qavi A, Anyanwu PE, Greenfield G, Greaves F, Costelloe C. Patient portal functionalities and patient outcomes among patients with diabetes: systematic review. J Med Internet Res 2020 Sep 22;22(9):e18976 [FREE Full text] [doi: 10.2196/18976] [Medline: 32960182]

32. Lyles CR, Nelson EC, Frampton S, Dykes PC, Cemballi AG, Sarkar U. Using electronic health record portals to improve patient engagement: research priorities and best practices. Ann Intern Med 2020 Jun 02;172(11 Suppl):S123-S129 [FREE Full text] [doi: 10.7326/M19-0876] [Medline: 32479176]

33. Bhatia A, Kara J, Janmohamed T, Prabhu A, Lebovic G, Katz J, et al. User engagement and clinical impact of the manage my pain app in patients with chronic pain: a real-world, multi-site trial. JMIR Mhealth Uhealth 2021 Mar 04;9(3):e26528 [FREE Full text] [doi: 10.2196/26528] [Medline: 33661130]

34. Jonker LT, Haveman ME, de Bock GH, van Leeuwen BL, Lahr MM. Feasibility of perioperative eHealth interventions for older surgical patients: a systematic review. J Am Med Dir Assoc 2020 Dec;21(12):1844-51.e2 [FREE Full text] [doi: 10.1016/j.jamda.2020.05.035] [Medline: 32694000]

35. Elfanagely O, Toyoda Y, Othman S, Mellia JA, Basta M, Liu T, et al. Machine learning and surgical outcomes prediction: a systematic review. J Surg Res 2021 Aug;264:346-361. [doi: 10.1016/j.jss.2021.02.045] [Medline: 33848833]

36. Anderson AB, Grazal CF, Balazs GC, Potter BK, Dickens JF, Forsberg JA. Can Predictive Modeling Tools Identify Patients at High Risk of Prolonged Opioid Use After ACL Reconstruction? Clin Orthop Relat Res 2020 Jul;478(7):1603-1618 [FREE Full text] [doi: 10.1097/CORR.0000000000001251] [Medline: 32282466]

37. Sharma V, Kulkarni V, Jess E, Gilani F, Eurich D, Simpson SH, et al. Development and validation of a machine learning model to estimate risk of adverse outcomes within 30 days of opioid dispensation. JAMA Netw Open 2022 Dec 01;5(12):e2248559 [FREE Full text] [doi: 10.1001/jamanetworkopen.2022.48559] [Medline: 36574245]

38. Knowles SE, Allen D, Donnelly A, Flynn J, Gallacher K, Lewis A, et al. Participatory codesign of patient involvement in a learning health system: how can data-driven care be patient-driven care? Health Expect 2022 Feb;25(1):103-115 [FREE Full text] [doi: 10.1111/hex.13345] [Medline: 34668634]

39. Shaw J, Brewer LC, Veinot T. Recommendations for health equity and virtual care arising from the COVID-19 pandemic: narrative review. JMIR Form Res 2021 Apr 05;5(4):e23233 [FREE Full text] [doi: 10.2196/23233] [Medline: 33739931]

40. Dorn SD. Backslide or forward progress? Virtual care at U.S. healthcare systems beyond the COVID-19 pandemic. NPJ Digit Med 2021 Jan 08;4(1):6 [FREE Full text] [doi: 10.1038/s41746-020-00379-z] [Medline: 33420420]

41. Enticott J, Johnson A, Teede H. Learning health systems using data to drive healthcare improvement and impact: a systematic review. BMC Health Serv Res 2021 Mar 05;21(1):200 [FREE Full text] [doi: 10.1186/s12913-021-06215-8] [Medline: 33663508]

42. Kingsley C, Patel S. Patient-reported outcome measures and patient-reported experience measures. BJA Educ 2017 Apr;17(4):137-144. [doi: 10.1093/bjaed/mkw060]

Abbreviations

EMR: electronic medical record
ERAS: enhanced recovery after surgery
HHQ: health history questionnaire
MD: median difference

MME: morphine milligram equivalents
OR: odds ratio
PHC: Providence Health Care
POQI: Perioperative Opioid Quality Improvement
POQI-H: Perioperative Opioid Quality Improvement platform for high-risk patients
POQI-L: Perioperative Opioid Quality Improvement platform for low-risk patients
PROM: patient-reported outcome measure
QoR-15: quality of recovery-15
SQUIRE: Standards for Quality Improvement Reporting Excellence

---

XSL•FO
RenderX

<u>Original Paper</u>

Preoperative Anesthesia Virtual Video Consultations in a Preadmission Clinic: Quality Improvement Study

Yamini Subramani[1*], MD; Jill Querney[1*], MD; Priyanka Singh[1*], MD; Yifan Zhang[1*], MD; Lee-Anne Fochesato[1*], MSc; Nida Fatima[1*], MBBS; Natasha Wood[2*], MSc; Mahesh Nagappa[1*], MD

[1]Department of Anesthesia and Perioperative Medicine, London Health Sciences Centre, St. Joseph Health Care, Schulich School of Medicine and Dentistry, Western University, London, ON, Canada
[2]Department of Nursing, London Health Sciences Centre, Western University, London, ON, Canada
*all authors contributed equally

Corresponding Author:
Mahesh Nagappa, MD
Department of Anesthesia and Perioperative Medicine
London Health Sciences Centre, St. Joseph Health Care, Schulich School of Medicine and Dentistry
Western University
339 Windermere Road
London, ON, N6A 5A5
Canada
Phone: 1 5196858500 ext 34436
Email: Mahesh.Nagappa@lhsc.on.ca

Abstract

Background: The preadmission clinic (PAC) is crucial in perioperative care, offering evaluations, education, and patient optimization before surgical procedures. During the COVID-19 pandemic, the PAC adapted by implementing telephone visits due to a lack of infrastructure for video consultations. While the pandemic significantly increased the use of virtual care, including video appointments as an alternative to in-person consultations, our PAC had not used video consultations for preoperative assessments.

Objective: This study aimed to develop, implement, and integrate preoperative video consultations into the PAC workflow.

Methods: A prospective quality improvement project was undertaken using the Plan-Do-Study-Act (PDSA) methodology. The project focused on developing, implementing, and integrating virtual video consultations at London Health Sciences Centre and St. Joseph Health Care (London, Ontario, Canada) in the PAC. Data were systematically collected to monitor the number of patients undergoing video consultations, address patient flow concerns, and increase the percentage of video consultations. Communication between the PAC, surgeon offices, and patients was analyzed for continuous improvement. Technological challenges were addressed, and procedures were streamlined to facilitate video calls on appointment days.

Results: The PAC team, which includes professionals from medicine, anesthesia, nursing, pharmacy, occupational therapy, and physiotherapy, offers preoperative evaluation and education to surgical patients, conducting approximately 8000 consultations annually across 3 hospital locations. Following the initial PDSA cycles, the interventions consistently improved the video consultation utilization rate to 17%, indicating positive progress. With the onset of PDSA cycle 3, there was a notable surge to a 29% utilization rate in the early phase. This upward trend continued, culminating in a 38% utilization rate of virtual video consultations in the later stages of the cycle. This heightened level was consistently maintained throughout 2023, highlighting the sustained success of our interventions.

Conclusions: The quality improvement process significantly enhanced the institution's preoperative video consultation workflow. By understanding the complexities within the PAC, strategic interventions were made to integrate video consultations without compromising efficiency, morale, or safety. This project highlights the potential for transformative improvements in health care delivery through the thoughtful integration of virtual care technologies.

KEYWORDS

preoperative evaluation; preadmission clinic; telemedicine; remote; virtual care; remote consultation; video consultation; telehealth; online health; digital health; perioperative medicine; preoperative; eMedicine; surgery; consultation; safety; assessment; virtual care; workflow; implementation; integration; hospital

Introduction

Amid the COVID-19 pandemic, many in-person consultations in the preadmission clinic (PAC) at our tertiary academic centers of London Health Sciences Centre (LHSC) and St. Joseph's Health Care in London, Ontario, Canada, shifted to telephone consultations. Telephone consultations were instrumental in reducing unnecessary hospital visits and in-person interactions, thereby mitigating the risk of COVID-19 transmission. While phone consultations facilitate thorough patient history–taking and chart review, they inherently lack the capability for a physical examination, which is essential in preanesthesia evaluations. Specifically, an airway assessment, which is critical for anesthesia planning, cannot be conducted effectively over the phone. By integrating a telemedicine model that includes audio and visual components in the PAC, several significant advantages emerge, including (1) an enhanced physical assessment, as the visual capability over video calls ensures a more accurate and comprehensive evaluation than phone consultations; (2) improved patient interaction given that nonverbal communication plays a crucial role in interpreting patient concerns and responses, which is lost in phone consultations; (3) increased diagnostic accuracy, since visual examinations can aid in identifying physical signs that might indicate underlying health issues, which may not be apparent through phone calls; and (4) enhanced patient engagement and education, as visual tools can be used to educate patients about their procedure and anesthesia plan, making it easier for them to understand complex information [1,2].

Telehealth involves electronic video communication between patients and health care providers to improve patient health remotely [3,4]. While telemedicine has long been used in rural areas without access to specialists, its prevalence increased widely during the COVID-19 pandemic [5,6]. When strategically deployed, virtual care enhances the quality and effectiveness of patient care and enables dynamic risk stratification through big data and machine learning [7].

LHSC and St. Joseph's Health Care collectively handle approximately 50,000 surgical cases annually across various subspecialties. The PAC is a designated setting for multidisciplinary preoperative assessments and optimization of operating room efficiency. Notably, not all patients receive preoperative assessments in the PAC, as limitations in time, office space, and human resources restrict the number of patients seen. The PAC team, comprising professionals from medicine, anesthesia, nursing, pharmacy, occupational therapy, and physiotherapy, offers preoperative evaluation and education to surgical patients, totaling approximately 8000 consultations annually across 3 hospital locations.

Over the years, the PAC has undergone alterations in office location, size, caseload, and staffing. The PAC team's preoperative consultations often include internal medicine and/or anesthesiology consultations and cover all surgical subspecialties. Some consultations are time-sensitive or involve mandatory in-person visits due to combined procedures such as x-rays, electrocardiograms, echocardiography, surgical team consultations, and blood work. Therefore, implementing video consultations requires meticulous planning and decision-making to ensure smooth clinic operations [8].

On a national and global level, virtual care video appointments have become a popular alternative to in-person and phone appointments during the COVID-19 pandemic [9,10]. Patients benefit from time and cost savings, increased communication with providers, improved access to care, and involvement of family members or caregivers [1,11]. Telemedicine has been shown to reduce missed appointments, wait times, and readmissions; enhance office efficiency with fewer front desk phone calls; and increase medication adherence. The ability of health care providers to make eye contact, assess body language, discuss sensitive topics, and conduct a limited physical examination over a virtual video platform can improve the patient-physician relationship [12]. This approach aligns with the trend toward digital health care solutions and ensures that patient safety and care quality are maintained at the highest standards.

During the COVID-19 pandemic, the PAC adapted by implementing telephone visits due to a lack of infrastructure for video consultations. While the pandemic significantly increased the use of virtual care, including video appointments as an alternative to in-person consultations, our PAC had not used video consultations for preoperative assessments. A preliminary assessment indicated room for development and improvement of video consultations before routine integration. The initiative focused on enhancing preoperative care without direct patient participation or using identifiable data, potentially offering valuable insights to the broader health care community. This project aimed to develop, implement, and integrate structured steps and process changes using Cisco DX80 Webex devices, measuring the impact on the number or percentage of video consultations through validated continuous quality improvement Plan-Do-Study-Act (PDSA) cycles.

Methods

Ethical Considerations

Ethics approval was not obligatory for this initiative; however, we secured Western Research Ethics Board approval (project ID: 118733) before commencing the quality improvement project, conducted between May 2021 and December 2023. No data or personal identifiers from participants were collected. Only information related to the process, such as patient selection, the percentage of successful video consultations, and issues encountered, were documented in a patient-independent manner.

Study Objective

The primary objective of this study was to develop, implement, and integrate virtual video consultations within the PAC, offering surgical patients the option of a virtual video consultation as an alternative to in-person visits in collaboration with our institution's multidisciplinary team.

Participants and Data Sources

Initial data collection covered 4 weeks, from the first to the last day of the month, following the implementation of the March 2021 video consultations. Following the initiation of changes, repeat data were gathered for up to 1 month to evaluate the sustainability and ongoing enhancement of the revised practice. Daily video consultations in each PAC were systematically documented throughout the project to facilitate continuous quality improvement.

In the project's initial phase, the data supported the suitability of virtual video consultations for patients undergoing bariatric surgery. Our workgroup decided to pilot the project with this population as these patients were already familiar with the Cisco Webex platform. Notably, the acceptance rate for preoperative video consultations among patients undergoing bariatric surgery reached 100% owing to their preexisting use in the bariatric program for preoperative education. This success among this group of patients catalyzed the broader expansion and implementation of video consultations across PACs.

Approximately 100 virtual video consultations were conducted to streamline preoperative video consultation steps. PAC nursing teams held small group meetings to assess the strengths and weaknesses of telephone and video consultations, documenting opinions shared during the discussions. However, no participant-specific information was collected. Stakeholders were briefed on the results of this preliminary assessment.

To identify areas for expansion and improvement, we sought feedback through an audit and a series of PDSA cycles to facilitate change and monitor progress. A key theme emerging from baseline information and staff feedback was enhancing communication between the PAC, patients, and surgeons' secretaries to offer the option of virtual video consultations postsurgical diagnosis. Additionally, patients' emails were collected to enable sending invitation links for video consultations. A unique shared mailbox was established for this purpose.

We enlisted champions from each stakeholder group to garner support for our rapid cycle changes. Leveraging data and stakeholder feedback, we used the PDSA methodology to shape our quality improvement strategy over 3 years, abstaining from formal statistical analyses for before-and-after comparisons.

Strategy

Overview

We carried out 3 PDSA test cycles over the 3 years. Figure 1 outlines the steps involved in establishing and implementing virtual care appointments.

Figure 1. Steps involved in a virtual care appointment (VCA).

First Intervention: PDSA Cycle 1

Approval from the hospital for the secure Cisco Webex platform prompted the use of cameras for the Cisco DX80 Webex devices in dedicated PAC rooms for video consultations. Collaborative group meetings involving PAC nurses, anesthesiologists, hospital IT staff, and the hospital virtual care team, were held to implement process improvements. Repeated data collection occurred several weeks later using the same preliminary assessment questionnaire after this intervention. The hospital invested in computer-integrated cameras (Cisco DX80 Webex devices) through the virtual care funding program, which were installed in PAC rooms. PAC nurses received 4 training sessions, and video virtual appointment scheduling and registration was established. A common email was created with a shared folder/inbox and regular updates were implemented to enhance virtual care.

Second Intervention: PDSA Cycle 2

A dedicated video consultation booking clerk was appointed at the PAC, aiming to boost the percentage of video consultations and simplify the process. Several weeks after the intervention, a reaudit was conducted on the various steps of video consultations.

Third Intervention: PDSA Cycle 3

The objective of this stage was to increase the percentage of video consultations further and streamline the process. This involved improving the booking process, routinely collecting patients' email IDs into electronic records, easing connection to the meeting link (web-based) for patients and health care providers, and integrating them into the patient's electronic record. With integration of Cisco Webex in Cerner health information technology software, the booking clerk clicks a single button to send the invitation to the patient for a video link. The automatic reminders are sent to the patient to prepare for the video consultation. Once the booking is confirmed, a

Webex video link appears in the patient's electronic chart under the "Virtual Care Appointments" section. The other health care providers can connect with the patient at the scheduled time by clicking the hyperlink "Click here to join." This prevents clerical errors in sending email invitations and avoids steps for sharing the PINs for the video connections. Training sessions were conducted for the PAC clinic team, including nurses, medicine and anesthesia staff, clinical fellows, and residents. This served as a brief introduction to the initiative and familiarization with the new video consultation process. Changes in provincial rules and regulations for video consultations increased physicians' acceptance rate, addressing persistent improvement opportunities identified in previous implementation cycles.

Results

Our initial workup indicated that our PAC did not have a video consultation platform before initiating this project. Following the first and second PDSA cycles, the interventions consistently enhanced this metric to a 17% utilization rate, signaling positive developments. As PDSA cycle 3 commenced, there was a substantial increase to a 29% utilization rate during the initial phase. This trend continued, reaching a 38% utilization rate of virtual video consultations in the later phase of the cycle. Utilization was persistently maintained at a high level throughout the entirety of 2023, highlighting the sustained success of our interventions (Figure 2).

Figure 3 provides a comprehensive flow diagram detailing the steps and communication pathways involved in patients' video consultations. Additionally, this figure highlights the specific changes introduced during the PDSA cycles within the project.

Figure 2. Run chart showing the percentage of patients who completed the video consultation. PDSA: Plan-Do-Study-Act.
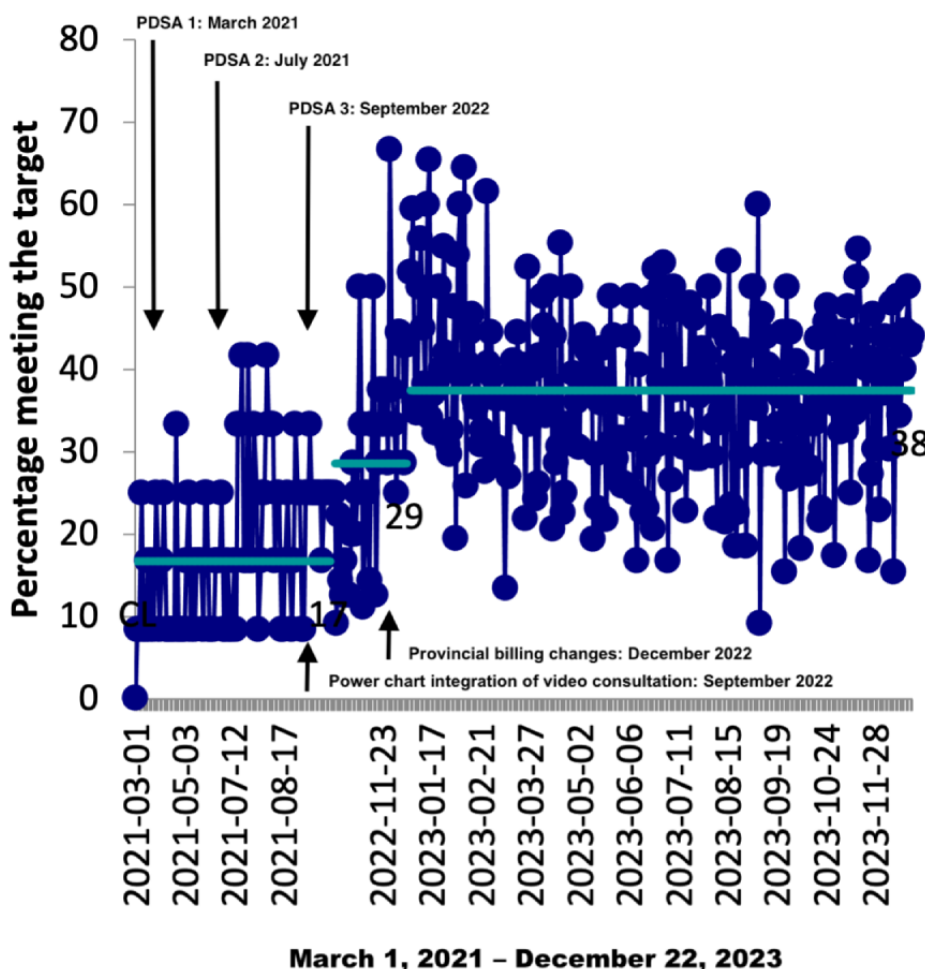
Figure 3. Comprehensive flow diagram detailing the steps and communication pathways involved in patients' video consultations during the PDSA cycles. PAC: preadmission clinic; PDSA: Plan-Do-Study-Act.
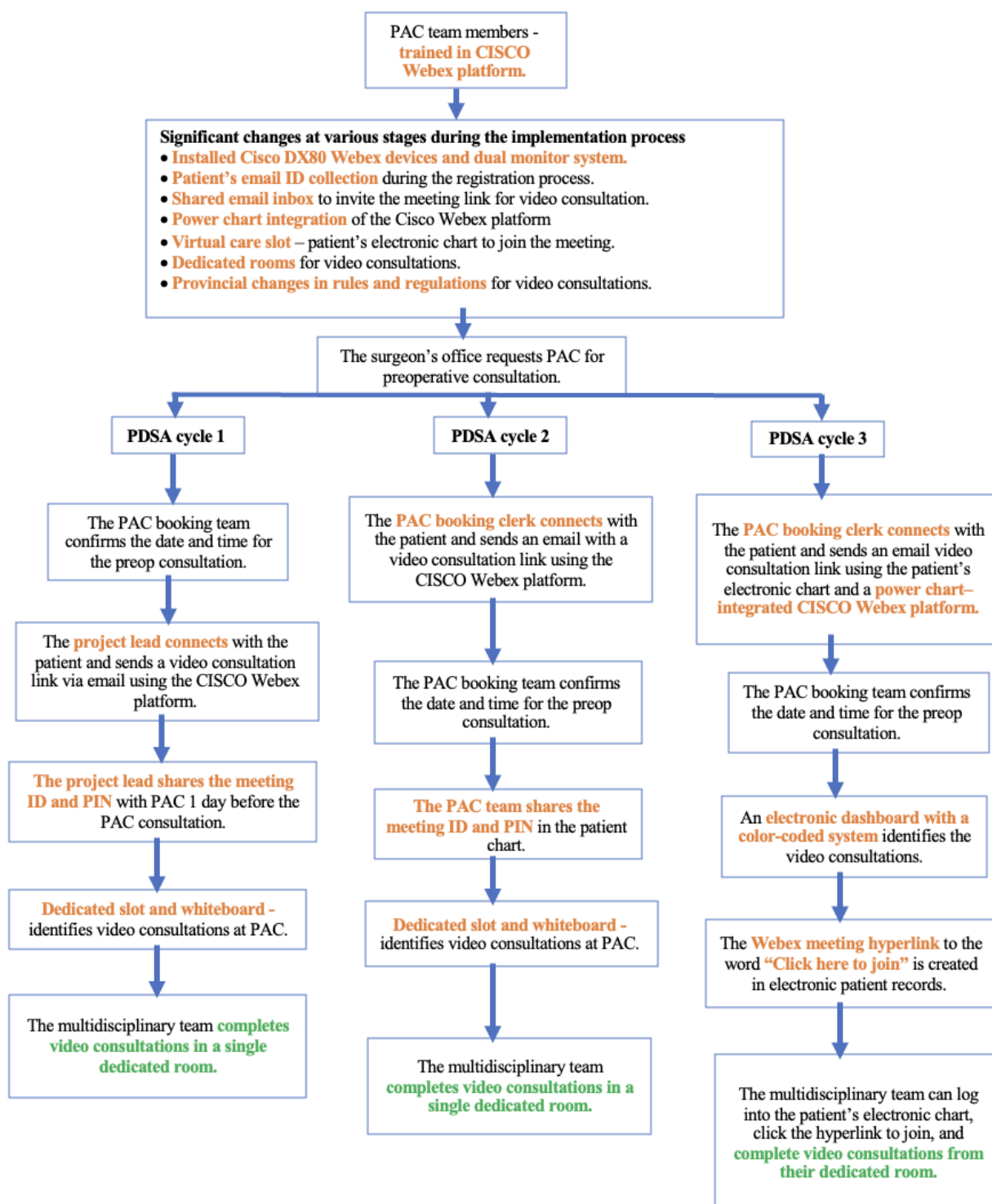
Discussion

Our results demonstrated that following the interventions through 3 successive PDSA cycles, the utilization rate of video consultations increased to 17% and then to 29% and finally to 38%, maintaining this high level throughout 2023, confirming the sustained success of our quality improvement project.

The PAC under study is part of the perioperative process in a Canadian academic tertiary health sciences center within a publicly funded health care system. While this quality improvement program may have limited applicability to other institutions due to variations in staffing, office space, equipment, technology, expertise, scheduling, communication, patient volumes, and guidelines, the lessons learned here may still offer valuable insights into enhancing patient satisfaction through the introduction of video consultations during the perioperative period of care.

The primary objective of this quality improvement project was to explore, develop, implement, and integrate virtual video consultations within the PAC, ensuring that patient-centered care remains timely, efficient, and safe while preserving the importance of in-person consultations. Key to the project's success was enhancing communication among PAC staff, patients, and surgeons' offices; incorporating OneChart Video Webex Appointments; and aligning with provincial changes in rules and regulations. The surgeon's office electronically communicated patients' preference for video consultation to the PAC staff while requesting a preoperative consultation. This decentralized the work for the PAC booking clerk. Significant clinical enhancements in video consultations were achieved throughout the preoperative journey without compromising patient care, as evidenced by the increase of video consultations in the PAC from 0% to 38%. The sustainability of said video consultations was confirmed over the past 12 months, indicating enduring improvement and garnering ongoing support and acceptance from the staff. The groundwork for video consultations positions them for long-term continuation, providing a compelling case for improved staffing, IT support, and physical space. This successful implementation of innovative methods empowers stakeholders to advocate for PAC maintenance and further enhancement.

One prominent observation in our project stems from significant variability observed across PACs and within the same clinic on different days, resulting in total virtual video consultation fluctuations. Various factors contribute to this variability, including the volume of patients referred to the PAC from surgical specialties, medical comorbidities of patients rendering them ineligible for video consultations, specific surgical procedures necessitating in-person consultations, variations in the booking staff at the PAC responsible for sending email invitations for video consultations, the number of surgeries conducted during specific slow-down periods such as holidays, and fluctuations in the overall caseload seen in the PAC. Notably, certain days, labeled as "Super Wednesdays" and "Super Tuesdays" in our PAC, presented twice as many patients, leading to increased video consultations on those days. To mitigate the inconsistency in scheduling personnel, a specialized team member was assigned to facilitate clear communication between patients and surgeons' offices, focusing on effectively organizing video consultations. Some of the other challenges that may be experienced while implementing the video consultations are (1) poor patient internet connectivity, (2) challenges in implementing hardware accessibility in all PAC

rooms, and (3) lack of digital literacy among older patients and health care providers.

While the patient information system facilitated data collection, manual data collection remains necessary. Working closely with the hospital's IT and virtual care teams and their resources proved essential in enhancing patient flow throughout the project by seamlessly integrating video calls into electronic records. In the continuous improvement process, communication options such as "virtual care appointments using Webex" were incorporated into electronic record views, enhancing the efficiency of joining video consultations for the multidisciplinary team in the PAC.

Changes in the PAC were noted during the project, coinciding with broader system and provincial changes. Increased acceptance rates among patients, PAC staff, and physicians led to higher numbers of video consultations. Workforce issues were addressed by assigning additional clerks to assist with the booking process, although no increase in medical and nursing staff occurred. These modifications underscored the clinic's significance within larger hospitals and the provincial system, emphasizing the need for innovative methods to enhance patient flow, efficiency, and satisfaction without compromising safety.

A key limitation of our study is the lack of consideration for total virtual care usage, as we did not monitor the number of phone visits during the implementation period. Without this information, it is challenging to grasp the impact on overall virtual care usage fully. Another significant limitation is the provincial billing changes that disincentivized phone use, which occurred simultaneously with PDSA cycle 3. These changes substantially affected the PDSA cycle and should be considered when interpreting the results.

Virtual care video appointments offer a reasonable alternative to in-person and phone consultations, gaining prominence during the COVID-19 pandemic and likely continuing to play a significant role in health care [13]. Future directions involve advancing the newly implemented video consultation by integrating an app-based preoperative education system already used at our hospital. Additionally, expanding electronic communication options such as asynchronous preoperative messages will deliver real-time, crucial, and up-to-date information and education about the preoperative journey without interrupting a phone call. This approach aims to empower patients and enhance their compliance with preoperative instructions.

Conflicts of Interest

None declared.

References

1. Greenhalgh T, Vijayaraghavan S, Wherton J, Shaw S, Byrne E, Campbell-Richards D, et al. Virtual online consultations: advantages and limitations (VOCAL) study. BMJ Open 2016 Jan 29;6(1):e009388 [FREE Full text] [doi: 10.1136/bmjopen-2015-009388] [Medline: 26826147]
2. Burton BN, Arastoo S, Wu S, Liu N, Ong MK, Vazirani S. The association of medical preoperative evaluation using clinical video telehealth with hospital length of stay: descriptive analysis. JMIR Form Res 2022 Jul 25;6(7):e38054 [FREE Full text] [doi: 10.2196/38054] [Medline: 35877170]

3.   What is telehealth? NEJM Catalyst. 2018 Feb 01. URL: https://catalyst.nejm.org/doi/full/10.1056/CAT.18.0268 [accessed 2024-02-04]

4.   Ong MK, Pfeffer M, Mullur RS. Telemedicine for adults. UpToDate. 2021. URL: https://www.uptodate.com/contents/telemedicine-for-adults [accessed 2024-02-04]

5.   Kichloo A, Albosta M, Dettloff K, Wani F, El-Amir Z, Singh J, et al. Telemedicine, the current COVID-19 pandemic and the future: a narrative review and perspectives moving forward in the USA. Fam Med Community Health 2020 Aug;8(3):e000530 [FREE Full text] [doi: 10.1136/fmch-2020-000530] [Medline: 32816942]

6.   James HM, Papoutsi C, Wherton J, Greenhalgh T, Shaw SE. Spread, scale-up, and sustainability of video consulting in health care: systematic review and synthesis guided by the NASSS framework. J Med Internet Res 2021 Jan 26;23(1):e23775 [FREE Full text] [doi: 10.2196/23775] [Medline: 33434141]

7.   Kruse CS, Krowski N, Rodriguez B, Tran L, Vela J, Brooks M. Telehealth and patient satisfaction: a systematic review and narrative analysis. BMJ Open 2017 Aug 03;7(8):e016242 [FREE Full text] [doi: 10.1136/bmjopen-2017-016242] [Medline: 28775188]

8.   Stark C, Gent A, Kirkland L. Improving patient flow in pre-operative assessment. BMJ Qual Improv Rep 2015 Jan 07;4(1):u201341.w1226 [FREE Full text] [doi: 10.1136/bmjquality.u201341.w1226] [Medline: 26734351]

9.   Wosik J, Fudim M, Cameron B, Gellad ZF, Cho A, Phinney D, et al. Telehealth transformation: COVID-19 and the rise of virtual care. J Am Med Inform Assoc 2020 Jun 01;27(6):957-962 [FREE Full text] [doi: 10.1093/jamia/ocaa067] [Medline: 32311034]

10. Johnsen TM, Norberg BL, Kristiansen E, Zanaboni P, Austad B, Krogh FH, et al. Suitability of video consultations during the COVID-19 pandemic lockdown: cross-sectional survey among Norwegian general practitioners. J Med Internet Res 2021 Feb 08;23(2):e26433 [FREE Full text] [doi: 10.2196/26433] [Medline: 33465037]

11. Wherton J, Shaw S, Papoutsi C, Seuren L, Greenhalgh T. Guidance on the introduction and use of video consultations during COVID-19: important lessons from qualitative research. BMJ Leader 2020 May 18;4(3):120-123. [doi: 10.1136/leader-2020-000262]

12. Watt SA, Berger RC, Hirshfield LE, Yudkowsky R. Telemedicine in anesthesiology: using simulation to teach remote preoperative assessment. J Educ Perioper Med 2023 Mar 9;25(1):E699 [FREE Full text] [doi: 10.46374/volxxv_issue1_watt] [Medline: 36960032]

13. Gilbert AW, Billany JCT, Adam R, Martin L, Tobin R, Bagdai S, et al. Rapid implementation of virtual clinics due to COVID-19: report and early evaluation of a quality improvement initiative. BMJ Open Qual 2020 May;9(2):e000985 [FREE Full text] [doi: 10.1136/bmjoq-2020-000985] [Medline: 32439740]

Abbreviations

LHSC: London Health Sciences Centre
PAC: preadmission clinic
PDSA: Plan-Do-Study-Act

XSL•FO
RenderX

<u>Original Paper</u>

Comparing Anesthesia and Surgery Controlled Time for Primary Total Knee and Hip Arthroplasty Between an Academic Medical Center and a Community Hospital: Retrospective Cohort Study

Thy B Nguyen[1], BA; Nathaen Weitzel[2], MD; Craig Hogan[3], MD; Rachel M Kacmar[2], MD; Kayla M Williamson[4], MS; Jack Pattee[4], PhD; Vesna Jevtovic-Todorovic[2], MD, MBA, PhD; Colby G Simmons[2], DO, MBA; Adeel Ahmad Faruki[2,5], MD, MBA

[1]University of Colorado School of Medicine, Aurora, CO, United States

[2]Department of Anesthesiology, University of Colorado Anschutz Medical Campus, Aurora, CO, United States

[3]Department of Orthopaedic Surgery, University of Colorado Anschutz Medical Campus, Aurora, CO, United States

[4]Department of Biostatistics and Informatics, Colorado School of Public Health, University of Colorado - Anschutz Medical Campus, Aurora, CO, United States

[5]Department of Anesthesiology and Perioperative Medicine, MD Anderson Cancer Center, Houston, TX, United States

Corresponding Author:
Adeel Ahmad Faruki, MD, MBA
Department of Anesthesiology and Perioperative Medicine
MD Anderson Cancer Center
Faculty Center, Floor 13, FC13.2000
1400 Holcombe Blvd, Unit 409
Houston, TX
United States
Phone: 1 713 792 6911
Email: <u>aafaruki@mdanderson.org</u>

Abstract

Background: Osteoarthritis is a significant cause of disability, resulting in increased joint replacement surgeries and health care costs. Establishing benchmarks that more accurately predict surgical duration could help to decrease costs, maximize efficiency, and improve patient experience. We compared the anesthesia-controlled time (ACT) and surgery-controlled time (SCT) of primary total knee (TKA) and total hip arthroplasties (THA) between an academic medical center (AMC) and a community hospital (CH) for 2 orthopedic surgeons.

Objective: This study aims to validate and compare benchmarking times for ACT and SCT in a single patient population at both an AMC and a CH.

Methods: This retrospective 2-center observational cohort study was conducted at the University of Colorado Hospital (AMC) and UCHealth Broomfield Hospital (CH). Cases with current procedural terminology codes for THA and TKA between January 1, 2019, and December 31, 2020, were assessed. Cases with missing data were excluded. The primary outcomes were ACT and SCT. Primary outcomes were tested for association with covariates of interest. The primary covariate of interest was the location of the procedure (CH vs AMC); secondary covariates of interest included the American Society of Anesthesiologists (ASA) classification and anesthetic type. Linear regression models were used to assess the relationships.

Results: Two surgeons performed 1256 cases at the AMC and CH. A total of 10 THA cases and 12 TKA cases were excluded due to missing data. After controlling for surgeon, the ACT was greater at the AMC for THA by 3.77 minutes and for TKA by 3.58 minutes (*P*<.001). SCT was greater at the AMC for THA by 11.14 minutes and for TKA by 14.04 minutes (*P*<.001). ASA III/IV classification increased ACT for THA by 3.76 minutes (*P*<.001) and increased SCT for THA by 6.33 minutes after controlling for surgeon and location (*P*=.008). General anesthesia use was higher at the AMC for both THA (29.2% vs 7.3%) and TKA (23.8% vs 4.2%). No statistically significant association was observed between either ACT or SCT and anesthetic type (neuraxial or general) after adjusting for surgeon and location (all *P*>.05).

Conclusions: We observed lower ACT and SCT at the CH for both TKA and THA after controlling for the surgeon of record and ASA classification. These findings underscore the efficiency advantages of performing primary joint replacements at the

CH, showcasing an average reduction of 16 minutes in SCT and 4 minutes in ACT per case. Overall, establishing more accurate benchmarks to improve the prediction of surgical duration for THA and TKA in different perioperative environments can increase the reliability of surgical duration predictions and optimize scheduling. Future studies with study populations at multiple community hospitals and academic medical centers are needed before extrapolating these findings.

Introduction

Hip and knee osteoarthritis (OA) are pervasive causes of disability and pain globally, and the burden of OA is expected to increase due to population aging and the rising prevalence of obesity [1]. Total knee arthroplasty (TKA) and total hip arthroplasty (THA) are 2 of the most common and well-accepted surgical interventions to improve quality of life for patients with end-stage joint deterioration [2]. Therefore, a considerable increase has been projected for TKA and THA cases (673% and 174%, respectively) from 2005 to 2030 in the United States [3]. The anticipated demand for joint replacements combined with the importance of the operating room (OR) in hospital revenue and margins emphasize the importance of identifying factors that decrease cost and maximize efficiency in the OR [4,5]. One such process is establishing benchmarks that are accurate predictors of surgical duration in order to improve hospital operations, optimize OR schedule modeling and management, reduce health care costs, and improve patient satisfaction and experience.

Prior efforts have been made to assess OR efficiency using mean anesthesia-controlled time (ACT) and surgery-controlled time (SCT) values [6]. ACT is defined as the sum of the time starting when the patient enters the OR until the patient is ready for surgical positioning, added to the time starting when the incision is closed and ending when the patient leaves the OR [7]. SCT is defined as the time from when the patient is ready for positioning to when the surgical sites are closed. Studies examining SCT for TKA found that computer-based estimations of historical performance were a better predictor of actual SCT than the estimates provided by surgeons, while assessments of heterogeneity of ACT and SCT based on current procedural terminology (CPT) codes have also highlighted the need for more granular prediction models [8,9]. Moreover, ACT and SCT at academic institutions may be increased because of teaching responsibilities for anesthesia and surgery trainees and may not reflect mean ACT and SCT for the same procedures in other settings. Furthermore, a spectrum of clinical and nonclinical factors could contribute to significant variation in case duration between surgeons [10,11]. This study will compare the ACT and SCT of THA and TKA between an academic medical center (AMC) and a community hospital (CH) for 2 orthopedic surgeons.

We hypothesize that after adjusting for surgeon, the ACT and SCT between an AMC and a CH will have a statistically significant difference for both knee and hip procedures.

Methods

Design

This retrospective 2-center observational cohort study was conducted at an AMC—the University of Colorado Hospital—and a university-affiliated CH—UCHealth Broomfield Hospital. Prior to the COVID-19 pandemic, hip and knee replacement surgeries were primarily performed at the AMC. However, during the pandemic, these surgeries were relocated to the CH from March 2020 through August 2020 and again in November 2020. Both orthopedic surgeons work with the same team of orthopedic surgery physician assistants and trainees (residents and fellows) at both locations. The University of Colorado Department of Anesthesiology staffs both the AMC and CH with an anesthesia care-team model consisting of supervising attending physicians and anesthesia providers such as certified registered nurse anesthetists, anesthesiology assistants (AAs), or anesthesiology resident physicians-in-training. The academic center also has student AAs who often work alongside certified registered nurse anesthetists and AAs. The CH does not have anesthesiology residents or student AAs present for any procedure. The practice for anesthesiology at both locations includes primarily performing neuraxial anesthesia on both TKA and THA if patients are appropriate and amenable to this type of anesthetic. For TKA, single-shot adductor canal blocks were performed in the preoperative area before the patient was brought to the OR. In the OR, the neuraxial anesthetic or a general anesthetic was performed.

Eligibility Criteria

Inclusion criteria for the study included participants undergoing primary THA and TKA. These cases were performed by 2 fellowship-trained adult reconstructive orthopedic joint surgeons who operated at both the AMC and CH. The time frame for cases performed was from January 1, 2019, to December 31, 2020. Inclusion criteria included being aged older than 18 years and the procedure type was determined based on CPT codes billed for the case. Only CPT codes 27130 (THA) and 27447 (TKA) were assessed in this study. Exclusion criteria included cases with missing data required to calculate ACT and SCT.

Data Collection and Storage

Demographic data and time stamps for each case were collected from electronic medical records and stored securely on the AMC's cloud drive.

ACT and SCT Calculation

The time stamps for *In Room Time*, *Ready for Positioning and Prep Time*, *Incision Time*, *Close Time*, and *Out of Room Time* were collected for each case. *Ready for Positioning* is defined as the point when the anesthesia team has completed their activities, signifying that the patient was prepared for surgical positioning. *Ready for Positioning and Prep Time* indicated that all presurgical anesthesia-related activities were completed and the surgical team could begin positioning the patient and performing surgical preparation. ACT was calculated based on *([Ready for Positioning and Prep Time] – [In Room Time]) + ([Out of Room Time] – [Close Time])*. SCT was calculated based on *([Close Time] – [Ready for Positioning and Prep Time])*.

Statistical Analysis

Descriptive statistics were performed using means and SDs for continuous variables, whereas counts and percentages were used for categorical variables. The primary outcome was the duration of ACT and SCT. Several independent variables were investigated for association with ACT and SCT in TKA and THA procedures. These independent variables include the location (AMC vs CH), surgeon identity (1 of 2 surgeons), American Society of Anesthesiologists (ASA) classification (dichotomized into ASA class I/II, representing mild to moderate systemic disease, vs ASA class III/IV, representing severe systemic disease), and anesthesia type (general vs neuraxial). Several multiple regressions were fit to assess relevant associations. The first tested association describes 4 multivariable linear regressions; for each outcome (ACT or SCT), separate multivariable linear regressions were fit for each surgery type (TKA or THA). Location and surgeon identity were included as independent variables. The second tested association is of 4 separate multivariable regressions; however, the set of modeled independent variables changes including location, surgeon identity, and ASA classification as covariates. The third tested association is of 4 separate multivariable regressions using location, surgeon identity, and anesthetic type as covariates.

Associations were considered statistically significant if the *P* values were less than α at the .05 level. R^2 and adjusted R^2 are reported for multivariable regressions. R^2 characterizes the proportion of variability in the outcome explained by model covariates, thus providing an estimate of the predictive utility of the model. Adjusted R^2 likewise estimates the model's predictive usefulness, with a correction for the number of independent variables. R (version 4.0.4; R Core Team) was used for all analyses.

Ethical Considerations

The study was reviewed by the University of Colorado Denver Institutional Review Board and the study was approved for exempt status (Colorado Multiple Institutional Review Board Protocol 20-2987), as it involved an observational retrospective analysis of existing medical records and therefore did not require additional interventions or the collection of new data from human research participants. Given the exempt status of the study, the written consent requirements of participants were waived for this Colorado Multiple Institutional Review Board Protocol. The original informed consent for the primary data collection allowed for secondary analyses without additional consent, as approved by the institutional review board. This study was designed and executed following the STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) guidelines for cohort studies (Multimedia Appendix 1). To ensure the confidentiality and privacy of human research participant data, all patient records used in this study were deidentified prior to analysis. As there were no interactions or additional interventions with the participants, compensation was not applicable, and therefore not provided.

Results

There were 1256 observations for the 2 surgeons at the AMC and CH from January 1, 2019, to December 31, 2020. There were 619 THA observations and 637 TKA observations. A total of 10 (1.6%) out of 619 THA cases and 12 (1.8%) out of 637 TKA cases had missing values and were excluded from the analyses (Figure 1). One TKA case was missing ASA classifications and was omitted for regression controlling for this variable. The data set included 21 bilateral procedures at the AMC and 3 bilateral procedures at the CH. Secondary CPT codes were documented for a total of 5 cases including 1 cystoscopy, 1 tendon repair, 2 arteriograms, and 1 total hip liner exchange. All of the cases with secondary CPT codes documented occurred at the AMC.

Figure 1. STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) flow diagram.
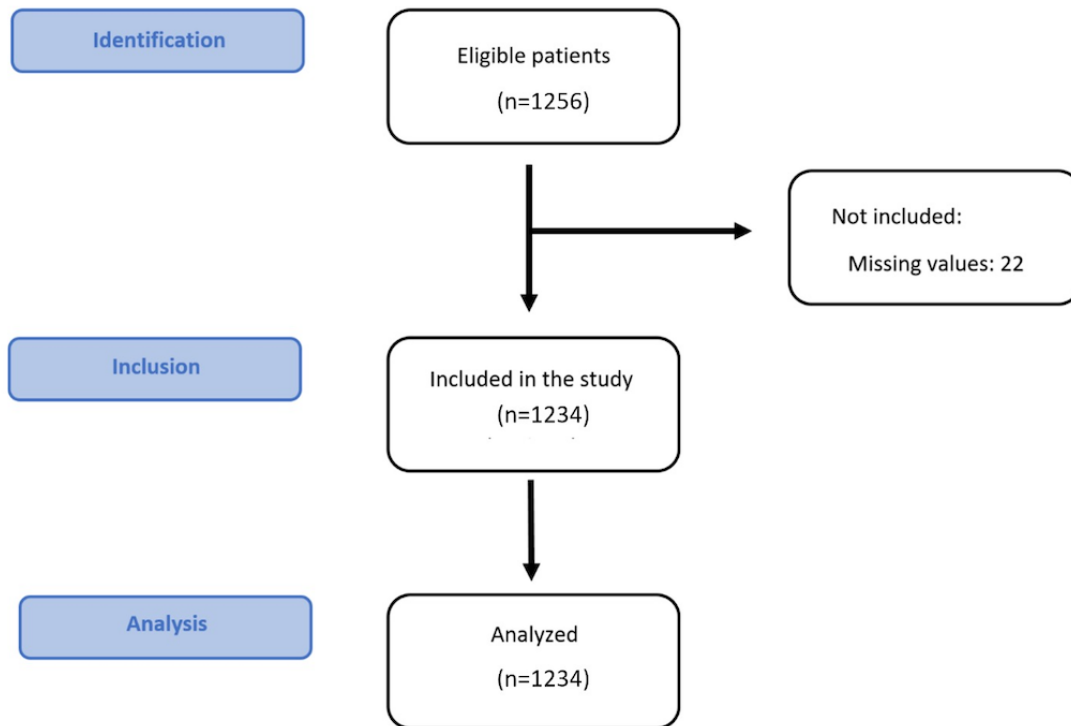
There were no significant differences between the AMC and CH patient groups for age, sex, and ASA classification (all $P>.05$; Table 1). For THA, 29.2% (130/445) of the cases performed at the AMC used general anesthesia, while 7.3% (12/164) of the cases performed at the CH used general anesthesia, despite no statistically significant difference in ASA classification. Results were similar for TKA, as 23.8% (109/457) of the cases performed at the AMC used general anesthesia, while 4.2% (7/168) of the cases performed at the CH used general anesthesia, despite no statistically significant difference in ASA classification. The observed average SCT was 14.61 minutes longer for surgeon 1 and 9.31 minutes longer for surgeon 2 at the AMC in comparison to the CH for THA procedures. Furthermore, the observed average SCT was 18.01 minutes longer for surgeon 1 and 14.37 minutes longer for surgeon 2 at the AMC in comparison to the CH for TKA procedures (Table 2). The values for ACT also consistently showed increased time at the AMC for both THA and TKA cases for both surgeons (Table 2).

Table 1. Patient demographics and case characteristics.

Characteristics	Cases performed at AMC[a] (n=902)	Cases performed at CH[b] (n=332)	P value[c]
Patient demographics			
Age (years), mean (SD)	63.1 (12.5)	63.5 (10.4)	.59
Female sex, n (%)	n (59.1)	n (60.5)	.70
Procedure and its ASA[d] classification, n (%)			
THA[e] (AMC: n=445; CH: n=164)			
I/II	266 (59.8)	110 (67.1)	.12
III/IV	179 (40.2)	54 (32.9)	N/A[f]
TKA[g] (AMC: n=457; CH: n=168)			
I/II	261 (57.1)	107 (63.7)	.17
III/IV	195 (42.7)	61 (36.3)	N/A
Procedure and its anesthetic classification, n (%)			
THA (AMC: n=445; CH: n=164)			
General anesthesia	130 (29.2)	12 (7.3)	<.001
Neuraxial anesthesia	315 (70.8)	152 (92.7)	N/A
TKA (AMC: n=457; CH: n=168)			
General anesthesia	109 (23.8)	7 (4.2)	<.001
Neuraxial anesthesia	348 (76.2)	161 (95.8)	N/A
Missing documentation	1 (0.2)	0 (0)	N/A

[a]AMC: academic medical center.

[b]CH: community hospital.

[c]P values correspond to a hypothesis test for the association of the study variable with surgical location. Continuous variables are assessed via 2-tailed t test and dichotomous variables via a difference of proportions test.

[d]ASA: American Society of Anesthesiologists.

[e]THA: total hip arthroplasty.

[f]N/A: not applicable.

[g]TKA: total knee arthroplasty.

Table 2. Comparison of the mean (SD) ACT[a] and SCT[b] for total hip arthroplasty and total knee arthroplasty between surgeons and between operative settings.

Outcome and variable	Total hip arthroplasty		Total knee arthroplasty	
	AMC[c], mean (SD)	CH[d], mean (SD)	AMC, mean (SD)	CH, mean (SD)
ACT (min)				
Surgeon 1	27.03 (12.97)	24.07 (8.01)	24.91 (11.34)	20.29 (7.72)
Surgeon 2	25.18 (10.69)	20.98 (8.67)	22.71 (8.34)	20.51 (7.42)
SCT (min)				
Surgeon 1	116.46 (27.03)	101.85 (25.08)	116.49 (25.56)	102.63(18.45)
Surgeon 2	111.96 (31.7)	102.61 (23.03)	106.26 (43.72)	91.99 (16.28)

[a]ACT: anesthesia-controlled time.

[b]SCT: surgery-controlled time.

[c]AMC: academic medical center.

[d]CH: community hospital.

Location and surgeon identity were included as independent variables. After adjusting for surgeon, the mean ACT for THA at the AMC was 3.77 (95% CI 1.83-5.71) minutes longer than for the CH and 3.58 (95% CI 1.91-5.26) minutes longer for TKA (both *P*<.001; Table 3). After adjusting for surgeon, the mean SCT at the AMC was 11.14 (95% CI 6.02-16.26) minutes

longer for THA and 14.04 (95% CI 8.43-19.65) minutes longer for TKA (both P<.001; Table 3) in comparison to the CH. Having a moderate to severe systemic disease (ASA class III/IV) increased the ACT by 3.76 (95% CI 2.00-5.51; P<.001) minutes and SCT by 6.33 (95% CI 1.66-10.99; P=.008) minutes for THA after adjusting for location and surgeon (Table 4). Having an ASA classification of III/IV did not significantly increase

the ACT time for TKA (P=.08; Table 4). There was no significant difference noted for ACT and SCT between neuraxial anesthesia and general anesthesia (all P>.05; Table 5). For all models, the adjusted R^2 was less than 10%, indicating that a significant amount of the variation in ACT and SCT is not explained by hospital, surgeon, ASA classification, or anesthetic used.

Table 3. Multivariable linear regression coefficients for the association of ACT[a] and SCT[b] with hospital and surgeon.

Outcome and variable	Total hip arthroplasty[c]			Total knee arthroplasty[d]		
	Estimates (min)	95% CI	P value	Estimates (min)	95% CI	P value
ACT						
Coefficient intercept	23.47	21.42 to 25.51	<.001	21.03	19.47 to 22.58	<.001
AMC[e]	3.77	1.83 to 5.71	<.001	3.58	1.91 to 5.26	<.001
Surgeon 1	–2.18	–3.98 to –0.38	.02	–1.57	–3.06 to –0.08	.04
SCT						
Coefficient intercept	104.43	99.04 to 109.83	<.001	102.50	97.29 to 107.71	<.001
AMC	11.14	6.02 to 16.26	<.001	14.04	8.43 to 19.65	<.001
Surgeon 1	–3.12	–7.87 to 1.63	.20	–10.34	–15.33 to –5.35	<.001

[a]ACT: anesthesia-controlled time.

[b]SCT: surgery-controlled time.

[c]ACT for total hip arthroplasty had 609 observations and an R^2/R^2 adjusted value of 0.033/0.030; and total knee arthroplasty had 625 observations and an R^2/R^2 adjusted value of 0.033/0.029.

[d]SCT for total hip arthroplasty had 609 observations and an R^2/R^2 adjusted value of 0.032/0.029; and total knee arthroplasty had 625 observations and an R^2/R^2 adjusted value of 0.058/0.055.

[e]AMC: academic medical center.

Table 4. Multivariable linear regression coefficients for the association of ACT[a] and SCT[b] with ASA[c], hospital, and surgeon.

Outcome and variable	Total hip arthroplasty[d]			Total knee arthroplasty[e]		
	Estimates (min)	95% CI	P value	Estimates (min)	95% CI	P value
ACT						
Coefficient intercept	22.13	20.02 to 24.24	<.001	20.53	18.87 to 22.18	<.001
ASA class III/IV	3.76	2.00 to 5.51	<.001	1.33	–0.18 to 2.84	.08
AMC[f]	3.50	1.58 to 5.42	<.001	3.50	1.82 to 5.18	<.001
Surgeon 1	–2.03	–3.81 to –0.25	.03	–1.53	–3.02 to –0.03	.045
SCT						
Coefficient intercept	102.18	96.56 to 107.80	<.001	101.56	96.02 to 107.11	<.001
ASA class III/IV	6.33	1.66 to 10.99	.008	2.61	–2.46 to 7.67	.31
AMC	10.69	5.58 to 15.79	<.001	13.82	8.19 to 19.44	<.001
Surgeon 1	–2.87	–7.60 to 1.86	.23	–10.36	–15.36 to –5.36	<.001

[a]ACT: anesthesia-controlled time.

[b]SCT: surgery-controlled time.

[c]ASA: American Society of Anesthesiologists.

[d]ACT for total hip arthroplasty had 609 observations and an R^2/R^2 adjusted value of 0.061/0.056; and total knee arthroplasty had 624 observations and an R^2/R^2 adjusted value of 0.037/0.003.

[e]SCT for total hip arthroplasty had 609 observations and an R^2/R^2 adjusted value of 0.043/0.039; and total knee arthroplasty had 624 observations and an R^2/R^2 adjusted value of 0.060/0.055.

[f]AMC: academic medical center.

Table 5. Multivariable linear regression coefficients for the association of ACT[a] and SCT[b] with anesthesia, hospital, and surgeon.

Outcome and variable	Total hip arthroplasty[c]			Total knee arthroplasty[d]		
	Estimates (min)	95% CI	*P* value	Estimates (min)	95% CI	*P* value
ACT						
Coefficient intercept	22.15	19.29 to 25.01	<.001	19.35	16.91 to 21.78	<.001
Neuraxial anesthesia	1.38	–0.71 to 3.47	.92	1.75	–0.21 to 3.70	.11
AMC[e]	4.08	2.08 to 6.07	<.001	3.83	2.21 to 5.64	<.001
Surgeon 1	–2.12	–3.92 to –0.32	.02	–1.56	–3.05 to –0.07	.04
SCT						
Coefficient intercept	105.56	98.01 to 113.11	<.001	103.01	94.93 to 111.20	<.001
Neuraxial anesthesia	–1.18	–6.71 to 4.35	.68	–0.53	–7.09 to 6.03	.87
AMC	10.88	5.62 to 16.15	<.001	13.93	8.17 to 19.70	<.001
Surgeon 1	–3.17	–7.93 to 1.59	.19	–10.34	–15.34 to –5.35	<.001

[a]ACT: anesthesia-controlled time.

[b]SCT: surgery-controlled time.

[c]ACT for total hip arthroplasty had 609 observations and an R^2/R^2 adjusted value of 0.036/0.031; and total knee arthroplasty had 625 observations and an R^2/R^2 adjusted value of 0.037/0.033.

[d]SCT for total hip arthroplasty had 609 observations and an R^2/R^2 adjusted value of 0.033/0.028; and total knee arthroplasty had 625 observations and an R^2/R^2 adjusted value of 0.058/0.054.

[e]AMC: academic medical center.

Discussion

Overview

A paucity of literature exists for benchmarking operative times in different surgical settings, and our study therefore aimed to refine the prediction of surgical case duration for THA and TKA between an academic center and a CH for the same orthopedic surgeons. Our results showed that both SCT and ACT were statistically significantly longer for primary hip and knee arthroplasty at the AMC compared with the CH. The mean ACT was higher at the AMC by less than 4 minutes for THA and TKA for both surgeons, and this modest increase in ACT when trainees are present is consistent with previous reports [12,13]. Therefore, although the participation of anesthesia trainees at the AMC may elongate the ACT, these results are not clinically meaningful in the context of OR efficiency—decreases in ACT have not been shown to permit the scheduling of another OR case in a workday but may be relevant for patient satisfaction and experience [14]. In addition, it is crucial to recognize the value of surgical training and its pivotal role in preparing the next generation of health care providers. Finding a balance between providing trainees with comprehensive experiences while maintaining operational efficiency is crucial.

The mean SCT was greater at the academic center for THA and TKA procedures compared with the CH. Our results may have clinically significant implications, as a 16-minute difference in 4 cases can result in an extra hour of operating time per day, allowing for the scheduling of another short case during a normal surgical block or relieving staff in the OR earlier to reduce overtime call coverage pay. Previous studies have shown that operative time significantly increases when procedures are

performed with surgical resident or surgical fellow participation [15,16]. The R^2 values in our results (<10%, Tables 3-5) also indicate the existence of other covariates that were not adjusted for in our multiple linear regression modeling such as the presence of scrub technician trainees, anesthesia trainees, surgical trainees, or traveling nursing staff who are not regularly participating in orthopedic surgery cases at the hospital. Therefore, understanding this cost of training surgical residents, nursing, and scrub technician staff can help OR managers find a balance between achieving scheduling and financial targets while exploring strategies to provide adequate educational opportunities.

Furthermore, it is pragmatic to identify other factors that could affect OR efficiency (ie, type of anesthesia, performing secondary procedures during the joint replacement, or performing bilateral procedures). In this study, we observed no significant differences between the ACT or SCT for both surgical centers when comparing general anesthesia versus neuraxial anesthesia. The current literature offers mixed results about the effect of anesthesia type on surgical time. A meta-analysis comparing the use of neuraxial anesthesia versus general anesthesia found no significant differences in surgical time for a variety of cases [17]. Contrastingly, a different study found that spinal anesthesia significantly reduced the duration of TKA surgery and resulted in decreases in the rates of thromboembolic events, infections, blood transfusion rates, and hospital length of stay [18]. Another study also found significant decreases in ACT when regional anesthesia was used [19-21]. Furthermore, there is limited literature exploring the implication of ASA classification on SCT or ACT. Previous studies propose a positive correlation between ASA classification and perioperative complication rates for patients undergoing fixation

of hip fractures [22]. ASA classification is also a significant predictor of length of stay cost for patients undergoing TKA [23,24]. In our study, there was an increase in ACT and SCT by approximately 4 and 6 minutes respectively for both surgical centers when the patient had moderate to severe systemic disease (ASA class III or IV) compared with patients with mild or no systemic disease (ASA class I or II). With over 3700 primary joint arthroplasty cases performed across the AMC's hospitals per year, a 10-minute decrease in ACT and SCT per case could result in 37,000 available OR minutes, equating to greater than 200 additional orthopedic cases (at an average of 155 minutes per case).

Limitations

Our study has several limitations. One of the limitations of this study is the sample size. Even with 1234 cases, there was still an underrepresentation of patients with ASA classifications of I and IV. While we feel this sample represents the patient population that normally receives primary joint replacement surgery, a larger cohort would allow for a more granular analysis of each ASA classification group. A second limitation is associated with the generalizability of this study. Our analysis was performed at 1 AMC and 1 CH. Only 2 surgeons were tracked for this study due to their unique movement between the 2 clinical sites. A larger cohort of surgeons with a similar multisite practice pattern could provide data that would be more generalizable. Furthermore, the perioperative environment and considerations at other academic and CHs could lead to different results. Therefore, the increased difference seen in SCT in our study could be a result of differences in OR culture between academic institutions and CHs, along with increased time required for on-the-job education for trainees in nursing and scrub technicians. Individual variation in the documentation of the surgery process could also be a confounding variable for the calculation of ACT and SCT. In addition, the decision-making process regarding the choice of surgical center involves a complex interplay of patient and surgical factors, some of which may not have been captured in our analysis. For example, the selection of cases for the academic center hospital may be influenced by factors such as case complexity, patient comorbidities, or surgeon preference. These potential biases could introduce uncontrolled variability into the ACT or SCT. Last, we define *Ready for Positioning* as the time point when anesthesia had completed its activities and when the patient was prepared for surgical positioning including completion of any additional intravenous lines or invasive monitoring if required for the procedure. However, other logistical factors may influence the actual commencement of surgery. Therefore, although our definition represents the point when anesthesia activities were complete, it does not imply the presence and readiness of the surgical team. Future directions of this study include assessing the effect of different levels of trainee and surgical nursing team involvement in our analysis, in addition to comparisons of cost and clinical outcomes between the 2 hospital locations and postoperative outcomes including complication rates.

Conclusions

OA is 1 of the 10 leading causes of disability in developed countries and the consequential growth in the volume of hip and knee replacement surgeries to manage end-stage OA will contribute to substantial and rising health expenditure [25,26]. Therefore, it is critical to optimize OR scheduling and management to maximize efficiency and decrease costs for both health systems and patients. As the demand for THA and TKA grows, it will be increasingly important to optimize OR efficiency for those surgeries. This study aims to validate and compare benchmarking times for ACT and SCT in a single patient population in both an academic center and a CH. One major application of these findings is that there is an efficiency benefit of performing primary joint replacements in our CH, as demonstrated by an average 16-minute reduction of SCT and a 4-minute reduction of ACT per case. This equates to a savings of approximately 80 minutes over the course of 4 surgical cases in a day, which could allow for the scheduling of another case. Such data can help to increase the reliability of surgical duration predictions and optimize scheduling to ultimately improve OR use, reduce cost, and improve patient experience.

Data Availability

The data sets generated or analyzed during this study are available from the corresponding author on reasonable request.

Authors' Contributions

TBN, KMW, NW, CH, RMK, VJT, CS, and AAF drafted the manuscript. TBN, KMW, NW, CH, RMK, VJT, CS, and AAF revised the manuscript. TBN, KMW, and AAF performed data analysis and interpretation. AAF was the principal investigator, performed the study design, and drafted the study protocol.

Conflicts of Interest

None declared.

XSL•FO

RenderX

Multimedia Appendix 1
STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) checklist.
[PDF File (Adobe PDF File), 89 KB - periop_v7i1e45126_app1.pdf]

References

1. Hootman JM, Helmick CG. Projections of US prevalence of arthritis and associated activity limitations. Arthritis Rheum 2006;54(1):226-229 [FREE Full text] [doi: 10.1002/art.21562] [Medline: 16385518]

2. Ethgen O, Bruyère O, Richy F, Dardennes C, Reginster JY. Health-related quality of life in total hip and total knee arthroplasty. a qualitative and systematic review of the literature. J Bone Joint Surg Am 2004;86(5):963-974 [FREE Full text] [doi: 10.2106/00004623-200405000-00012] [Medline: 15118039]

3. Kurtz S, Ong K, Lau E, Mowat F, Halpern M. Projections of primary and revision hip and knee arthroplasty in the United States from 2005 to 2030. J Bone Joint Surg Am 2007;89(4):780-785 [FREE Full text] [doi: 10.2106/JBJS.F.00222] [Medline: 17403800]

4. Singh JA, Yu S, Chen L, Cleveland JD. Rates of total joint replacement in the United States: future projections to 2020-2040 using the national inpatient sample. J Rheumatol 2019;46(9):1134-1140 [FREE Full text] [doi: 10.3899/jrheum.170990] [Medline: 30988126]

5. Boggs SD, Tan DW, Watkins CL, Tsai MH. OR management and metrics: how it all fits together for the healthcare system. J Med Syst 2019;43(6):147 [FREE Full text] [doi: 10.1007/s10916-019-1272-y] [Medline: 31011825]

6. van Veen-Berkx E, van Dijk MV, Cornelisse DC, Kazemier G, Mokken FC. Scheduling anesthesia time reduces case cancellations and improves operating room workflow in a university hospital setting. J Am Coll Surg 2016;223(2):343-351 [FREE Full text] [doi: 10.1016/j.jamcollsurg.2016.03.038] [Medline: 27063614]

7. Dexter F. Regional anesthesia does not significantly change surgical time versus general anesthesia—a meta-analysis of randomized studies. Reg Anesth Pain Med 1998;23(5):439-443. [doi: 10.1016/s1098-7339(98)90024-4] [Medline: 9773694]

8. Wu A, Huang CC, Weaver MJ, Urman RD. Use of historical surgical times to predict duration of primary total knee arthroplasty. J Arthroplasty 2016;31(12):2768-2772. [doi: 10.1016/j.arth.2016.05.038] [Medline: 27396691]

9. Simmons CG, Alvey NJ, Kaizer AM, Williamson K, Faruki AA, Kacmar RM, et al. Benchmarking of anesthesia and surgical control times by Current Procedural Terminology (CPT®) codes. J Med Syst 2022;46(4):19. [doi: 10.1007/s10916-022-01798-z] [Medline: 35244783]

10. Eijkemans MJC, van Houdenhoven M, Nguyen T, Boersma E, Steyerberg EW, Kazemier G. Predicting the unpredictable: a new prediction model for operating room times using individual characteristics and the surgeon's estimate. Anesthesiology 2010;112(1):41-49 [FREE Full text] [doi: 10.1097/ALN.0b013e3181c294c2] [Medline: 19952726]

11. Wang J, Cabrera J, Tsui KL, Guo H, Bakker M, Kostis JB. Clinical and nonclinical effects on operative duration: evidence from a database on thoracic surgery. J Healthc Eng 2020;2020:3582796 [FREE Full text] [doi: 10.1155/2020/3582796] [Medline: 32104558]

12. Urman RD, Sarin P, Mitani A, Philip B, Eappen S. Presence of anesthesia resident trainees in day surgery unit has mixed effects on operating room efficiency measures. Ochsner J 2012;12(1):25-29 [FREE Full text] [Medline: 22438778]

13. Eappen S, Flanagan H, Bhattacharyya N. Introduction of anesthesia resident trainees to the operating room does not lead to changes in anesthesia-controlled times for efficiency measures. Anesthesiology 2004;101(5):1210-1214 [FREE Full text] [doi: 10.1097/00000542-200411000-00022] [Medline: 15505458]

14. Nzeako O, Back D. Learning curves in arthroplasty in orthopedic trainees. J Surg Educ 2016;73(4):689-693 [FREE Full text] [doi: 10.1016/j.jsurg.2016.02.006] [Medline: 27168384]

15. Woolson ST, Kang MN. A comparison of the results of total hip and knee arthroplasty performed on a teaching service or a private practice service. J Bone Joint Surg Am 2007;89(3):601-607 [FREE Full text] [doi: 10.2106/JBJS.F.00584] [Medline: 17332109]

16. Weber M, Benditz A, Woerner M, Weber D, Grifka J, Renkawitz T. Trainee surgeons affect operative time but not outcome in minimally invasive total hip arthroplasty. Sci Rep 2017;7(1):6152 [FREE Full text] [doi: 10.1038/s41598-017-06530-3] [Medline: 28733672]

17. Wilson JM, Farley KX, Erens GA, Guild GN. General vs spinal anesthesia for revision total knee arthroplasty: do complication rates differ? J Arthroplasty 2019;34(7):1417-1422 [FREE Full text] [doi: 10.1016/j.arth.2019.03.048] [Medline: 31005435]

18. Paziuk TM, Luzzi AJ, Fleischman AN, Goswami K, Schwenk ES, Levicoff EA, et al. General vs spinal anesthesia for total joint arthroplasty: a single-institution observational review. J Arthroplasty 2020;35(4):955-959. [doi: 10.1016/j.arth.2019.11.019] [Medline: 31983564]

19. Mariano ER, Chu LF, Peinado CR, Mazzei WJ. Anesthesia-controlled time and turnover time for ambulatory upper extremity surgery performed with regional versus general anesthesia. J Clin Anesth 2009;21(4):253-257 [FREE Full text] [doi: 10.1016/j.jclinane.2008.08.019] [Medline: 19502033]

20. Williams BA, Kentor ML, Williams JP, Figallo CM, Sigl JC, Anders JW, et al. Process analysis in outpatient knee surgery: effects of regional and general anesthesia on anesthesia-controlled time. Anesthesiology 2000;93(2):529-538 [FREE Full text] [doi: 10.1097/00000542-200008000-00033] [Medline: 10910504]

XSL•FO
RenderX

21. Rundgren J, Navarro CM, Ponzer S, Regberg A, Serenius S, Enocson A. Regional or general anesthesia in the surgical treatment of distal radial fractures: a randomized clinical trial. J Bone Joint Surg Am 2019;101(13):1168-1176 [FREE Full text] [doi: 10.2106/JBJS.18.00984] [Medline: 31274718]

22. Garcia A, Bonnaig JV, Yoneda ZT, Richards JE, Ehrenfeld JM, Obremskey WT, et al. Patient variables which may predict length of stay and hospital costs in elderly patients with hip fracture. J Orthop Trauma 2012;26(11):620-623 [FREE Full text] [doi: 10.1097/BOT.0b013e3182695416] [Medline: 22832431]

23. Australian Orthopaedic Association Limited (AOA). Length of hospital stay after total knee replacement: the effect of patient controled analgesia. Orthop Proc 2012;94(Supp_XXIII):46 [FREE Full text] [doi: 10.1302/1358-992X.94BSUPP_XXIII.AOAoz2009-046]

24. Dexter F, Coffin S, Tinker JH. Decreases in anesthesia-controlled time cannot permit one additional surgical operation to be reliably scheduled during the workday. Anesth Analg 1995;81(6):1263-1268 [FREE Full text] [doi: 10.1097/00000539-199512000-00024] [Medline: 7486114]

25. Health at a Glance 2019 OECD Indicators. Paris: OECD Publishing; 2019.

26. Hunter DJ, Schofield D, Callander E. The individual and socioeconomic impact of osteoarthritis. Nat Rev Rheumatol 2014;10(7):437-441. [doi: 10.1038/nrrheum.2014.44] [Medline: 24662640]

Abbreviations

AA: anesthesiology assistant
ACT: anesthesia-controlled time
AMC: academic medical center
ASA: American Society of Anesthesiologists
CH: community hospital
CPT: current procedural terminology
OA: osteoarthritis
OR: operating room
SCT: surgery-controlled time
STROBE: Strengthening the Reporting of Observational Studies in Epidemiology
THA: total hip arthroplasty
TKA: total knee arthroplasty

XSL•FO
RenderX

<u>Original Paper</u>

Factors Influencing Neuromuscular Blockade Reversal Choice in the United States Before and During the COVID-19 Pandemic: Retrospective Longitudinal Analysis

Vladimir Turzhitsky[1], PhD; Lori D Bash[1], PhD; Richard D Urman[2*], MBA, MD; Michael Kattan[3*], PhD; Ira Hofer[4*], MD

[1]Merck & Co, Inc, Rahway, NJ, United States

[2]College of Medicine, The Ohio State University, Columbus, OH, United States

[3]Cleveland Clinic, Cleveland, OH, United States

[4]Icahn School of Medicine at Mount Sinai, New York, NY, United States

[*]these authors contributed equally

Corresponding Author:
Vladimir Turzhitsky, PhD
Merck & Co, Inc
126 E Lincoln Avenue
Rahway, NJ, 07065
United States
Phone: 1 781206642
Email: vladimir.turzhitsky@merck.com

Abstract

Background: Neuromuscular blockade (NMB) agents are a critical component of balanced anesthesia. NMB reversal methods can include spontaneous reversal, sugammadex, or neostigmine and the choice of reversal strategy can depend on various factors. Unanticipated changes to clinical practice emerged due to the COVID-19 pandemic, and a better understanding of how NMB reversal trends were affected by the pandemic may help provide insight into how providers view the tradeoffs in the choice of NMB reversal agents.

Objective: We aim to analyze NMB reversal agent use patterns for US adult inpatient surgeries before and after the COVID-19 outbreak to determine whether pandemic-related practice changes affected use trends.

Methods: A retrospective longitudinal analysis of a large all-payer national electronic US health care database (PINC AI Healthcare Database) was conducted to identify the use patterns of NMB reversal during early, middle, and late COVID-19 (EC, MC, and LC, respectively) time periods. Factors associated with NMB reversal choices in inpatient surgeries were assessed before and after the COVID-19 pandemic reached the United States. Multivariate logistic regression assessed the impact of the pandemic on NMB reversal, accounting for patient, clinical, procedural, and site characteristics. A counterfactual framework was used to understand if patient characteristics affected how COVID-19–era patients would have been treated before the pandemic.

Results: More than 3.2 million inpatients experiencing over 3.6 million surgical procedures across 931 sites that met all inclusion criteria were identified between March 1, 2017, and December 31, 2021. NMB reversal trends showed a steady increase in reversal with sugammadex over time, with the trend from January 2018 onwards being linear with time (R^2>0.99). Multivariate analysis showed that the post–COVID-19 time periods had a small but statistically significant effect on the trend, as measured by the interaction terms of the COVID-19 time periods and the time trend in NMB reversal. A slight increase in the likelihood of sugammadex reversal was observed during EC relative to the pre–COVID-19 trend (odds ratio [OR] 1.008, 95% CI 1.003-1.014; *P*=.003), followed by negation of that increase during MC (OR 0.992, 95% CI 0.987-0.997; *P*<.001), and no significant interaction identified during LC (OR 1.001, 95% CI 0.996-1.005; *P*=.81). Conversely, active reversal (using either sugammadex or neostigmine) did not show a significant association relative to spontaneous reversal, or a change in trend, during EC or MC (*P*>.05), though a slight decrease in the active reversal trend was observed during LC (OR 0.987, 95% CI 0.983-0.992; *P*<.001).

Conclusions: We observed a steady increase in NMB active reversal overall, and specifically with sugammadex compared to neostigmine, during periods before and after the COVID-19 outbreak. Small, transitory alterations in the NMB reversal trends

XSL•FO
RenderX

were observed during the height of the COVID-19 pandemic, though these alterations were independent of the underlying NMB reversal time trends.

Introduction

The neuromuscular blockade (NMB) agents rocuronium and vecuronium help achieve and maintain optimal levels of muscle paralysis to facilitate intubation and ensure patient immobility during surgery. Following surgery, recovery of neuromuscular function is accomplished via spontaneous recovery or through active pharmacologic reversal. Spontaneous recovery can be slow and unpredictable and can result in residual neuromuscular blockade (rNMB) associated with deleterious consequences, including muscle weakness, impaired respiration, and postoperative pulmonary complications [1-4]. The incidence of rNMB with spontaneous recovery can vary widely but can reach and exceed 50% [3,5-7].

Additionally, 2 pharmacologic agents, neostigmine and sugammadex, are available for active NMB reversal. Neostigmine is an anticholinesterase inhibitor, while sugammadex acts as a selective direct inhibitor of rocuronium and vecuronium that allows for rapid, predictable reversal, even at deep NMB levels. Following the approval of sugammadex in the United States in 2016, the proportion of procedures using active reversal (vs spontaneous reversal) steadily increased through mid-2019. This coincided with the growing use of sugammadex for reversal, though significant practice variability has been observed based on patient, procedural, and environmental factors [8,9].

At the start of the COVID-19 pandemic, hospitals rapidly adopted measures to reduce viral exposure and reallocated resources to emergency departments and intensive care units. For surgical units, elective procedures were largely postponed while recommendations favored anesthetic techniques aimed to minimize aerosolization and contamination of the environment [10-12]. For example, the use of rapid sequence intubation became common if not standard, and interventions to shorten postanesthesia care unit (PACU) stay duration, such as using efficient NMB reversal strategies, would be advantageous in minimizing exposure risk. However, initial studies during the early COVID-19 period had not revealed the long-lasting impacts of the pandemic on surgical practice [13-15]. A more in-depth assessment may reveal subtle changes in anesthesia practice as hospitals transitioned from early to late COVID-19 eras.

This study analyzes NMB reversal agent use patterns for US adult inpatient surgeries before and after the COVID-19 outbreak to determine whether pandemic-related practice changes affected use trends established before COVID-19. By understanding these trends, we can gain insight into how NMB management has evolved following COVID-19 and potentially recognize patient, procedural, and institutional factors that were associated with these changes. We hypothesize that the use of sugammadex for NMB reversal would accelerate in the post–COVID-19 period given the evidence demonstrating decreased PACU time and, potentially, diminished exposure to COVID-19 [16,17]. We make use of methods such as counterfactual analysis, which have been introduced as an effective approach for inferring causality on retrospective health care data in general [18-25] and impacts of the COVID-19 pandemic in particular [26,27].

Methods

Data Source

A retrospective analysis was conducted on US adult inpatient surgical procedures occurring between March 1, 2017, and December 31, 2021, within the PINC AI Healthcare Database (PHD) [28]. The PHD is a large, US hospital–based, service-level, all-payer database that contains information on inpatient discharges, primarily from geographically diverse nonprofit, nongovernmental, and community and teaching hospitals and health systems from rural and urban areas. Hospitals or health care systems submit administrative, health care use, and financial data from patient encounters. Inpatient admissions include over 108 million visits with more than 8 million per year since 2012, representing approximately 25% of annual US inpatient admissions.

Ethical Considerations

This study used preexisting data with no identifiable information and therefore does not require institutional review board review per Federal Regulations for the Protection of Human Research Subjects (45CFR 46.102(e)) or patient consent [29]. All patient-related study data (eg, demographics, disease state, and information on billed services such as medications, laboratory tests, diagnostics, and therapeutic services) were accessed in compliance with the Health Insurance Portability and Accountability Act of 1996. This analysis was conducted and reported per the Strengthening the Reporting of Observational Studies in Epidemiology guidelines.

Patient Selection

US adults aged ≥18 years and who received rocuronium or vecuronium during an inpatient surgical procedure were

included. Exclusion criteria were a diagnosis of myasthenia gravis or renal failure, receiving pyridostigmine therapy, NMB reversal with both sugammadex and neostigmine, pregnancy (proxied by women undergoing obstetrical procedures), or those diagnosed with COVID-19 (for encounters occurring in 2020 and 2021). For any hospitalized patient undergoing multiple surgeries during a calendar 30-day period or a given inpatient stay, only the first surgery was included in the analysis.

For each eligible patient, information on demographics, clinical characteristics (eg, age, gender, anthropometrics, and comorbidities), insurance status, admission status (eg, elective, emergency, or trauma), site characteristics (eg, hospital size and geographic region), and anatomic location of the surgery were collected. Additionally, the type of NMB agent administered (rocuronium or vecuronium) as well as the reversal strategy (eg, neostigmine, sugammadex, or no active pharmacologic reversal) were recorded. The use of rocuronium or vecuronium for NMB was the inclusion criteria for this study due to the aim of quantifying NMB reversal practice changes in the sugammadex-eligible population. Data were categorized by time period in the following manner: baseline period (BP, March 1, 2017, to February 29, 2019); before COVID-19 era (BC, March 1, 2019, to February 29, 2020); early COVID-19 era (EC, April 1, 2020, to July 31, 2020); middle COVID-19 era (MC, August 1, 2020, to December 31, 2020); and late COVID-19 era (LC, January 1, 2021, to December 31, 2021). For this study, the post–COVID-19 period encompasses EC, MC, and LC time periods. The month of March 2020 was omitted in these analyses to account for a transition period and due to the unavailability of COVID-19 diagnostic information. The EC period was predominated by the early part of the breakout, the lack of information beyond testing for COVID-19 and implementing strict measures to reduce viral exposure within the hospital setting; the MC period correlated with the initial availability of COVID-19 vaccination for health care workers, thus (theoretically) lessening the impact of the pandemic on health care decisions; the LC period reflects when vaccines were available to the general public and restrictive infection control measures were loosened.

Statistical Analyses

NMB use was summarized by characteristics using descriptive statistics. Similarly, NMB reversal strategies (ie, sugammadex, neostigmine, or no reversal) were summarized by time period, patient, site, and procedural characteristics using descriptive statistics.

Multivariable Analysis

To identify factors related to NMB reversal choice during the COVID-19 and pre–COVID-19 eras, 2 multivariable logistic regression models were developed similarly to previous studies that modeled NMB reversal choices using PHD through June 2019 [8,9]. The first logistic regression models (model 1a and model 1b) aimed to test the effect of the COVID-19 time period on reversal choices by accounting for patient, hospital, and procedural characteristics. Encounters spanning both time periods (pre– and post–COVID-19) were included in these models to test for the overall effect of the COVID-19 era on reversal patterns, after accounting for all the covariates. Model

1a evaluated the effect of active (pharmacological) versus no (nonpharmacological) NMB reversal while model 1b evaluated sugammadex versus neostigmine reversal. Model 1 takes into account the trend in reversal over time by modeling the changes in NMB reversal as a linear trend over the period of January 1, 2018, to December 31, 2021. The effect of EC, MC, and LC eras are modeled as an interaction of the corresponding time period flag with the time-trend variable. For example, a positive interaction term coefficient between a post–COVID-19 period and time-trend variable in model 1b indicates a more rapidly increasing likelihood of sugammadex being used in the post–COVID-19 era as compared to the trend in the pre–COVID-19 time periods. The results from model 1 provide an overall estimate of the effect of the COVID-19 time period but do not provide insight into the effects for various population subtypes.

Counterfactual Analysis

Model 2 was constructed and used in a counterfactual analysis to address model 1's inability to evaluate changes in NMB reversal over time within patient subgroups. Models 2a (active vs no NMB reversal) and 2b (sugammadex vs neostigmine) were constructed using pre–COVID-19 data (January 1, 2018, to February 29, 2020) to be able to predict how a patient would have their NMB reversed (or not) based on their encounter characteristics. These models also include a continuous time variable that accounts for a linear trend to the log likelihood of the NMB reversal choice, to extrapolate this trend to the COVID-19 eras. Model accuracy, such as the receiver operating characteristic curve, is reported to help gauge the utility of these models for counterfactual analysis.

Counterfactual analysis was conducted to predict how COVID-19–era patients would have been reversed had they been treated during the pre–COVID-19 era based on their demographic, clinical, and institutional characteristics. The differences between the observed sugammadex reversal in the COVID-19 eras (actual) and the hypothetical or predicted reversal had each of those patients been seen pre–COVID-19 based on model 2 (counterfactual) were calculated. The differences in actual versus counterfactual reversal choices were then compared for each of the patient demographic, clinical, and institutional characteristics (eg, age group, comorbidities, surgery type, or hospital size). The counterfactual model was calibrated by adjusting the cutoff probability threshold to result in the same number of predicted classes (eg, sugammadex and neostigmine) as were actually observed in the combined COVID-19 eras. The odds ratios (OR) were also normalized such that the total patient-weighted OR was 1, which removed any residual time-dependent drift from the counterfactual model. The NMB reversal was compared between actual and counterfactual for each demographic, clinical, and institutional characteristic by obtaining ORs and CIs based on contingency tables for each covariate.

All statistical analyses were performed using SAS software (version 9.4; SAS Institute Inc).

Results

Study Population

Among the nearly 39.4 million inpatient encounters evaluated between March 1, 2017, and December 31, 2021, in the PHD, a total of 3,289,747 patients and 3,602,887 procedures involved the use of rocuronium or vecuronium and met all inclusion and exclusion criteria. The number of encounters included 1,644,370 during BP, 820,078 during BC, and 1,138,439 during the 3 post–COVID-19 periods (Table S1 in Multimedia Appendix 1). Patient demographics and characteristics were generally similar across the time periods despite attaining statistical significance driven by the large sample size (Table 1). Mean age (SD) ranged from 58.5 (16.76) years in the EC period to 59.0 (16.35) years during BC. A slightly higher percentage of patients were women (range 108,541/209,451, 51.8% in EC to 890,910/1,644,370, 54.2% in BP), and most patients identified as White (range 477,774/628,197, 76.1% in LC to 1,287,545/1,644,370, 78.3% in BP) throughout the study.

The percentage of patients with at least 1 comorbidity trended higher during this study's period, increasing from 80.4% (1,321,911/1,644,370) during BP to 85.2% (535,076/628,197)

by LC. The largest increases in comorbidity rates (>2% increase from BP to LC) were observed in cardiac arrhythmias, fluid or electrolyte disorders, and obesity or overweight conditions. The percentage of admissions due to elective procedures decreased between BC and EC (from 451,190/820,078, 55%, to 98,637/209,451, 47.1%) and there was a corresponding rise in the percentage of emergency or urgent admissions during these time periods (from 348,840/820,078, 42.5%, during BC to 104,123/209,451, 49.7% during EC).

Among the 3.6 million patient encounters included in this analysis, a majority involved teaching hospitals (range 885,068/1,644,370, 53.8%, in BP to 358,262/628,197, 57% in LC) and approximately 90% occurred in urban institutions (range 188,028/209,451, 89.8% in EC to 571,412/828,197, 91% in LC, Table S2 in Multimedia Appendix 1). The largest proportion of encounters (1,516,497/3,602,887, 42.1%) involved hospitals with 500 or more beds, while institutions with fewer than 200 beds accounted for approximately 15.5% (559,884/3,602,887) of encounters. Nearly half (1,736,173/3,602,887, 48.2%) of the encounters involved institutions in the South, 23% (828,275/3,602,887) from the Midwest, 14.6% (525,401/3,602,887) from the West, and the remaining 14.2% (513,038/3,602,887) from the Northeast.

Table 1. Patient characteristics.

	BP[a] (n=1,644,370)	BC[b] (n=820,078)	EC[c] (n=209,451)	MC[d] (n=300,791)	LC[e] (n=628,197)
Age[f] (years)					
Mean (SD)	58.6 (16.31)	59.0 (16.35)	58.5 (16.76)	58.6 (16.57)	58.8 (16.85)
Minimum, Maximum	18, 89	18, 89	18, 89	18, 89	18, 89
Median (IQR)	61 (48-70)	61 (48-71)	61 (47-71)	61 (48-71)	61 (47-71)
Age category[f] (years), n (%)					
18-30	112,133 (6.8)	54,225 (6.6)	15,683 (7.5)	21,128 (7)	45,338 (7.2)
31-40	147,963 (9)	73,238 (8.9)	19,839 (9.5)	28,467 (9.5)	61,031 (9.7)
41-50	217,072 (13.2)	105,670 (12.9)	27,043 (12.9)	39,092 (13)	80,868 (12.9)
51-60	340,761 (20.7)	162,767 (19.8)	40,873 (19.5)	58,449 (19.4)	117,202 (18.7)
61-70	416,743 (25.3)	207,379 (25.3)	51,304 (24.5)	74,935 (24.9)	153,046 (24.4)
71-80	288,194 (17.5)	153,377 (18.7)	38,255 (18.3)	55,684 (18.5)	118,827 (18.9)
>80	121,504 (7.4)	63,422 (7.7)	16,454 (7.9)	23,036 (7.7)	51,885 (8.3)
Sex female[f], n (%)	890,910 (54.2)	440,317 (53.7)	108,541 (51.8)	159,893 (53.2)	333,931 (53.2)
Race[f], n (%)					
Asian	25,205 (1.5)	13,155 (1.6)	3811 (1.8)	5502 (1.8)	13,947 (2.2)
Black	172,317 (10.5)	86,619 (10.6)	22,820 (10.9)	34,421 (11.4)	74,791 (11.9)
White	1,287,545 (78.3)	634,056 (77.3)	163,018 (77.8)	232,506 (77.3)	477,774 (76.1)
Hispanic ethnicity[f], n (%)	141,183 (8.6)	73,837 (9)	18,426 (8.8)	27,853 (9.3)	68,885 (11)
Insurance[f,g], n (%)					
Commercial	665,441 (40.5)	317,972 (38.8)	79,909 (38.2)	115,013 (38.2)	231,540 (36.9)
Government	749,389 (45.6)	383,018 (46.7)	96,045 (45.9)	138,052 (45.9)	289,800 (46.1)
Low-income	212,173 (12.9)	108,509 (13.2)	30,647 (14.6)	43,737 (14.5)	97,210 (15.5)
Comorbidites ≥1[f], n (%)	1,321,911 (80.4)	676,491 (82.5)	175,939 (84)	252,355 (83.9)	535,076 (85.2)
Comorbidities[h], n (%)					
Cardiac arrhythmias[f]	278,499 (16.9)	148,374 (18.1)	39,801 (19)	56,421 (18.8)	124,456 (19.8)
Chronic pulmonary disease[f]	303,871 (18.5)	157,402 (19.2)	40,808 (19.5)	58,895 (19.6)	123,865 (19.7)
Congestive heart failure[f]	114,852 (7)	64,837 (7.9)	18,118 (8.7)	25,313 (8.4)	57,681 (9.2)
Depression[f]	216,235 (13.2)	115,225 (14.1)	29,414 (14)	44,250 (14.7)	91,828 (14.6)
Diabetes (complicated)[f]	131,594 (8)	74,660 (9.1)	21,230 (10.1)	29,410 (9.8)	65,836 (10.5)
Diabetes (uncomplicated)[f]	223,314 (13.6)	108,624 (13.2)	26,276 (12.5)	38,592 (12.8)	80,350 (12.8)
Fluid or electrolyte disorders[f]	325,819 (19.8)	174,481 (21.3)	52,486 (25.1)	70,018 (23.3)	152,579 (24.3)
Hypothyroidism[f]	200,129 (12.2)	103,612 (12.6)	25,704 (12.3)	37,537 (12.5)	78,411 (12.5)
Obesity or overweight[f]	394,421 (24)	210,688 (25.7)	54,282 (25.9)	82,251 (27.3)	173,667 (27.6)
Other neurological disorders[f]	117,534 (7.1)	63,352 (7.7)	18,501 (8.8)	25,511 (8.5)	55,371 (8.8)
Peripheral vascular disorders[f]	125,078 (7.6)	67,508 (8.2)	18,339 (8.8)	26,595 (8.8)	58,697 (9.3)
Sleep apnea[f]	147,851 (9)	81,705 (10)	19,498 (9.3)	30,259 (10.1)	65,179 (10.4)
Solid tumor without metastasis[f]	194,163 (11.8)	98,675 (12)	27,302 (13)	36,644 (12.2)	81,145 (12.9)
COVID-19 not present[f,i], n (%)	1,644,142 (100)	819,852 (100)	209,200 (99.9)	299,296 (99.5)	601,470 (95.7)

	BP[a] (n=1,644,370)	BC[b] (n=820,078)	EC[c] (n=209,451)	MC[d] (n=300,791)	LC[e] (n=628,197)
Admission type[f], n (%)					
Elective	932,608 (56.7)	451,190 (55)	98,637 (47.1)	156,479 (52)	307,003 (48.9)
Emergency or urgent	674,323 (41)	348,840 (42.5)	104,123 (49.7)	136,181 (45.3)	302,208 (48.1)
Trauma center	37,439 (2.3)	20,048 (2.4)	6691 (3.2)	8131 (2.7)	18,986 (3)

[a]BP: baseline period.

[b]BC: before COVID-19 era.

[c]EC: early COVID-19 era.

[d]MC: middle COVID-19 era.

[e]LC: late COVID-19 era.

[f]Statistically significant at the $P<.05$ level.

[g]Commercial category includes managed care, workers' compensation, and self-pay. The government category includes Medicare and other government insurance types. The low-income category includes Medicaid, charity, and indigent.

[h]Most frequently observed Elixhauser comorbidities shown.

[i]No history of COVID-19 within 2 months of encounter.

NMB Use Patterns

During the total study period, the vast majority of encounters involved rocuronium use with or without succinylcholine (3,229,651 encounters, 89.6%; Table S3 in Multimedia Appendix 1). A general trend of increasing rates of rocuronium only (with or without succinylcholine) was observed during this study's period, increasing from 87.1% during BP to 93% during LC. The use of succinylcholine with rocuronium or vecuronium was used in 5.3% of patient encounters overall. This rate increased from 4.8% during BP to a peak of 6.9% during the EC period, before falling to 5.4% during LC.

NMB Reversal Agent Use Patterns

Before the COVID-19 outbreak, the use of sugammadex for NMB reversal steadily increased following its approval in 2016, with approximately 1 in 4 encounters using this agent for reversal during BP (Table 2; Figure 1) [9]. This trend continued through the post–COVID-19 eras, reaching 51.1% (321,268/628,197) of encounters during LC. Consequently, reversal with neostigmine decreased from 47.1% from BP to 26.6% during LC. Overall, the rate of active NMB reversal with either sugammadex or neostigmine gradually increased over time. Spontaneous reversal steadily decreased from 27.5% (451,838/1,644,370) of encounters during BP to 22.3% (139,854/628,197) during LC. The trends in sugammadex, neostigmine, and active reversal were approximately linear from 2018 until the end of this study's period ($R^2>0.99$, for sugammadex and neostigmine, $R^2=0.95$ for active reversal).

When comparing patient characteristics by reversal type (ie, spontaneous, sugammadex, or neostigmine), the distribution by age, race, and ethnicity was similar, though statistical significance was achieved due to the large sample size (Tables S4-S6 in Multimedia Appendix 1). Encounters involving reversal with neostigmine or sugammadex tended to involve younger patients (mean 57.4, SD 17.15 to 58.2, SD 16.56 years for neostigmine and 58.7, SD 16.83 to 59.2, SD 16.43 years for sugammadex) compared to spontaneous reversal (mean 59.2, SD 16.28 to 59.9, SD 15.83 years). Women comprised a higher proportion of those reversed with sugammadex (49,534/92,709, 53.4%, to 231,852/417,266, 55.6%) or neostigmine (36,704/67,321, 54.5%, to 441,284/775,266, 56.9%) and a lower proportion of spontaneous reversal (22,303/49,421, 45.1%, to 217,774/451,838, 48.2%) compared to men. Those who underwent spontaneous reversal were more likely to have ≥1 comorbidity (379,136/451,838, 83.9% to 124,367/139,854, 88.9%) compared to those reversed with sugammadex (334,071/417,266, 80.1%, to 273,297/321,268, 85.1%) or neostigmine (608,704/775,266, 78.5%, to 137,412/167,075, 82.2%).

The use of NMB reversal agents was similar based on institution type. During BP, sugammadex was used in 24.8% (219,463/885,068) of encounters in teaching hospitals and 26.1% (197,803/759,302) in nonteaching hospitals. The use of sugammadex increased to 50.2% (179,721/358,262) among teaching hospitals and 52.4% (141,547/269,935) in nonteaching hospitals during the LC era.

Table 2. Pharmacological and nonpharmacological reversal of NMB[a] during COVID-19 time periods.

Reversal strategy	Total (n=3,602,887)	Baseline period (n=1,644,370)	Before COVID (n=820,078)	Early COVID (n=209,721)	Middle COVID (n=300,791)	Late COVID (n=628,197)
Neostigmine, n (%)	1,411,570 (39.2)	775,266 (47.1)	307,727 (37.5)	67,321 (32.1)	94,181 (31.3)	167,075 (26.6)
Sugammadex, n (%)	1,280,618 (35.5)	417,266 (25.4)	311,227 (38)	92,709 (44.3)	138,148 (45.9)	321,268 (51.1)
No active reversal, n (%)	910,699 (25.3)	451,838 (27.5)	201,124 (24.5)	49,421 (23.6)	68,462 (22.8)	139,854 (22.3)

[a]NMB: neuromuscular blockade.

XSL·FO

RenderX

Figure 1. Quarterly proportions of NMB reversal agent use during this study's period. Trend lines evaluate linearity after January 2018, the time period used for logistic regression models. NMB: neuromuscular blockade.
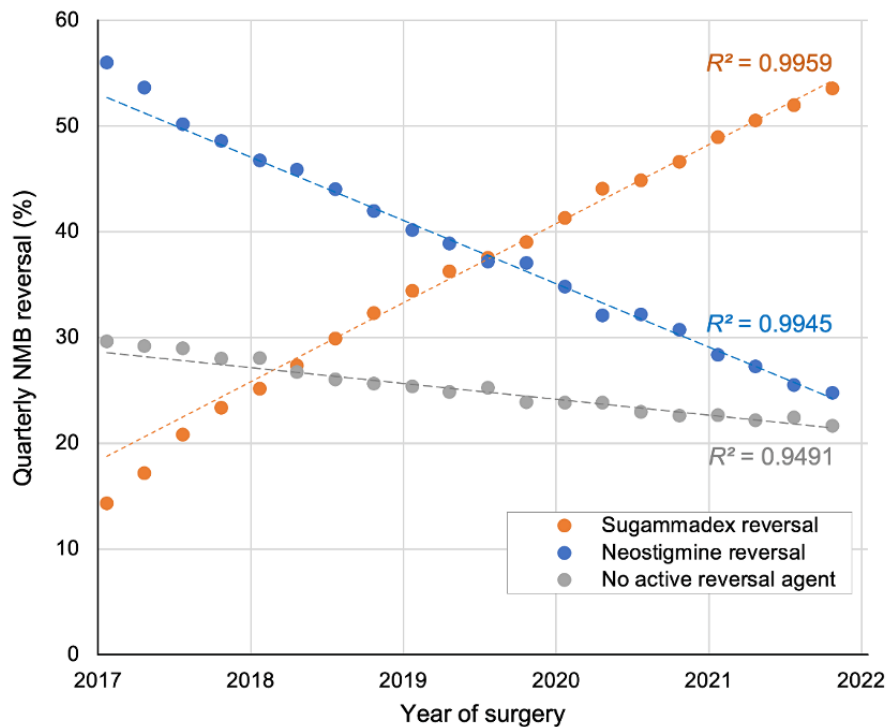
Multivariable Analysis

Multivariable regression analyses were used to identify time trends and their interaction terms with post–COVID-19 time periods for pharmacologic (active) versus no pharmacologic (spontaneous) reversal (model 1a), and for reversal with sugammadex versus neostigmine (model 1b; Table 3; Figures 2 and 3). The overall yearly time-trend throughout this study's period demonstrated an increase in the use of active reversal (using either sugammadex or neostigmine) compared to no pharmacologic reversal (OR 1.129; $P<.001$). However, there were variations in the interaction term coefficient when analyzing specific post–COVID-19 time periods (refer to the Multivariable Analysis section of the Methods section for details on the analysis approach). Active reversal did not show a significant association, or change in trend, during EC (OR 1.002, 95% CI 0.997-1.008; $P=.44$) or MC (OR 0.996, 95% CI 0.991-1.001; $P=.12$). A slight but statistically significant decrease in the active reversal trend (ie, there was a slowing of the trend toward increased use of active reversal) was observed in LC (OR 0.987, 95% CI 0.983-0.992; $P<.001$). Based on these observations, the counterfactual analysis (model 2a) was not evaluated.

Significant associations in the use of active reversal were also observed based on patient, procedure, and institutional factors (Table 3; Figure 2). Except for those aged 18-30 years, fewer older adults (aged 41 to 70 years) tended to show a decreased odds of active reversal (OR range 0.941-0.983; reference those aged 31-40 years), while older adults (aged >70 years) were more likely to use active reversal (OR range 1.094-1.349). Compared to elective surgical procedures (reference),

emergency, trauma, and urgent admissions revealed significantly decreased use of active pharmacologic reversal (OR 0.641, 95% CI 0.637-0.645; 0.612, 95% CI 0.602-0.622; and 0.668, 95% CI 0.662-0.675; respectively; $P<.001$ for each).

When comparing the use of sugammadex versus neostigmine in model 1b (Table 3, Figure 3), the yearly time-trend from January 2018 onwards demonstrated a steady increase in the use of sugammadex over neostigmine (OR 1.388, 95% CI 1.381-1.396; $P<.001$). Analysis of the specific post–COVID-19 time periods revealed a small but statistically significant interaction with the time trend in NMB reversal (Table 3). A slight but statistically significant increase in sugammadex reversal was observed during EC (OR 1.008, 95% CI 1.003-1.014; $P=.003$), followed by negation of that trend during MC (OR 0.992, 95% CI 0.987-0.997; $P<.001$). There was no significant interaction identified in the LC period (OR 1.001, 95% CI 0.996-1.005; $P=.81$).

Other covariates in model 1b that were significantly associated with sugammadex reversal included older age categories, urgent or emergent and trauma admissions, cardiac comorbidities (including arrhythmias, peripheral vascular disorders, congestive heart failure), obesity, chronic pulmonary disease, and diabetes. Most surgical types were associated with higher rates of sugammadex reversal as compared to the reference (musculoskeletal surgeries or surgeries involving the nervous system) with the exception of female genitalia. Hospitals with fewer beds (0-199 or 200-399 vs 400+) were associated with a lower likelihood of sugammadex reversal. Hospitals in the Northeast and South geographic regions of the United States also had significantly lower odds of sugammadex reversal as compared to the West and Midwest.

Table 3. Logistic regression estimates from multivariate models (active vs spontaneous and sugammadex vs neostigmine).

	Model 1a: active vs spontaneous		Model 1b: sugammadex vs neostigmine	
	Odds ratio (95% CI)	*P* value	Odds ratio (95% CI)	*P* value
Time trend (yearly)	1.129 (1.123-1.135)	<.001	1.388 (1.381-1.396)	<.001
Time trend×EC[a]	1.002 (0.997-1.008)	.44	1.008 (1.003-1.014)	.003
Time trend×MC[b]	0.996 (0.991-1.001)	.13	0.992 (0.987-0.997)	<.001
Time trend×LC[c]	0.987 (0.983-0.992)	<.001	1.001 (0.996-1.005)	.81
NMB group (reference=rocuronium+succinylcholine or vecuronium+succinylcholine)				
>1 class of long-acting NMB + succinylcholine	0.469 (0.455-0.483)	<.001	0.542 (0.517-0.567)	<.001
Rocuronium or vecuronium	1.501 (1.484-1.519)	<.001	1.421 (1.404-1.440)	<.001
Age (y; reference=31-40 y)				
18-30	1.057 (1.041-1.072)	<.001	0.917 (0.904-0.930)	<.001
41-50	0.959 (0.947-0.972)	<.001	1.042 (1.030-1.054)	<.001
51-60	0.941 (0.930-0.952)	<.001	1.095 (1.083-1.107)	<.001
61-70	0.983 (0.971-0.995)	.004	1.108 (1.095-1.120)	<.001
71-80	1.094 (1.080-1.108)	<.001	1.137 (1.123-1.150)	<.001
>80	1.349 (1.329-1.369)	<.001	1.251 (1.233-1.269)	<.001
Female vs male	1.110 (1.103-1.116)	<.001	0.989 (0.983-0.995)	<.001
Race (reference=White)				
Asian	0.905 (0.887-0.925)	<.001	0.929 (0.909-0.950)	<.001
Black	1.002 (0.993-1.012)	.62	0.897 (0.889-0.905)	<.001
Other	0.926 (0.916-0.937)	<.001	0.803 (0.794-0.812)	<.001
Unknown	0.938 (0.921-0.956)	<.001	0.686 (0.673-0.698)	<.001
Ethnicity (reference=not Hispanic)				
Hispanic	0.945 (0.935-0.955)	<.001	1.171 (1.159-1.184)	<.001
Unknown	0.910 (0.903-0.918)	<.001	1.096 (1.087-1.105)	<.001
Admission type (reference=elective)				
Emergency	0.641 (0.637-0.645)	<.001	1.158 (1.150-1.165)	<.001
Trauma center	0.612 (0.602-0.622)	<.001	1.652 (1.621-1.685)	<.001
Urgent	0.668 (0.662-0.675)	<.001	1.156 (1.145-1.168)	<.001
Low-income (reference=not low-income[d])	0.972 (0.964-0.981)	<.001	1.069 (1.060-1.079)	<.001
Comorbidities (present vs absent)				
Valvular disease	0.710 (0.702-0.718)	<.001	0.940 (0.927-0.953)	<.001
Diabetes (complicated)	0.870 (0.862-0.878)	<.001	1.019 (1.009-1.030)	<.001
Cardiac arrhythmias	0.766 (0.760-0.772)	<.001	1.020 (1.012-1.029)	<.001
Sleep apnea	1.034 (1.024-1.044)	<.001	1.034 (1.024-1.044)	<.001
Solid tumor without metastasis	1.124 (1.113-1.135)	<.001	1.057 (1.047-1.067)	<.001
Peripheral vascular disorders	1.443 (1.428-1.457)	<.001	1.071 (1.059-1.084)	<.001
Obesity or overweight	1.013 (1.006-1.020)	<.001	1.096 (1.089-1.104)	<.001
Congestive heart failure	0.810 (0.802-0.819)	<.001	1.100 (1.087-1.114)	<.001
Chronic pulmonary disease	1.012 (1.004-1.019)	.002	1.102 (1.094-1.110)	<.001
Surgical type (reference=MSK[e] and CNS[f])				
Female genital	1.877 (1.845-1.911)	<.001	0.980 (0.967-0.994)	.005

	Model 1a: active vs spontaneous		Model 1b: sugammadex vs neostigmine	
	Odds ratio (95% CI)	*P* value	Odds ratio (95% CI)	*P* value
Cardiovascular	0.372 (0.369-0.376)	<.001	1.044 (1.033-1.055)	<.001
Urinary and male genital	1.408 (1.386-1.430)	<.001	1.101 (1.085-1.116)	<.001
Digestive	2.056 (2.040-2.072)	<.001	1.115 (1.107-1.123)	<.001
Integumentary hemic and lymphatic	0.906 (0.893-0.919)	<.001	1.237 (1.218-1.256)	<.001
Endocrine	0.794 (0.764-0.825)	<.001	1.326 (1.274-1.381)	<.001
Eye	1.226 (1.108-1.356)	<.001	1.531 (1.377-1.702)	<.001
Others, unknown, or missing	0.981 (0.912-1.056)	.614	1.596 (1.484-1.717)	<.001
ENT[g]	0.702 (0.680-0.724)	<.001	1.632 (1.572-1.695)	<.001
Respiratory	0.847 (0.835-0.858)	<.001	1.651 (1.627-1.676)	<.001
Bed size (reference=400+)				
0-199	0.828 (0.820-0.835)	<.001	0.823 (0.815-0.830)	<.001
200-399	0.858 (0.852-0.865)	<.001	0.864 (0.858-0.870)	<.001
Teaching vs not teaching	0.971 (0.964-0.977)	<.001	1.006 (0.999-1.012)	.09
Institution region (reference=West)				
Midwest	1.263 (1.250-1.275)	<.001	0.956 (0.947-0.966)	<.001
Northeast	1.013 (1.002-1.024)	.021	0.431 (0.426-0.435)	<.001
South	1.203 (1.192-1.213)	<.001	0.617 (0.612-0.623)	<.001
History of COVID-19 (reference=no COVID-19)	0.976 (0.947-1.005)	.10	1.018 (0.989-1.048)	.23

[a]EC: early COVID-19 era.

[b]MC: middle COVID-19 era.

[c]LC: late COVID-19 era.

[d]Low-income insurance types include Medicaid, charity, and indigent.

[e]MSK: musculoskeletal.

[f]CNS: central nervous system.

[g]ENT: ear nose throat.

XSL•FO
RenderX

Figure 2. Forest plot of odds ratio: active versus spontaneous reversal (model 1a). The time period between January 1, 2018, and February 29, 2020, was considered as a reference to evaluate the interaction of the time trend with EC, MC, and LC periods. Bars represent 95% CI. Low income includes Medicaid, charity, and indigent insurance types. CNS: central nervous system; EC: early COVID-19 (April 1, 2020, and July 31, 2020; the month of March 2020 was omitted to account for a transition period and due to the unavailability of COVID-19 diagnostic information); ENT: ear nose throat; LC: late COVID-19 (January 1, 2021, to December 31, 2021); MC: middle COVID-19 (August 1, 2020, to December 31, 2020); MSK: musculoskeletal; NMB: neuromuscular blockade; ROC: rocuronium; SUC: succinylcholine; VEC: vecuronium.
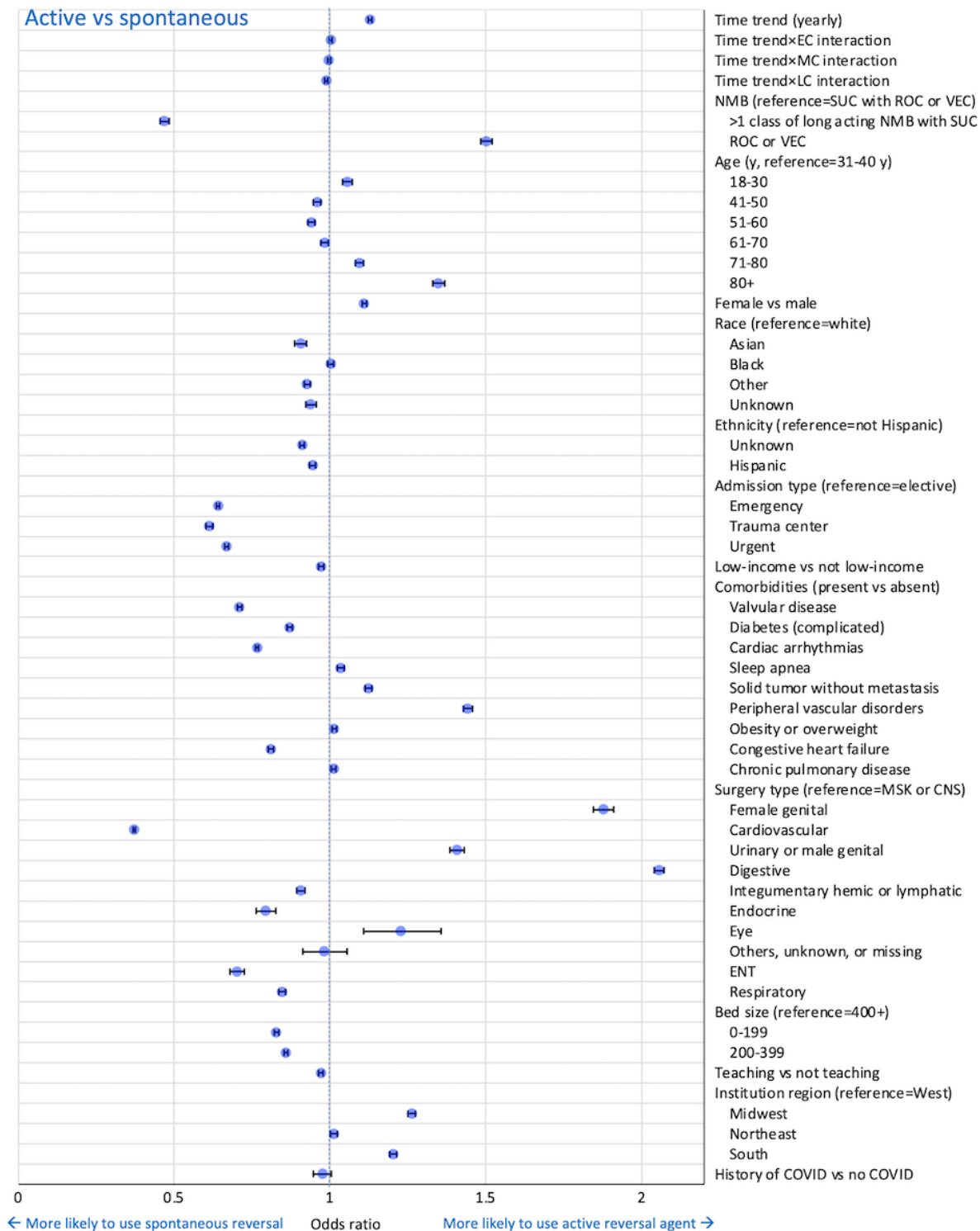
Figure 3. Forest plot of odds ratio: sugammadex vs neostigmine (model 1b). The time period between January 1, 2018, and February 29, 2020, was considered as a reference to evaluate the interaction of the time trend with EC, MC, and LC periods. Bars represent 95% CI. Low income includes Medicaid, charity, and indigent insurance types. CNS: central nervous system; EC: early COVID-19 (April 1, 2020, to July 31, 2020; the month of March 2020 was omitted to account for a transition period and due to the unavailability of COVID-19 diagnostic information); ENT: ear nose throat; LC: late COVID-19 (January 1, 2021, to December 31, 2021); MC: middle COVID-19 (August 1, 2020, to December 31, 2020); MSK: musculoskeletal; NMB: neuromuscular blockade; ROC: rocuronium; SUC: succinylcholine; VEC: vecuronium.
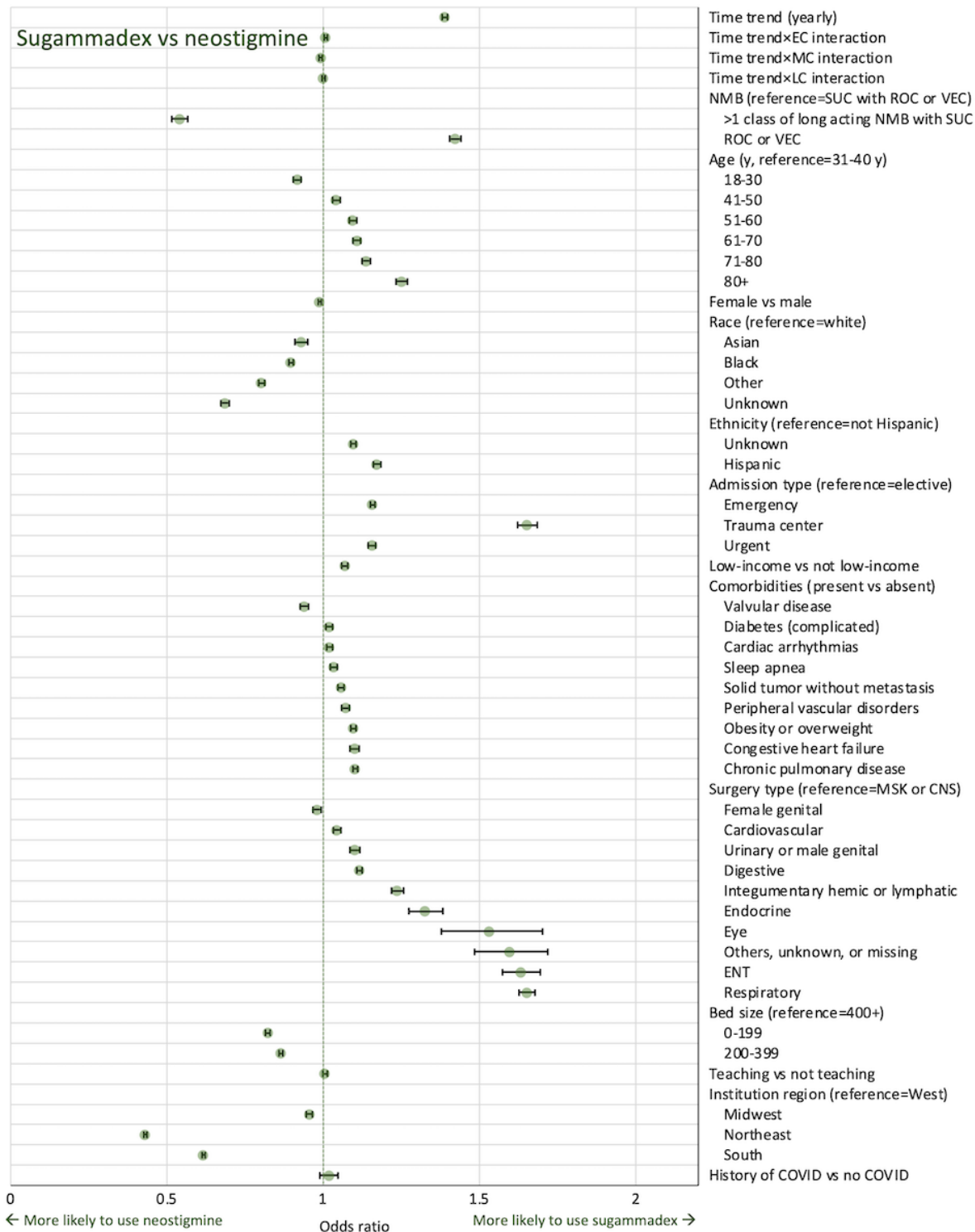
Counterfactual Analysis

When comparing EC, MC, and LC time periods within patient subgroups, only a few differences were observed in actual NMB reversal compared to expected use. Most differences were observed in LC among institution and multimodal NMB characteristics (Figure 4). After normalization, only a few patient and institutional characteristics showed a significant deviation from the expected trend of the sugammadex reversal rate. Of the patient characteristics that had an observable counterfactual difference, patients with Hispanic ethnicity were reversed with sugammadex less frequently in the LC era as compared to how they would have been reversed before COVID-19. Institutions

with 400 or more beds or classified as teaching institutions also had a relative decrease in sugammadex reversal rates as compared to expected trends from before COVID-19 data. On the other hand, small hospitals (0-199 beds), mid-sized hospitals (200-399), and those located in the south of the United States had higher rates of sugammadex reversal than expected from pre–COVID-19 trends, having relative actual or counterfactual ratios greater than 1.

Figure 4. Counterfactual analysis comparing actual sugammadex reversal odds relative to prepandemic multivariate model–based reversal odds (model 2b). Normalized ORs were calculated by dividing observed ORs with counterfactual ORs of sugammadex reversal and multiplied by a frequency-weighted scaling factor for relative comparison between time periods. Bars represent 95% CI. Low income includes Medicaid, charity, and indigent insurance types. CNS: central nervous system; ENT: ear nose throat; MSK: musculoskeletal; NMB: neuromuscular blockade; OR: odds ratio; ROC: rocuronium; SUC: succinylcholine; VEC: vecuronium.
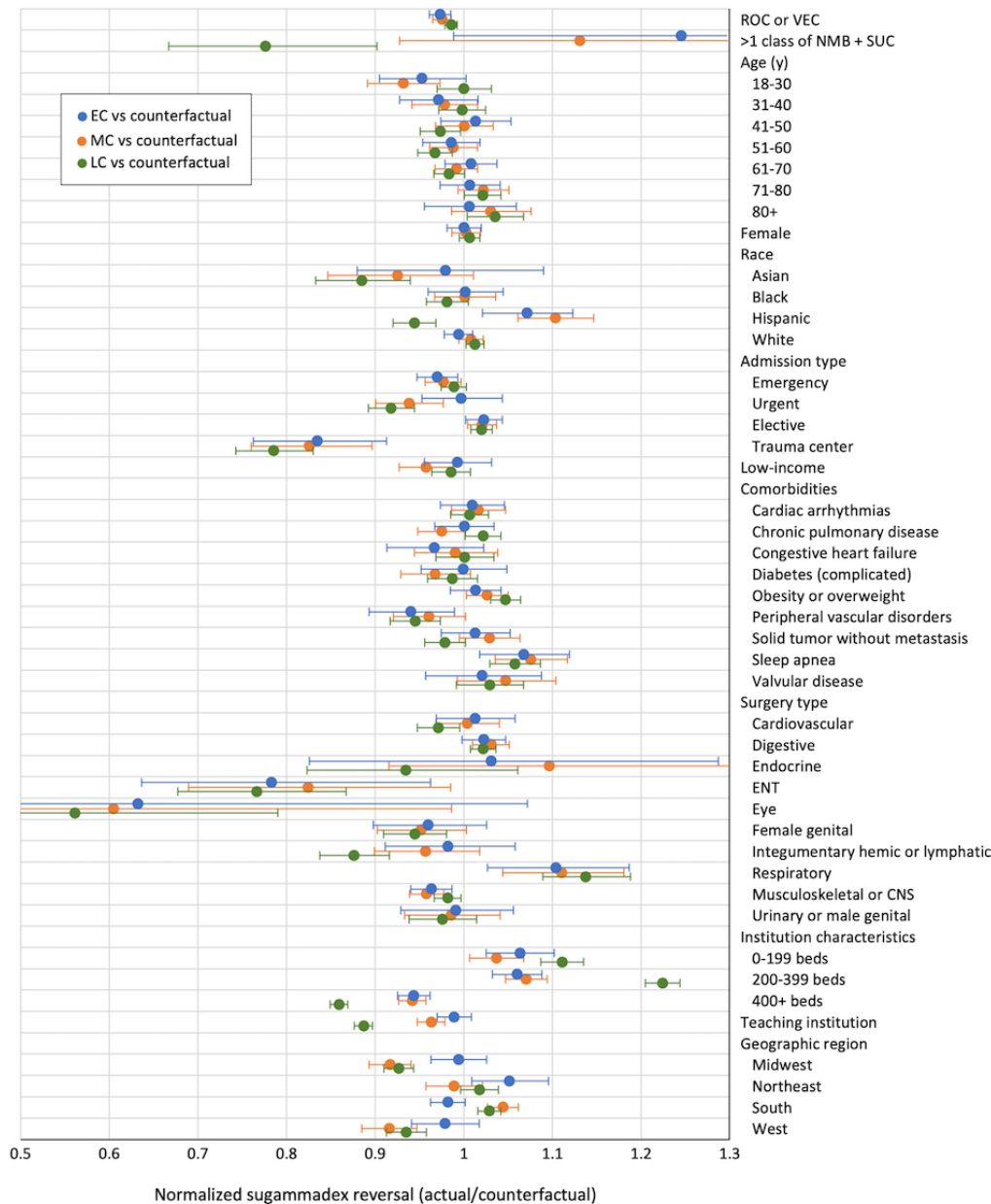
Discussion

Principal Results

This study used a large health care database comprising 931 sites across the United States to identify changes in use trends for NMB and NMB reversal agents for inpatients before and after health care systems experienced the COVID-19 outbreak. Through multivariable regression analysis, we identified factors related to the patient, procedure, and institution that were associated with NMB reversal choices.

We originally hypothesized that the use of sugammadex for NMB reversal in the post–COVID-19 period would increase given the evidence demonstrating decreased PACU time and, thus, diminished potential exposure to COVID-19. When analyzing changes in the sugammadex use trend for NMB reversal, a slight, transient effect was observed during the post–COVID-19 time points. During EC, a small but statistically

significant increase in sugammadex use (compared to neostigmine) was revealed, though this trend was negated by an equivalent decrease during the MC period. However, the association with sugammadex use was small and short-lived, thus arguing that other factors in the complex process of NMB and NMB reversal selection are influencing these decisions. Logistic regression analysis showed that sugammadex use was favored in emergency and urgent admissions compared to elective admissions, and the number of emergency and urgent admissions increased from 42.5% (348,840/820,078) in the BC period to 49.7% (104,123/209,451) in the EC period (Table 1). However, this did not translate to an increase in sugammadex reversal in the counterfactual analysis (model 2b, Figure 4), which largely showed no significant difference in the sugammadex reversal rates of patients being treated in the COVID-19 eras relative to how they would have been treated before COVID-19. It is also important to point out that this study is attempting to identify an association or change in trend, beyond the currently established time-trend, which has observed a strong, steady increase in sugammadex before COVID-19, likely due to increasing evidence of the benefit of sugammadex in avoiding rNMB and in quicker time to reach a train-of-four (TOF) ratio of >0.9 [17,30]. To help account for this, the analysis used data starting in January 2018, which showed a more linear and predictable increase in sugammadex use leading to the start of the COVID-19 pandemic in March 2020. Given the strong association of sugammadex in the yearly time-trend (OR 1.388, 95% CI 1.381-1.396), it is possible that small but significant changes to the NMB reversal trend following COVID-19 are being masked by the existing time-trend.

The counterfactual analysis in this study was intended to identify trends in patient and institutional characteristics that deviated from overall sugammadex reversal patterns captured in the multivariate analysis, which assumes constant effects for all of the covariates. Most of the changes that deviated from the prepandemic trend, as observed from the significantly higher or lower actual or counterfactual ratio in Figure 4, were a reversal of the characteristics that were found to be associated with the early adoption of sugammadex [9]. For example, a lower-than-predicted use of sugammadex in trauma center patients and large hospitals in the peri–COVID-19 time periods may be explained as a renormalization caused by a higher-than-expected adoption of sugammadex in these settings in the initial years after sugammadex approval.

Limitations

Though this study used robust methodology and a large US database of over 3.5 million inpatient encounters, several limitations must be addressed. The PHD includes patients covered by all payer types from both teaching and nonteaching institutions of various bed sizes. However, it is not representative of geographic location, with the South region more heavily weighted, which could limit the generalizability of the results. The PHD did not include information on the depth of NMB block (moderate vs deep), use of quantitative neuromuscular monitoring, or detection of postoperative rNMB, which can impact NMB reversal selection. The PHD also did not provide individual hospital data on census or capacity limitations. Methods were proposed to account for controlling for the

variability in experience between regions, sites, and time periods relative to this capacity. However, there was still a possibility that the impact of a burden on each hospital was either captured incorrectly in general or relative to the BC experience, though the burden was likely to be just as well or just as poorly, captured from one site to another. This study does not take into account reporting sites that were not continuously enrolled throughout this study's period. During this study's period extending over 4.5 years, practice and policy changes in surgery and anesthesiology were likely to occur that could have influenced the selection of NMB and NMB reversal agents. Additionally, variations in hospital protocols as well as access to reversal agents were not accounted for in this study. These could include external factors on anesthesia practice among institutions, such as adherence to enhanced recovery protocols, quantitative neuromuscular monitoring following surgery, budgetary constraints, and quality initiatives. Certain patient characteristics (eg, American Society of Anesthesiology physical status classification or smoking status) and procedure data (eg, drug dose or duration of procedure) were not available that could impact NMB reversal choice. By the nature of this study and data collection, there is a potential for recording errors. Lastly, the determination of early, mid, and late COVID-19 time periods was largely subjective. In the absence of nationwide, standardized protocols to guide surgical and anesthesia practices in the wake of the COVID-19 outbreak, each institution adapted independently to the pandemic based on available resources and local impacts of the pandemic, which can vary widely over time and location. Despite the limitations of the data source and our limited ability to identify certain details, our study provides an aggregate observation on the effect of the COVID-19 pandemic on NMB reversal practices in non–COVID-19 patients in the United States.

Comparison With Prior Work

Before COVID-19, rocuronium (with or without succinylcholine) was the predominant NMB used among US inpatient procedures, accounting for approximately 87% (1,432,947/1,644,370) of patient encounters during the BP. Preference for rocuronium over vecuronium continued through the post–COVID-19 time periods, with 93% (583,815/628,197) of encounters using rocuronium (with or without succinylcholine) in LC. These findings were consistent with prior studies on NMB use among US inpatients. Bash et al [9] demonstrated a trend in preference for rocuronium over vecuronium (with or without succinylcholine) from 2014 to 2019 among US inpatients, increasing from 84.3% in 2014 to 90.7% by the first half of 2019. This trend was even more pronounced among US outpatients, with rocuronium (with or without succinylcholine) accounting for over 96% of NMB use during the first half of 2019 [8].

Database studies revealed trends in NMB reversal favoring active over spontaneous (or no pharmacologic agent) reversal. Among US inpatients, the percentage of encounters using spontaneous reversal gradually decreased from 36.5% in 2014 to 34.3% in 2016 [9]. This decreasing trend accelerated in 2016 (with the approval of sugammadex) and reached 27.6% by the first half of 2019. This current study demonstrated that a decreasing trend in the use of spontaneous reversal continued

through the COVID-19 time periods. Logistic regression estimates did not reveal any significant association, or change in the trend, between active versus spontaneous reversal during the EC and MC time periods. During LC, a small but significant association was observed showing a decrease in the rate of active reversal change (effective change in OR of time trend from 1.129 to 1.115). Analyses revealed several patient, procedural, and institutional factors with significant associations with the choice of reversal approach. The most pronounced association identified was related to admission type, with emergency, trauma center, and urgent admissions strongly favoring the use of spontaneous reversal compared to elective procedures. The percentage of elective admissions decreased substantially from 55% (451,190/820,078) in BC to 47.1% (98,637/209,451) in EC, and only partially returned during the MC and LC periods. This was likely the result of a nationwide response to postpone nonessential, elective surgeries as a means to limit COVID-19 exposure in hospitals and focus health care resources on managing the pandemic [14,15].

Contrary to our hypothesis, this study suggests that the impact of COVID-19 on NMB reversal selection was generally limited during the post–COVID-19 era throughout the United States. Though the change in trend for sugammadex use was small and transient in the post–COVID-19 era, the steady trend of increasing sugammadex use over neostigmine that started before COVID-19 and continued in the post–COVID-19 era eclipsed the small transient effects of the pandemic. This trend may be attributed to evidence demonstrating certain benefits of sugammadex over neostigmine, including diminished reversal time, more rapid discharge from the PACU, and a lower incidence of rNMB [17,30-32]. However, the lack of an acceleration of sugammadex use during the post–COVID-19 periods may be attributed to several factors, including clinical inertia or a lack of evidence related to the potential reduction in viral exposure associated with quicker NMB reversal time (and earlier extubation in the operating room). Educational programs can help to ensure current standards of care are attained and maintained in the postoperative setting.

Nonetheless, neostigmine remains a reasonable alternative for NMB reversal in certain patients with minimal blockade. Recent guidelines from the American Society of Anesthesiologists and the European Society of Anesthesiology and Intensive Care (both guidelines released after the date of final data collection of this study) confirm neostigmine's place in therapy and offer recommendations on the appropriate use of this agent in NMB reversal when accompanied with quantitative neuromuscular monitoring [33,34]. American Society of Anesthesiologists recommends quantitative neuromuscular monitoring for all patients and prefers sugammadex over neostigmine at deep, moderate, and shallow depths (ie, TOF ratio <0.4) of NMB induced by rocuronium or vecuronium [33]. Yet, neostigmine is indicated as a reasonable alternative for patients with minimal blockade (ie, TOF ratio = 0.4 to <0.9) [31]. Similarly, the European Society of Anesthesiology and Intensive Care recommends sugammadex for deep, moderate, and shallow NMB (TOF ratio <0.4) induced by rocuronium or vecuronium, while neostigmine can be considered following advanced spontaneous recovery (ie, TOF ratio >0.2) [34]. Future research using databases that collect TOF information would be instrumental in understanding the impact of these guidelines on current trends and outcomes in NMB reversal selection.

Conclusions

This large, retrospective database study analyzed over 3.5 million inpatient encounters throughout the United States to identify changes in NMB use and reversal trends during the COVID-19 pandemic. We hypothesized that sugammadex use for NMB reversal would accelerate during the post–COVID-19 eras as a means to reduce PACU or operating room time and, subsequently, the risk of COVID-19 exposure. However, our findings demonstrated only a slight, transient acceleration of sugammadex use during the EC that was largely negated with time. This study did not attempt to investigate the reasons for the lack of change in the existing trend in the use of NMB reversal agents. Additional research is needed to better understand how pandemic-related practice changes have affected long-term NMB and reversal selection based on patient, procedural, or institutional factors, and potentially recognize patient subpopulations that experienced greater changes in anesthesia practice during this period.

Authors' Contributions

VT helped design, analyze, and interpret the results, draft this paper, and critically review this paper for important intellectual content. IH, MK, LDB and RDU helped design this study, interpret the results, draft this paper, and critically review this paper for important intellectual content.

Conflicts of Interest

VT and LDB are full-time employees of Merck & Co, Inc, which manufactures and distributes sugammadex, and may own stock or hold stock options in Merck & Co, Inc. MK and IH receive consulting fees from Merck & Co, Inc. RDU receives consulting fees from Merck & Co, Inc and AcelRx.

Multimedia Appendix 1

Tables showing patient attrition, patient and institution characteristics by COVID era and NMB reversal mechanism. NMB: neuromuscular blockade.

[DOCX File , 82 KB - periop_v7i1e52278_app1.docx]

References

1. Alenezi FK, Alnababtah K, Alqahtani MM, Olayan L, Alharbi M. The association between residual neuromuscular blockade (RNMB) and critical respiratory events: a prospective cohort study. Perioper Med (Lond) 2021;10(1):14 [FREE Full text] [doi: 10.1186/s13741-021-00183-7] [Medline: 33941287]

2. Butterly A, Bittner EA, George E, Sandberg WS, Eikermann M, Schmidt U. Postoperative residual curarization from intermediate-acting neuromuscular blocking agents delays recovery room discharge. Br J Anaesth 2010;105(3):304-309 [FREE Full text] [doi: 10.1093/bja/aeq157] [Medline: 20576632]

3. Murphy GS, Brull SJ. Residual neuromuscular block: lessons unlearned. Part I: definitions, incidence, and adverse physiologic effects of residual neuromuscular block. Anesth Analg 2010;111(1):120-128 [FREE Full text] [doi: 10.1213/ANE.0b013e3181da832d] [Medline: 20442260]

4. Murphy GS, Szokol JW, Avram MJ, Greenberg SB, Marymont JH, Vender JS, et al. Intraoperative acceleromyography monitoring reduces symptoms of muscle weakness and improves quality of recovery in the early postoperative period. Anesthesiology 2011;115(5):946-954 [FREE Full text] [doi: 10.1097/ALN.0b013e3182342840] [Medline: 21946094]

5. Cammu G, De Witte J, De Veylder J, Byttebier G, Vandeput D, Foubert L, et al. Postoperative residual paralysis in outpatients versus inpatients. Anesth Analg 2006;102(2):426-429 [FREE Full text] [doi: 10.1213/01.ane.0000195543.61123.1f] [Medline: 16428537]

6. Domenech G, Kampel MA, Guzzo MEG, Novas DS, Terrasa SA, Fornari GG. Usefulness of intra-operative neuromuscular blockade monitoring and reversal agents for postoperative residual neuromuscular blockade: a retrospective observational study. BMC Anesthesiol 2019;19(1):143 [FREE Full text] [doi: 10.1186/s12871-019-0817-4] [Medline: 31390986]

7. Saager L, Maiese EM, Bash LD, Meyer TA, Minkowitz H, Groudine S, et al. Incidence, risk factors, and consequences of residual neuromuscular block in the United States: the prospective, observational, multicenter RECITE-US study. J Clin Anesth 2019;55:33-41 [FREE Full text] [doi: 10.1016/j.jclinane.2018.12.042] [Medline: 30594097]

8. Bash LD, Black W, Turzhitsky V, Urman RD. Neuromuscular blockade and reversal practice variability in the outpatient setting: insights from US utilization patterns. Anesth Analg 2021;133(6):1437-1450 [FREE Full text] [doi: 10.1213/ANE.0000000000005657] [Medline: 34784330]

9. Bash LD, Turzhitsky V, Black W, Urman RD. Neuromuscular blockade and reversal agent practice variability in the US inpatient surgical settings. Adv Ther 2021;38(9):4736-4755 [FREE Full text] [doi: 10.1007/s12325-021-01835-2] [Medline: 34319550]

10. Forrester JD, Nassar AK, Maggio PM, Hawn MT. Precautions for operating room team members during the COVID-19 pandemic. J Am Coll Surg 2020;230(6):1098-1101 [FREE Full text] [doi: 10.1016/j.jamcollsurg.2020.03.030] [Medline: 32247836]

11. Patel V, Jimenez E, Cornwell L, Tran T, Paniagua D, Denktas AE, et al. Cardiac surgery during the coronavirus disease 2019 pandemic: perioperative considerations and triage recommendations. J Am Heart Assoc 2020;9(13):e017042 [FREE Full text] [doi: 10.1161/JAHA.120.017042] [Medline: 32418460]

12. Wax RS, Christian MD. Practical recommendations for critical care and anesthesiology teams caring for Novel Coronavirus (2019-nCoV) patients. Can J Anaesth 2020;67(5):568-576 [FREE Full text] [doi: 10.1007/s12630-020-01591-x] [Medline: 32052373]

13. Athanassoglou V, Zhong H, Poeran J, Liu J, Cozowicz C, Illescas A, et al. Anaesthesia practice in the first wave of the COVID-19 outbreak in the United States: a population-based cohort study. Br J Anaesth 2022;129(1):e16-e18 [FREE Full text] [doi: 10.1016/j.bja.2022.04.003] [Medline: 35562227]

14. Boyev A, Sanjeevi S, Estrada MM, Ko TC, Wray CJ. The impact of COVID-19 pandemic upon non-elective admissions and surgery at a safety-net hospital: a retrospective cohort study. J Surg Res 2022;278:376-385 [FREE Full text] [doi: 10.1016/j.jss.2022.04.004] [Medline: 35691248]

15. Pirracchio R, Mavrothalassitis O, Mathis M, Kheterpal S, Legrand M. Response of US hospitals to elective surgical cases in the COVID-19 pandemic. Br J Anaesth 2021;126(1):e46-e48 [FREE Full text] [doi: 10.1016/j.bja.2020.10.013] [Medline: 33187635]

16. Bardia A, Treggiari MM, Dai F, Johnson C, Singh M, Kunze K, et al. Efficacy and safety of sugammadex to shorten time-to-extubation following cardiac surgery: a single-center randomized placebo-controlled trial. Crit Care Explor 2022;4(12):e0821 [FREE Full text] [doi: 10.1097/CCE.0000000000000821] [Medline: 36601562]

17. Carron M, Zarantonello F, Lazzarotto N, Tellaroli P, Ori C. Role of sugammadex in accelerating postoperative discharge: a meta-analysis. J Clin Anesth 2017;39:38-44 [FREE Full text] [doi: 10.1016/j.jclinane.2017.03.004] [Medline: 28494905]

18. Ohlsson H, Kendler KS. Applying causal inference methods in psychiatric epidemiology: a review. JAMA Psychiatry 2020;77(6):637-644 [FREE Full text] [doi: 10.1001/jamapsychiatry.2019.3758] [Medline: 31825494]

19.   Prosperi M, Guo Y, Sperrin M, Koopman J, Min J, He X, et al. Causal inference and counterfactual prediction in machine learning for actionable healthcare. Nat Mach Intell 2020;2(7):369-375. [doi: 10.1038/s42256-020-0197-y]

20.   Pearl E. Probabilistic Reasoning in Intelligent Systems: Networks of Plausible Inference. San Francisco, CA: Morgan Kaufmann Publishers Inc; 1988.

21.   McGough JJ, Faraone SV. Estimating the size of treatment effects: moving beyond P values. Psychiatry (Edgmont) 2009;6(10):21-29 [FREE Full text] [Medline: 20011465]

22.   Parascandola M, Weed DL. Causation in epidemiology. J Epidemiol Community Health 2001;55(12):905-912 [FREE Full text] [doi: 10.1136/jech.55.12.905] [Medline: 11707485]

23.   Zenil H, Kiani NA, Zea AA, Tegnér J. Causal deconvolution by algorithmic generative models. Nat Mach Intell 2019;1(1):58-66. [doi: 10.1038/s42256-018-0005-0]

24.   Glymour MM, Spiegelman D. Evaluating public health interventions: 5. causal inference in public health research-do sex, race, and biological factors cause health outcomes? Am J Public Health 2017;107(1):81-85. [doi: 10.2105/AJPH.2016.303539] [Medline: 27854526]

25.   Ling Y, Upadhyaya P, Chen L, Jiang X, Kim Y. Emulate randomized clinical trials using heterogeneous treatment effect estimation for personalized treatments: Methodology review and benchmark. J Biomed Inform 2023;137:104256 [FREE Full text] [doi: 10.1016/j.jbi.2022.104256] [Medline: 36455806]

26.   Xia Z, Stewart K. A counterfactual analysis of opioid-involved deaths during the COVID-19 pandemic using a spatiotemporal random forest modeling approach. Health Place 2023;80:102986 [FREE Full text] [doi: 10.1016/j.healthplace.2023.102986] [Medline: 36774811]

27.   Smith LV, Tarui N, Yamagata T. Assessing the impact of COVID-19 on global fossil fuel consumption and CO2 emissions. Energy Econ 2021;97:105170 [FREE Full text] [doi: 10.1016/j.eneco.2021.105170] [Medline: 33612887]

28.   PINC AI healthcare database: data that informs and performs. PINC AI Applied Sciences. 2023. URL: https://offers. pinc-ai.com/PINC-AI-Healthcare-Database-White-Paper-LP.html [accessed 2024-04-26]

29.   Code of Federal Regulations: Basic HHS Policy for Protection of Human Research Subjects. U.S. Department of Health and Human Services. 2018 Jun 19. URL: https://www.hhs.gov/ohrp/regulations-and-policy/regulations/45-cfr-46/ revised-common-rule-regulatory-text/index.html#46.102

30.   Carron M, Linassi F, De Cassai A. Role of sugammadex in accelerating postoperative discharge: an updated meta-analysis. J Clin Anesth 2020;65:109895. [doi: 10.1016/j.jclinane.2020.109895] [Medline: 32464475]

31.   Abad-Gurumeta A, Ripollés-Melchor J, Casans-Francés R, Espinosa A, Martínez-Hurtado E, Fernández-Pérez C, et al. A systematic review of sugammadex vs neostigmine for reversal of neuromuscular blockade. Anaesthesia 2015;70(12):1441-1452 [FREE Full text] [doi: 10.1111/anae.13277] [Medline: 26558858]

32.   Hurford WE, Eckman MH, Welge JA. Data and meta-analysis for choosing sugammadex or neostigmine for routine reversal of rocuronium block in adult patients. Data Brief 2020;32:106241 [FREE Full text] [doi: 10.1016/j.dib.2020.106241] [Medline: 32944599]

33.   Thilen SR, Weigel WA, Todd MM, Dutton RP, Lien CA, Grant SA, et al. 2023 American Society of Anesthesiologists practice guidelines for monitoring and antagonism of neuromuscular blockade: a report by the American Society of Anesthesiologists Task Force on neuromuscular blockade. Anesthesiology 2023;138(1):13-41 [FREE Full text] [doi: 10.1097/ALN.0000000000004379] [Medline: 36520073]

34.   Fuchs-Buder T, Romero CS, Lewald H, Lamperti M, Afshari A, Hristovska AMJ, et al. Peri-operative management of neuromuscular blockade: a guideline from the European Society of Anaesthesiology and Intensive Care. Eur J Anaesthesiol 2023;40(2):82-94 [FREE Full text] [doi: 10.1097/EJA.0000000000001769] [Medline: 36377554]

Abbreviations

BC: before COVID-19 era
BP: baseline period
EC: early COVID-19 era
LC: late COVID-19 era
MC: middle COVID-19 era
NMB: neuromuscular blockade
OR: odds ratio
PACU: postanesthesia care unit
PHD: PINC AI Healthcare Database
rNMB: residual neuromuscular blockade
TOF: train-of-four

XSL•FO
RenderX

XSL•FO

RenderX

XSL•FO

RenderX