Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Digital Health Interventions targeting patient-led ERAS Behaviours across Perioperative Care Pathways: A Systematic Review

Emma Sansalone

Emma.Sansalone@newcastle.edu.au

University of Newcastle

Priscilla Viana da Silva

University of Newcastle

Erin Forbes

University of Newcastle

Rebecca K Hodder

University of Newcastle Australia

Alison Zucca

University of Newcastle

Mitch J Duncan

University of Newcastle Australia

Stephen Smith

Calvary Mater Newcastle Hospital

Rebecca Wyse

University of Newcastle

Systematic Review

Keywords:

Posted Date: August 30th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-7896523/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

Additional Declarations: No competing interests reported.

Digital Health Interventions targeting patient-led ERAS Behaviours across Perioperative Care Pathways: A Systematic Review.

Journal: **npj Digital Medicine**

AUTHORS

Emma Sansalone[1,2]	Emma.Sansalone@newcastle.edu.au
Priscilla Viana da Silva[1,2]	priscilla.vianadasilva@newcastle.edu.au
Erin Forbes[1]	erin.forbes@newcastle.edu.au
Rebecca K Hodder[1,2,5,6]	Rebecca.Hodder@health.nsw.gov.au
Alison Zucca[1,2,6]	alison.zucca@newcastle.edu.au
Mitch J Duncan[4]	mitch.duncan@newcastle.edu.au
Stephen Smith[1,2,3]	stephen.smith@health.nsw.gov.au
Rebecca Wyse[1,2,6]	rebecca.wyse@health.nsw.gov.au

1. School of Medicine and Public Health, University of Newcastle, Callaghan, NSW, Australia
2. Hunter Medical Research Institute, New Lambton Heights, NSW, Australia
3. Calvary Mater Newcastle, Hunter New England Local Health District, Waratah, NSW, Australia
4. Centre for Active Living and Learning, University of Newcastle, Callaghan NSW 2308, Australia
5. College of Health, Medicine and Wellbeing, The University of Newcastle, Callaghan, NSW, Australia
6. Hunter New England Population Health, Hunter New England Local Health District, Wallsend, NSW, Australia

CORRESPONDING AUTHOR

Emma Sansalone

School of Medicine and Public Health, University of Newcastle, Callaghan, NSW, Australia

Hunter Medical Research Institute, New Lambton Heights, NSW, Australia

Email: Emma.Sansalone@newcastle.edu.au

AUTHOR CONTRIBUTIONS

All authors (ES, PVS, EF, RKH, AZ, MJD, SS, RW) contributed to the planning and design of the review. ES, PVS, EF and RW screened titles, abstracts and full texts. ES and PVS completed the data extraction. ES and EF independently assessed study quality and risk of bias. ES drafted the manuscript. All authors (ES, PVS, EF, RKH, AZ, MJD, SS, RW) contributed to the interpretation of findings, critically revised the manuscript, and approved the final version for submission.

COMPETING INTERESTS

The authors declare no competing interests.

FUNDING STATEMENT

This work was supported by the School of Medicine and Public Health, University of Newcastle, through a Pilot Scheme grant awarded by the Deputy Vice-Chancellor (Research and Innovation). RW is supported by a CINSW Fellowship (2021/ECF1355) which also provides a PhD stipend for ES. RKH is supported by NHMRC Early Career Fellowship (APP1160419). MJD is supported in part by the Commonwealth of Australia 2022 Effective Treatments and Therapies Grant (MRF2023434).

DATA STATEMENT

The data supporting the findings of this review are available in the cited published articles. Extracted data and analysis files are available from the corresponding author on reasonable request.

ABBREVIATIONS

ERAS: Enhanced Recovery After Surgery
DHI: Digital Health Intervention
ED: Emergency Department
PROMS: Patient Reported Outcome Measures
BCTs: Behaviour Chance Techniques
NR: Not Reported
IQR: Interquartile Range
QoL: Quality of Life
QoR: Quality of Recovery
SWiM: Synthesis Without Meta-analysis
SD: Standard Deviation
CI: Confidence Interval
THR: Total Hip Replacement
TKR: Total Knee Replacement
LoS: Length of Stay

ABSTRACT

Globally, around 313 million surgeries are performed annually, emphasising the need for effective postoperative recovery. Enhanced Recovery After Surgery (ERAS) guidelines, including clinician-led and patient-led recommendations, can reduce hospital length of stay (LoS), complications, readmissions, and improve quality of life. However, patient adherence remains low. Digital health interventions (DHIs) may offer scalable, personalised support to improve adherence. This systematic review assessed the effectiveness of DHIs on adherence to patient-led ERAS behaviours, LoS, and other clinical and patient reported outcomes. Searches across five databases identified 3,286 records; seven studies were included. Adherence findings were inconsistent, except for mobilisation, where all three relevant studies favoured DHIs. All six studies reporting mean LoS found reductions favouring DHIs, with four showing significant differences. Other outcomes were mixed, limited by inconsistent definitions, high risk of bias, and methodological heterogeneity.
Overall, DHIs appear promising for reducing LoS after surgery, though evidence for other outcomes remains uncertain.

INTRODUCTION

Each year, more than 313 million surgeries are performed worldwide [1]. Optimising recovery from surgery has benefits for both patients (who are able to return to work, family, social and leisure activities sooner) and for health systems (which can more efficiently use resources by reducing hospital length of stay, complications and re-admissions). Enhanced Recovery After Surgery (ERAS) is a comprehensive perioperative care strategy designed to support faster recovery in patients undergoing major surgical procedures [2]. ERAS guidelines were initially developed for colorectal surgery, but there are now over 25 endorsed ERAS guidelines for a range of specialties for major surgeries [2]. ERAS guidelines encompass a comprehensive set of perioperative practices aimed at optimising surgical outcomes through evidence-based interventions. These include both clinician-delivered components (e.g., intraoperative fluid management, anaesthetic techniques) and patient-led behaviours (e.g., early mobilisation, nutritional intake, smoking cessation). For clarity, we refer to the patient-facing elements of the ERAS protocol as *patient-led behaviours* throughout this paper. These patient recommendations target preoperative behaviours (e.g. smoking and alcohol cessation, being physically active and maintaining a healthy weight), and postoperative behaviours (e.g. early mobilisation, early resumption of oral feeding and drinking, physiotherapy exercises, and opioid minimisation) [3].

Evidence suggests that adhering to ERAS guidelines can reduce hospital length of stay, rates of postoperative complications, hospital readmissions, and emergency department (ED) presentations [4]. In addition to improving these clinical outcomes, adhering to ERAS protocols can also positively influence patient-reported outcome measures (PROMS) such as quality of life (QoL) [4], and quality of recovery (QoR) [5]. Patients adhering to ERAS pathways have also been shown to experience accelerated post operative recovery, leading to improved physical function and overall well-being [6].

While clinician adherence to intraoperative ERAS components is generally high (~72%)[7], this figure may vary depending on the clinical setting, the specific ERAS elements assessed, and how adherence is measured. In contrast, patient adherence to pre-and post-operative guidelines is more variable, highlighting significant room for improvement. A systematic review of enhanced recovery programs including nine studies found that patient rates of adherence to the early mobilisation guideline ranged between 55-90%, and early intake of oral liquids and solids were 49-84% and 51-86% respectively [8]. Cross-sectional studies show that ERAS components that are delivered by clinicians, such as implementing pre- and intraoperative protocols typically achieve high adherence (> 80 %), whereas patient-led postoperative tasks, such as early mobilisation and oral feeding, exhibit greater variability with rates of 49–90 % across studies. In one Chinese study of over 250

colorectal surgical patients, adherence to early mobilisation and early feeding was under 50% [9]. Similarly, a recent Chinese study of 300 colorectal surgical patients found only 16% mobilised within 24 hours post operatively [10].

Multiple studies have documented common barriers to patient adherence to ERAS behaviours, such as pain and discomfort, insufficient patient education or understanding, persistent outdated beliefs about recovery (e.g. bed rest is best, delayed oral intake is safer), fears of damaging the surgical wound, forgetting key behaviours, and limited staff time to instruct, encourage, and remind patients [11], [12], [13]. To increase adherence to patient-led ERAS behaviours and realise the associated benefits, patients need support to overcome these barriers. Given the time constraints on clinicians and hospital staff, strategies for delivering patient support that minimises both hospital resources and clinician time, warrants further investigation.

Previous research has shown that surgical patients are often poorly equipped to engage in recovery programs such as ERAS. A systematic review including 57 studies in a qualitative synthesis showed that more than one-third of surgical patients have inadequate health literacy, limiting their ability to understand and follow recovery instructions [14]. Low health literacy is consistently associated with lower adherence to patient-led ERAS components including early mobilisation, early feeding, and opioid minimisation, as well as increased complication rates [15]. Attempts to educate and support patients regarding ERAS commonly include the provision of generic materials that fail to address individual patient needs, resulting in limited motivation, understanding, and engagement opportunities [16]. Without tailored, accessible education and support, patient participation in ERAS protocols is likely to remain suboptimal.

Evidence from individual trials suggests digital health interventions (DHIs) can be effective in improving adherence to ERAS guidelines both before and after surgery [17]. Delivered via DHIs, behaviour change strategies offer an efficient way to provide tailored information and resources to large numbers of patients, supporting positive behaviour change across the perioperative pathway [17].

A systematic review by Pedersen et al [18] focused specifically on the use of digital technologies to support pre-surgical health behaviours, offering valuable insights into how interventions targeting patients before surgery can influence outcomes across the surgical pathway. The review examined a range of DHIs aimed at improving components such as physical activity, nutrition, psychological well-being, and patient engagement, all key elements of prehabilitation and ERAS protocols. The findings suggest that while DHIs are generally feasible and acceptable, their impact on improving these behaviours remains variable, highlighting a need for more rigorous, high-quality studies. These

findings underscore the importance of integrating preoperative behavioural support into surgical care pathways, particularly through scalable digital means. Furthermore, existing reviews have investigated the effectiveness of DHIs in improving individual ERAS behaviours in isolation (e.g. mobilisation post-surgery, or physiotherapy exercises) [19], [20]. However, to date, there has been no synthesis of the evidence of the effectiveness of DHI in increasing the adherence to a suite of patient-led ERAS behaviours across the perioperative period. This systematic review addresses this gap by synthesising evidence on the effectiveness of DHIs that target multiple patient-led ERAS behaviours across the perioperative journey. Specifically, it aimed to systematically review the effectiveness of behavioural DHIs in increasing adherence to patient-managed ERAS recommendations and improving recovery from surgery in terms of clinical outcomes (e.g. hospital length of stay) and patient-reported outcomes measures (PROMs).

METHODS

Study Design

This systematic review was conducted in accordance with the Cochrane Handbook and PRISMA 2020 guidelines [21] (Appendix 1) and was prospectively registered with PROSPERO (CRD42024511718).

Search Strategy

A comprehensive search was conducted across the following electronic databases- MEDLINE, EMBASE, the Cochrane Library, Cochrane CENTRAL and CINAHL (4th March 2025). The development of the search strategy was informed by an experienced university librarian in collaboration with the research team. The detailed search strategy for each database is provided in Appendix 2. No date limits were applied to the search. Literature searches were limited to those published in the English language. Manual searches were carried out on the references lists of eligible studies.

Eligibility Criteria

Study Design

Eligible studies were parallel group randomised controlled trials, cluster randomised controlled trials, quasi-randomised controlled trials and non-randomised controlled clinical trials. Systematic reviews were excluded.

Population

Studies that recruited adult patients (mean age of 18 years or older) undergoing surgery which required an overnight hospital stay were eligible for inclusion. Studies focusing on paediatric populations or day surgery patients were excluded.

Interventions

Included studies had to evaluate a digital intervention that aimed to increase adherence with patient-led ERAS guidelines. In the context of this review, digital interventions were defined as remotely delivered tools or platforms including SMS, email, websites, or mobile applications. Prior to the search being conducted, a study author (ES) reviewed all ERAS guidelines [2] and identified all behaviours that were patient-managed (Appendix 3). These were reviewed by a clinician (SS) for appropriate categorisation as "patient-managed" (as opposed to "clinician-managed"). Furthermore, the interventions had to target multiple (a minimum of 2) patient-led ERAS behaviours. Given the existence of prior reviews of interventions targeting single perioperative behaviours in isolation, [17], [18], [19] and given that ERAS guidelines emphasise a multimodal approach, targeting multiple behaviours concurrently to optimise surgical outcomes, this review aimed to evaluate the effectiveness of interventions that more closely reflect the integrated behavioural demands of ERAS protocols.

Comparison

Studies were included if they compared an eligible intervention to standard care, a control group, or another non-digital intervention.

Outcomes

Studies were included if they reported on at least one of the primary outcomes; adherence to patient-led ERAS behaviours (e.g. mobilisation) or the hospital length of stay.

Secondary outcomes included clinical outcomes such as hospital readmissions, postoperative complications (e.g. infections), emergency department (ED) visits, as well as patient-reported outcome measures (PROMs) related to recovery, including quality of life (QoL), quality of recovery (QoR), and patient satisfaction.

Study screening and selection

Search results from the selected databases were imported into EndNote and duplicate records were identified and removed. The de-duplicated records were then imported into the Covidence online systematic review management system [22]. Pairs of unblinded authors (ES, PVS, RW, EF) used Covidence to independently screen titles and abstracts and then full texts of identified records for potential inclusion [22]. Any discrepancies between reviewers were resolved through discussion. If consensus could not be reached, a third reviewer (RW) was consulted to make the final decision.

Data Extraction

A pair of unblinded authors (ES and PVS) independently extracted relevant information, using an extraction template adapted from the Cochrane Public Health data extraction template and piloted prior to use. Any discrepancies were resolved through discussion, and where consensus could not be reached, a third reviewer (RW) was consulted.

Extracted information included study design, participant characteristics (e.g. gender, age), surgery type (e.g. colorectal surgery), intervention characteristics, and behaviour change techniques based on the COM-B model of behaviour change [23]. Primary and secondary outcomes were also extracted. Where multiple measures or timepoints were reported for the same outcome, we applied a pre-specified hierarchy to guide data extraction. For the outcomes of interest, preference was given to validated measurement tools over non-validated or study-specific instruments, and to the most clinically relevant or commonly reported timepoint (e.g. 30-day outcomes for complications and readmissions.

Data Synthesis

Where sufficient and sufficiently homogeneous data were available, we planned to conduct a meta-analysis to synthesise the primary outcomes. Specifically, we aimed to pool mean differences using random-effects models, with 95% confidence intervals. Length of stay is typically right skewed, and because the mean is sensitive to skewness and outliers, while the median more accurately reflects the central tendency of skewed data, combining these summary measures directly in a meta-analysis would violate key statistical assumptions and potentially produce biased results. Although methods exist to estimate means from medians [24] , these rely on assumptions about the data distribution that may not hold, especially with heterogeneous clinical populations. To maintain methodological rigor and transparency, we therefore provide separate narrative syntheses of studies reporting means and those reporting medians. This approach respects the distinct statistical properties of each measure, reflects real-world reporting practices, and avoids misleading interpretations that could arise from inappropriate data transformation or pooling.

Where meta-analysis was not feasible, and for all other primary outcomes, we planned to conduct a narrative synthesis following the Synthesis Without Meta-analysis (SWiM) guidelines [25]. Studies were to be grouped by outcome domain (e.g. complications, readmissions, patient-reported outcomes), and the direction and magnitude of effects were to be described, including the consistency of findings across studies. Where appropriate, results were to be presented in summary meta-analysis to facilitate comparison.

Risk of Bias

Two reviewers (ES and EF) independently assessed the risk of bias of all included studies. Risk of bias was assessed using one of three different Cochrane tools, depending on the study design. Individually randomised trials were assessed using the Cochrane risk-of-bias tool for randomised trials (RoB 2) [26], while cluster-randomised trials were assessed using the RoB 2 tool adapted for cluster-randomised designs (RoB 2 CRT) [27]. The RoB 2 [26] tool consists of five individual domains: 1) randomisation process, 2) deviations from intended interventions, 3) missing outcome data, 4) measurement of the outcome, and 5) selection of the reported result. The cluster version of the tool [27] includes an additional domain: timing of identification or recruitment of participants in a cluster randomised trial. Judgements across domains are used to determine an overall risk of bias. Studies were assessed as having an overall RoB of either 'low' 'some concerns' or 'high'. A study was rated as 'high' if one or more of the domains were considered as high risk, some concerns if one or more domains were judged as having some concerns, and low if all domains were classified as having low risk of bias.

For non-randomised studies, the ROBINS-I tool (Risk Of Bias In Non-randomised Studies of Interventions) was applied [28], which evaluates seven domains: 1) confounding, 2) classification of interventions, 3) selection of participants, 4) deviations from intended interventions, 5) missing outcome data, 6) measurement of the outcome, and 7) selection of the reported result. These domains are then used to form an overall assessment of risk of bias. The overall RoB was judged as 'low', 'moderate', 'serious' or 'critical'. A study was classified as 'critical' if any domain was rated critical, as 'serious' if at least one domain was rated 'serious' but none critical, as 'moderate' of some or more domains were rated as moderate with none rated serious or critical, and as 'low' if all domains were rated as low risk.

Any discrepancies were resolved as per the method outlined for data extraction.

Quality Assessment

The overall quality of evidence for each primary outcome was rated according to the Grading of Recommendations Assessment, Development and Evaluation (GRADE) guidelines [29] which considered five domains: risk of bias, inconsistency, indirectness, imprecision, and publication bias. Two reviewers (ES and EF) conducted GRADE assessments (Appendix 4) with disagreements resolved through discussion with a third reviewer (RW).

RESULTS

Selection of eligible studies

The search yielded 4001 studies, of which 715 were identified as duplicates and excluded prior to title and abstract screening. A total of 3286 studies were assessed for eligibility during title and abstract screening, and 66 considered in full-text screening. Seven studies met the eligibility criteria and were included in the analysis. Figure 1 describes the process of eligibility assessment, including the reasons for exclusion from the full-text screening.

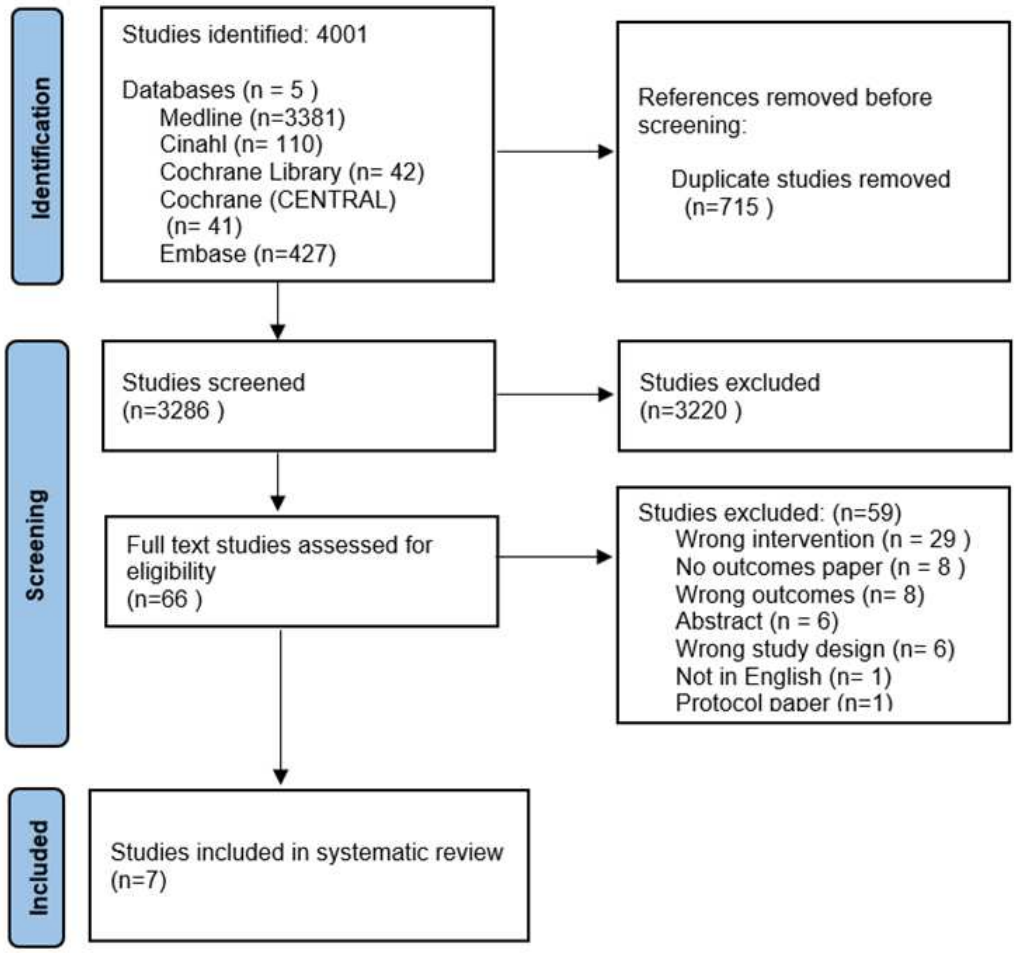


Figure 1. PRISMA flowchart for study selection

Study Characteristics

The included studies were published between 2017 and 2025 and originated from a range of countries, including the USA [30], UK [31], Australia [32], Canada [33], Denmark [34], the Netherlands [35], and New Zealand [36]. The characteristics of the included studies are summarised in Table 1. The review included five randomised controlled trials (RCTs) [32], [33], [34], [35], [36] and two non-randomised studies [30], [31]. The DHIs evaluated across the included studies were diverse but predominantly used mobile applications to support patient adherence to ERAS protocols. Four

interventions [30], [32], [33], [35] included mobile apps with a range of features including milestone checklists, daily questionnaires, personalised recovery timelines, and push notifications to prompt patient completion of daily goals (related to patient-led ERAS behaviours). The three other interventions [31], [34], [36] used TV-connected devices delivering interactive educational content, including 3D animations to explain recovery principles such as early mobilisation and nutrition, as well as online learning modules. These digital tools were built into the hospitals' existing recovery programs (ERAS), helping support patients without changing the overall care pathway.

Surgical Procedures

Of the seven studies included, three focused on colorectal surgery [30], [33], [35], one on both colorectal and gynaecological oncology surgery [36] one on hip replacement [34], one on knee replacement [32], and one on both hip and knee replacements [31], with data reported separately for each procedure.

Primary Outcomes:

Adherence to patient-led ERAS behaviours was reported in four studies [30], [33], [35], [36] .

Length of stay was reported in all seven studies [30], [31], [32], [33], [34], [35], [36].

Secondary Outcomes: Clinical and Patient-Reported Outcomes

All studies reported on hospital readmissions following surgery (n=7) [30], [31], [32], [33], [34], [35], [36], whereas a subset reported on complications (n= 5) [30], [31], [32], [33], [35] and ED presentations (n=2) [31], [33]. Patient reported outcome measures (PROMS) were reported in six studies [31], [32], [33], [34], [35], [36]. Four of these studies evaluated patient satisfaction [31], [32], [33], [35] [32], [33], [35]using a variety of methods: one employed global satisfaction questions, another used single item scales (options ranging from 0-10), one utilised a self-developed questionnaire, and another used a tool derived from the Surgical CAHPS survey. One study assessed Quality of Life (QoL) [34] and used the EQ-5D-3L tool, and one study evaluated Quality of Recovery (QoR) [36] and used the Myles QoR-15 tool.

Table 1. Characteristics of included studies

Study and Year	Location	Design (Randomisation and follow up)	Aim of the Trial	Surgery Type	Total Sample	ERAS Behaviours Targeted	Behaviour Change Strategies used (Michie et al.) [23] **	Digital Channel Used	Intervention Description
RCTs									
Vesterby et al., 2017	Denmark	RCT Patients randomised ~14 days pre-op to control (standard care) or intervention (fast-track pathway) and were followed up for 12 months after surgery.	To evaluate whether telemedicine support can reduce the length of hospital stay for patients undergoing fast-track total hip replacement surgery, without compromising safety, recovery, or patient satisfaction.	Hip Replacement surgery	N=73 Intervention 36 Control 37	Mobilisation and oral intake.	Instructions on how to perform the behaviour Credible source Information about health consequences Social support	Telemedicine connected to their home TV.	A TV-connected device providing interactive, multimedia educational content including animations, exercise demonstrations, daily task guidance, medication overviews, radiographs, and two-way video conferencing with clinicians.
Mata et al., 2020	Canada	RCT Randomised pre-operatively to intervention or control group; 1-month follow-up post-op	To evaluate whether a mobile app improves adherence to an enhanced recovery program for colorectal surgery.	Colorectal Surgery	N=100 Intervention 50 Control 50	Mobilisation, chewing gum, breathing exercises, oral fluid intake.	Self-monitoring of behaviour. Goal setting Instructions on how to perform the behaviour Credible source Social reward	Mobile App (tablet)	A tablet containing a novel mobile app which included milestone checklists, daily clinical questionnaires and education.
Van Der Storm et al., 2025	Netherlands	RCT Randomised pre-op to intervention or control groups, stratified by disease and age; followed from pre-op to 42 days post-op	To evaluate whether the DHI increases adherence with selected patient managed elements of the ERAS protocol for colorectal surgery.	Colorectal Surgery	N=140 Intervention 72 Control 68	Mobilisation and early intake of solid food.	Prompts and cues. Self-monitoring and feedback Goal setting	Mobile app & wearable activity tracker	The app generates a timeline based on the operation date which provides information and daily goals to complete. If new information or goals are available, push notifications are sent to stimulate patients to adhere to the protocol. The app 'dashboard' displays the completion of three subjects: 1) daily activity goal, 2) active ERAS elements, and 3) self-

									registered questionnaires throughout the entire study.
Jones et al., 2019	New Zealand	RCT (3-arms): intervention (animated video); active control (static education materials), control (usual care only). Randomisation post-scheduling of surgery date; pre-surgery; 30-day follow-up	To evaluate if providing animated visualization to patients shortly after surgery improves postoperative mobilisation.	Colorectal Surgery and Gynaecological Oncology Surgery	N=96 Intervention 33 Active Control 32 Control 31 Step count analysis *** 57 colorectal Intervention 18 Active Control 19 Control 20	Mobilisation and early oral food intake.	Present communication from a credible source. Instruction / demonstration of how to perform behaviours. Present info about health consequences Framing/reframing Goal Setting Action planning	Animated video	3D animation showing the purpose of early mobilisation and the importance of early oral nutrition and the link between the two for post-surgery recovery.
McDonall et al., 2019	Australia	Cluster RCT-crossover trial (2 clusters + control) Patients allocated post-surgery to clusters by ward/bed availability; follow-up 12–16 weeks post-surgery.	To test whether a clinician-facilitated, bedside multimedia intervention (called *MyStay*), delivered daily in the acute postoperative period after total knee replacement (TKR), can improve patient participation in their recovery.	Knee Replacement Surgery	N=241 Intervention 104 Control 137	Pain management and DVT prevention	Communication from a credible source Goal setting Information about health consequences Social support	Online modules (tablet) & printed material	"MyStay" chapter-based online modules that combined text, sound, graphics and animation and packaged for iPad presentation. It was designed to be both clinician-facilitated and patient self-directed.
Non-RCTs									
Schlund et al., 2020	USA	Non-randomised. Grouped retrospectively by enrolment in care program; Enrolled (Intervention-Received interactive app + ERAS); Not-	To assess whether an interactive app in an existing ERAS program enhanced adherence to ERAS protocols.	Colorectal Surgery	N=289 Intervention (Enrolled) 147 Control (Not enrolled) 142	Bowel prep, oral intake (liquid), solid intake and medication adherence	Communication from a credible source Provide instruction and demonstration. Prompts and cues.	Mobile app	A customised mobile phone app to reinforce ERAS pathway education, providing reminders and allowing for providers to monitor patient progress over their perioperative course.

		enrolled (received standard ERAS only). Follow up- within 48 hours of discharge. *							
Jayakumar et al., 2017	UK	Non-randomised; Participants were classified into "pre-program" (retrospectively assessed) and "program" (prospectively assessed) cohorts. Outcomes were based on patient-reported measures over 6 months (post-op)	To evaluate the impact of a digital, patient-focused program on clinical outcomes, patient engagement, and recovery after primary total hip and knee replacement surgery.	Hip and Knee Replacement Surgery	N=2080 Hip replacement 1034; Knee replacement 1046 **Intervention** Program cohort 1042 Outreach Support 401 Non outreach support 641 **Control** Pre-Program cohort 1038	Mobilisation and medication adherence	Communication from a credible source. Prompt/cues	Digital health platform (website)	A patient-focused, technology-enabled care pathway integrated with established ERAS practices including multimedia education and engagement, inpatient physiotherapy and outreach support (home visits)
THR: Total Hip Replacement; **TKR:** Total Knee Replacement									

*A specific post-discharge duration for readmission monitoring was not reported.

** BCTs were independently coded by two review authors based on the limited information available in the manuscript. No included paper explicitly referred to any BCT that they had included.

*** Step count data could not be collected for the entire sample due to the unexpected discontinuation of the fitness tracker company's online servers and application. As a result, data from participants recruited in the latter half of the study were inaccessible, and only those recruited earlier had step count data recorded.

Risk of Bias

Risk of bias was assessed for the two primary outcomes using ROB 2.0 for randomised controlled trials and ROBINS-I for non-randomised studies. A summary of overall risk of bias judgments is presented in Table 2, with domain-level assessments available in Appendix 5.

For both outcomes, risk of bias varied substantially across studies. Of the included RCTs, only one was assessed as low risk of bias overall for both outcomes [34]. The remaining trials were rated as either 'some concerns' or 'high risk', most commonly due to deviations from intended interventions and selective reporting, particularly where intention-to-treat principles were not adhered to.

Among the two non-randomised studies, both were rated low risk on several domains, but confounding remained a consistent issue. One study [31] was rated as having a 'moderate' overall risk of bias due to selective reporting, while the other [30] was rated as 'serious' due to potential confounding.

Overall, the majority of studies were rated as either high or moderate risk of bias, which may limit the certainty of the evidence. These limitations are further considered in the discussion.

Table 2. Overall risk of bias for Length of Stay and Adherence to ERAS behaviours.

Study (assessment tool)	Adherence to ERAS	Length of stay
Mata, 2020 (RoB 2)	▲– Some concerns	▲– Some concerns
Jones 2019 (RoB 2)	▲– Some concerns	▲ – Some concerns
Van der Storm 2025 (RoB 2)	■– High risk of bias	■ – High risk of bias
Versterby, 2017 (RoB 2)	N/A	● – Low risk of bias
McDonall, 2019 (RoB CRT)	N/A	■ – High risk of bias
Jayakumar, 2017 (ROBINS-I V2)	N/A	▲ – Moderate risk of bias
Schlund, 2020 (ROBINS-I V2)	■ – Serious risk of bias	■ – Serious risk of bias

Primary Review Outcomes

Adherence to Patient-led ERAS Behaviours

Four studies reported on outcomes relating to adherence to ERAS guidelines [30], [33], [35], [36]. Measures of adherence varied between studies, with three studies [30], [33], [35] reporting adherence to individual ERAS elements; bowel preparation [30], oral and solid intake [30], [33] and

medication adherence [30]. One study [35] also reported a composite adherence score reflecting overall ERAS adherence. Adherence to physical activity recommendations was assessed in one study [36] using step count data. Across the studies, adherence was evaluated at various timepoints ranging from postoperative day 1 to day 7. This heterogeneity in both measurement tools and timing limits comparability across studies. Due to the small number of studies, randomised and non-randomised trials are reported together.

Mobilisation and Physical Activity

In all three studies reporting mobilisation and physical activity [33], [35], [36] postoperative mobilisation favoured the intervention group, with two studies [35], [36] finding statistically significant differences. However, measures and effect sizes varied. Jones et al. [36] found significantly higher step counts (quantitative) 7-days post-surgery compared with usual care (2,294 vs 1,347 steps; $p < 0.05$). Van der Storm et al. [35] reported significantly higher Day 1 ERAS mobilisation adherence (dichotomous) in the intervention group (93.1% vs 66.2%; $p < 0.001$). Mata et al. [33] reported small, non-significant differences favouring the intervention group in getting out of bed (dichotomous) on days 1 and 2 (day 1: 20 vs 23 mean adherence; p=0.68; day 2: 10 vs 11; p= 1.00).

Oral Intake and Nutritional Adherence

Two out of the three interventions showed improvements in early nutrition [32], [33], with substantial variation in the magnitude of effect. However, only one reported statistically significant results [32]. Van der Storm et al. [35] observed substantial and statistically significant improvements in early solid food intake in the intervention group compared with controls (87.5% vs 45.6%; $p < 0.001$). Schlund et al.[30] reported smaller increases in oral (liquids) intake (67.3% vs 63.4%) and solid food intake (38.1% vs 31.7%), showing no statistical significance ($p = 0.559$ and $p = 0.309$, respectively). Mata et al. [33] found no differences in overall oral intake of fluids adherence on postoperative days one and two.

Adherence to ERAS recommendations (not otherwise reported)

Two studies reported relevant adherence outcomes, which are not covered elsewhere. Schlund et al. [30] found significantly higher medication adherence in the intervention group (82.1% vs 76.8%; $p = 0.005$), while other components such as bowel preparation, oral intake and solid intake did not differ significantly. Van der Storm et al. [35] reported significantly higher overall ERAS adherence using a composite measure (76.4% vs 66.4%; $p = 0.003$), although no significant differences were found for components such as GI stimulation (chewing gum), nutritional screening and assessment and urinary catheter removal.

Quality of Evidence and Confidence in Findings

The certainty of evidence was evaluated using the GRADE approach for two key outcomes: adherence to patient-led ERAS behaviours and hospital length of stay. For both outcomes, the certainty of evidence was rated as very low due to limitations across several domains.

For adherence, concerns included risk of bias (e.g., high attrition and retrospective allocation), inconsistency in outcome definitions and effects, indirectness in how adherence was operationalised, and imprecision due to small sample sizes and wide confidence intervals.

For length of stay, similar issues were identified. Although all studies assessed relevant surgical populations, inconsistency in measurement approaches and reporting, as well as some risk of bias and imprecision, contributed to a very low overall certainty rating.

No serious concerns were identified regarding publication bias or other factors for either outcome.

Length of Stay

All seven studies reported outcomes related to hospital length of stay. Three studies reported both mean and median values [30], [33], [34], three reported means only [31], [32], [36], and one reported median only [35]. Due to differences in study design and missing statistical data, meta-analysis was not feasible for length of stay data. Therefore, results are synthesised narratively in accordance with the SWiM (Synthesis Without Meta-analysis) guidelines [25] and are grouped by summary statistic (mean or median) and study design (randomised vs non-randomised trials). Table 3 presents a detailed overview of length of stay reporting across the included studies.

Mean Length of Stay

All six controlled studies that reported mean hospital length of stay showed shorter stays for patients in the intervention groups compared to controls. Reported unadjusted between-group differences ranged from 0.72 to 2.0 days. The largest reduction was reported in a non-randomised controlled study by Schlund et al., with a 2.0-day difference [30].

Among the randomised controlled trials, the largest mean difference was observed in the study by Jones et al., [36] showing a reduction of 1.85 days, followed closely by Mata et al. [33] with 1.8 days.

Randomised Trials

Among the five randomised trials, four studies reported statistically significant between-group reductions in mean length of stay, favouring the intervention group [32], [33], [34], [36]. McDonall et

al. [32] reported a mean length of stay of 5.29 days in the intervention group compared to 6.29 days in the control group, corresponding to a between-group difference of 1.0 day (95% CI −1.94 to −0.05; $p = 0.04$). Vesterby et al. [34] similarly reported a between-group reduction of 0.72 days (95% CI 0.42–1.02; $p < 0.001$). Mata et al. [33] found that the intervention group had a mean length of stay of 4.6 days compared to 6.4 days in the control group, resulting in a between-group difference of 1.8 days (95% CI −3.2 to −0.4). Jones et al. [36] reported a mean length of stay of 5.44 days in the intervention group versus 7.29 days in the usual care group, a significant between-group difference of 1.85 days ($p < 0.05$).

Non-Randomised Studies

Both non-randomised studies reported statistically significant reductions in mean length of stay. Schlund et al. [30] observed a significantly shorter mean length of stay in the intervention group (4.4 days) compared to the control group (6.4 days; $p = 0.006$). Jayakumar et al. [31] found a reduction in length of stay ($p < 0.0001$) in the intervention group (4.4 days) compared to the control group (6.0 days) among the total hip replacement (THR) patient group, and a decrease from decrease from 6.4 days to 5.2 days, in the total knee replacement (TKR) patient group.

Median Length of Stay

Four studies [30], [33], [34], [35], reported median length of stay and the findings across these studies were mixed. One study reported a statistically significant reduction in the intervention group [34], two found no statistically significant differences [33], [35] and one reported no difference without any statistical testing conducted [30].

Randomised Trials

Among the three randomised trials [33], [34], [35], reporting median, only one study [34] reported a significantly lower median length of stay in the intervention group compared with the control. Vesterby et al. [34] reported a statistically significant difference in median length of stay from 2 days (range 1–4) in the control group to 1 day (range 1–5) in the intervention group ($p < 0.001$). Van der Storm et al. [35] reported no difference in median length of stay between groups (5 days in both; IQR 4.00–6.75 vs 4.00–7.75; $p = 0.997$). Contrary to expectations, Mata et al. [33] found a higher median length of stay in the intervention group (4.0 days, IQR 2–5.8) compared to controls (3.0 days, IQR 2–5), although this difference was not statistically significant ($p = 0.33$).

Non-Randomised Studies

The non-randomised study by Schlund et al. [30] reported identical median length of stay in both the intervention and control groups (4 days), with no statistical test performed. Although a p-value of 0.006 was reported elsewhere in the study, no statistical comparison was presented specifically for the medians, limiting interpretability.

Quality of Evidence and Confidence in Findings

The findings related to length of stay should be interpreted in the context of the overall quality of evidence, which was rated as "very low" according to the GRADE Working Group criteria [37]. Downgrades were primarily due to risk of bias (such as lack of intention-to-treat analysis and retrospective allocation), inconsistency of findings across studies, imprecision (including wide confidence intervals and small sample sizes), and heterogeneity in study populations, interventions, and statistical reporting. The variability in both the direction and magnitude of effects for median length of stay, along with incomplete statistical reporting, precluded a formal meta-analysis and limits the certainty of conclusions regarding the impact of interventions on this outcome. In contrast, findings for mean length of stay were more consistent, with all six studies reporting shorter stays in the intervention group and all four that conducted significance testing reporting statistically significant reductions. This distinction between mean and median outcomes is important when interpreting the overall strength of evidence.

Table 3. Summary of hospital length of stay included studies. Data are reported as means or medians with associated standard deviations (SD), interquartile ranges (IQR), ranges, confidence intervals (CI), and p-values where available. No data transformations were applied. Studies are grouped by statistical summary measures and design for narrative synthesis.

Study	Design	Measure	Intervention	Control	Effect size
Mata	RCT	Mean (95% CI)	4.6 (3.8–5.4)	6.4 (2.6-10.2)	Mean (95% CI) reduction: −1.8 (−3.2 to −0.4)
Jones	RCT	Mean (SD)	5.44 (3.37)	7.29 (4.85)	Mean difference (intervention vs control) = -1.85
Vesterby	RCT	Mean (95% CI)	Reduced by 0.72 days (95% CI: 0.42–1.02)		p < 0.001
McDonall	Cluster RCT	Mean (95% CI)	5.29 (NR)	6.29 (NR)	p=0.04

					Mean (95% CI) reduction: −0.05 to −1.94
Schlund	Non-RCT	Mean (NR)	4.4	6.4	p = 0.006
Jayakumar	Non-RCT	Mean (SD)	Total Hip Replacement: Program: 4.4 (2.4) Program (outreach support) 3.5 Program (no outreach support: 4.8	Total Hip Replacement Pre-Program: 6.0 (6.8)	p <0.0001 Mean (%) reduction: 1.6, 27% reduction 2.5, 42% reduction 1.2, 20% reduction
		Mean (SD)	Total Knee Replacement: Program: 5.2 (3.1) Program (outreach support): 4.4 Program (no outreach support): 5.8	Total Knee Replacement: Pre-Program: 6.4 (4.1)	p <0.0001 Mean (%) reduction: 1.2, 19% reduction 2, 31% reduction 0.5, 9% reduction
Mata	RCT	Median (IQR)	4.0 (2–5.8)	3 (2–5)	P=0.33
Vesterby	RCT	Median (range)	1 (1–5)	2 (1–4)	p < 0.001
Van der Storm	RCT	Median (IQR)	5.00 (4.00 – 6.75)	5.00 (4.00–7.75)	p=0.997
Schlund	Non-RCT	Median (NR)	4 (NR)	4(NR)	No effect size or statistical test reported; unable to calculate effect size
Legend: SD = standard deviation, CI = confidence interval; THR: total hip replacement, TKR: total knee replacement, IQR: interquartile range; NR = not reported					

Secondary Review Outcomes

Readmissions

Hospital readmissions were reported across all seven studies, as summarised in Table 4, with the assessment time period ranging from 30 days to 6 months post-surgery. Where multiple timepoints were reported, the 30-day measure was prioritised for consistency with standard postoperative reporting guidelines.

Overall, the direction of effect for readmission rates was inconsistent across studies. Three studies [30], [33], [35] reported higher readmission rates in intervention groups, whereas two studies [31], [36] observed lower rates. Only Mata et al. [33] demonstrated a clinically meaningful reduction, with a statistically borderline reduction in 30-day readmissions (0% vs. 8%, p = 0.05). Jayakumar et al. [31] reported notable reductions in 30-day and 6-month readmissions for total hip replacement (THR) patients (36% and 56%, respectively), though these did not reach statistical significance. Reductions for total knee replacement (TKR) patients were smaller and similarly non-significant. Overall, the inconsistency and lack of statistical significance across studies limits definitive conclusions regarding the impact of digital interventions on readmission rates. No study reported a statistically significant increase in readmissions favouring the control group.

Table 4. Readmission Rates Across Studies

Study	Measure	Intervention	Control	Effect Size
Mata et al. [33]	30-day readmission – n (%)	0 (0%)	4 (8%)	p = 0.05
Vesterby et al. [34]	Readmissions – Mean (range)	0.03 (–0.03 to 0.08)	0	p = 0.3
McDonall et al. [32]	28-day readmission – n	3	3	p = 0.73
Van der Storm et al. [35]	Readmission – n (%)	13 (15.7%)	9 (10.6%)	p = 0.228
Jones et al. [36]	30-day readmission – n (%)	5 (15.6%)	Active Control: 6 (19.4%) Passive Control: 4 (12.9%)	p = 0.785
Schlund et al. [30]	Readmission rate – n (%)	22 (15%)	15 (10.6%)	p = 0.345

Jayakumar et al. [31]	Readmission rate (30 days) – Mean (SD)	Total Hip Replacement: 3.7% ± 0.19% Total Knee Replacement: 5.5% ± 0.23%	Total Hip Replacement: 5.8% ± 0.26% Total Knee Replacement: 6.5% ± 0.26%	THR: 36%, p = 0.102 TKR: 15%, p = 0.681
Jayakumar et al. [31] 6 months	Readmission rate (6 months– Mean (SD)	Total Hip Replacement: 2.7% ± 0.16% Total Knee Replacement: 6.3% ± 0.25%	Total Hip Replacement: 6.2% ± 0.32% Total Knee Replacement: 8.3% ± 0.28%	Total Hip Replacement: 56%, p = 0.063 Total Knee Replacement: 24%, p = 0.247

Complications

Postoperative complications were reported in five studies [30], [31], [32], [33], [35], however definitions, timepoints, and measurement approaches varied. Some studies reported overall complication rates [31], [33], [35], while others [30], [32] provided data on specific types of complications, (e.g. surgical site infections (SSIs) or deep vein thrombosis (DVT) events). The timeframes for reporting complications also varied, and included the in-hospital period [32], within 30 days of surgery [31], [32], [33] and were not specified in two studies [30], [35].

The direction of effect favoured the intervention, with lower rates of complications observed in four of the five studies [31], [33], [35],[30], although a significant reduction was only found in one study measuring surgical site infections [30]. One study [32] observed a non-significant increase in complications in the intervention group.

Emergency Department (ED) Presentations

Two studies [31], [33] reported on emergency department (ED) presentations following surgery. Neither study found significant differences, but Jayakumar et al. [31] observed small, non-significant reductions in ED attendance favouring the intervention for both hip and knee replacement patients. Mata et al. [33] found no difference in 30-day ED presentation rates between groups.

Quality of Life

The only study to assess QoL [34] found no significant between-group difference 12 months post-surgery.

Quality of Recovery

The only study to assess QoR [36] found a statistically and clinically significant improvement over seven days in the intervention group compared to control ($p = 0.043$), with an effect size indicative of a moderate to large benefit.

Patient Satisfaction

Three studies [31], [32], [33] reported on patient satisfaction; however, approaches to measurement varied. In two of the three studies [33], [35] small effects were observed favouring the intervention group, and in one of these studies the effects were statistically significant [35]. McDonall et al. [32] found small but significant changes in global satisfaction favouring the intervention. Jayakumar et al. [31] found non-significant small changes favouring the intervention measured preoperatively, at discharge, and 6 months post-surgery). Mata et al. [33] found no significant between-group differences in whether patients felt informed, confident, motivated, or satisfied with their care (S-CAHPS tool at time of discharge).

DISCUSSION

This systematic review synthesised the evidence from studies evaluating the effectiveness of DHIs aimed at supporting patient-led ERAS behaviours following surgery. Seven studies were included, predominantly in colorectal surgery, and the remainder in hip and knee replacement surgery. Overall, the findings suggest that these interventions may improve adherence to early mobilisation guidelines, mean length of hospital stay, and short-term patient quality of recovery, however evidence for other outcomes was inconsistent.

Adherence to ERAS behaviours was reported in four studies [30], [33], [35], [36], with mixed evidence on the impact of DHIs. The strongest benefit was observed for mobilisation, with all three RCTs [33], [35], [36] favouring the intervention and two [35], [36] showing significantly higher adherence in intervention groups. Findings for other ERAS elements, such as nutritional intake, oral fluids, and medication adherence, were less consistent. This pattern aligns with previous research on both digital and non-digital perioperative interventions, which similarly found that mobilisation is one of the most responsive behaviours to intervention, especially when supported by real-time feedback or self-monitoring tools [38]. In contrast, behaviours like oral intake or medication adherence are often influenced by clinical status, appetite, or hospital protocols, limiting the patient's capacity to fully engage [39].

The variability in outcomes may also be explained by differences in how adherence was measured, which ranged from composite ERAS adherence scores (aggregating performance across multiple ERAS behaviours) to individual binary indicators (e.g. whether oral intake was initiated: yes/no) and

objective metrics such as pedometer-measured step count. Furthermore, the timing of adherence assessment varied widely from postoperative day one to day seven limiting comparability across studies. These methodological differences are consistent with limitations noted in previous reviews on adherence measurement and digital behaviour change interventions in surgical patients [40], [41], and highlight the need for standardised adherence definitions and measurement tools in future research. Additionally, variability in patients' length of stay, means individuals may have different exposure windows to perform target behaviours, which can influence adherence estimates. Future analyses should account for this by adjusting for exposure time or using rate-based metrics (e.g. behaviours per day).

Among studies reporting mean length of stay (n=6), reductions in hospital stay for intervention groups were observed in all studies, with reductions in length of stay of 0.7 to 2.5 days. In all four studies that analysed between-group differences, statistically significant reductions were observed, including in randomised [34], [32] and non-randomised studies [30], [31]. In contrast, findings for median length of stay were less consistent, with only one study [34] demonstrating a significant reduction, while others found no difference or non-significant increases.

The certainty of evidence for length of stay outcomes was assessed as very low, primarily due to concerns about risk of bias (e.g., failure to adhere to intention-to-treat principles and retrospective allocation), inconsistency across studies, and imprecision of the results. There was substantial heterogeneity, wide confidence intervals, and variation in findings. For example, median length of stay increased in the intervention group in the study by Mata et al. contradicting expected trends. These discrepancies between the findings for mean and median length of stay likely reflect the typically skewed distribution of length of stay, where a small number of patients with prolonged hospitalisations disproportionately inflate the mean [42]. These findings may suggest that adherence to ERAS behaviours has a more pronounced effect on reducing length of stay among patients with longer hospitalizations; however, due to variability in data and potential outliers, further research is needed to definitively identify which patient subgroups derive the greatest benefit. While this may mean that the potential benefit of the intervention is not spread evenly across the patient samples, any reduction in length of stay, regardless of how it is distributed, has important implications for resource use across the whole health system. Given that each additional hospital day can cost several hundred to thousands of dollars depending on the setting [43], [44], even modest reductions in length of stay can translate into substantial cost savings and improved bed availability.

Overall, these findings suggest that DHIs may be effective in improving adherence to individual behaviours within the ERAS guidelines, particularly mobilisation. This is consistent with previous

research which indicates that DHIs targeting single behaviours may be more impactful than interventions targeting multiple behaviours concurrently [45]. The behaviours targeted in the included studies align with core elements of ERAS guidelines, which are grounded in robust evidence demonstrating their impact on clinical outcomes and patient wellbeing. Although individual studies in this review often did not show direct clinical effects, it is possibly due to limitations in study design and power. Importantly, the absence of observed clinical benefit in isolated trials should not be interpreted as evidence against the effectiveness of these behaviours, as guideline recommendations are based on large-scale syntheses of evidence. While previous research suggests that targeted, behaviour-specific interventions may yield stronger patient engagement and better adherence for individual actions, the findings of this review also highlight the need to support a broader suite of patient-led ERAS behaviours, particularly during the recovery phase. Focusing solely on one behaviour such as mobilisation may limit overall recovery outcomes. Instead, addressing multiple interconnected behaviours, especially during the recovery phase (e.g., nutrition, physiotherapy exercises and pain management), is crucial to optimise patient recovery and ensure comprehensive adherence to ERAS protocols. This reflects a shift toward empowering patients as active participants in their recovery and designing interventions that are both feasible and scalable. Future research should explore strategies to optimise delivery, potentially through phased or prioritised approaches, to improve adherence across multiple behaviours without overburdening patients.

Although most studies showed non-significant reductions in complications favouring the intervention group, there was limited evidence that the included DHIs meaningfully impacted clinical outcomes such as readmissions or emergency department (ED) visits. This is likely due to limitations in study design and statistical power, as well as the relatively low incidence of these events. Many studies were not adequately powered to detect differences in clinical endpoints, particularly when patient engagement or adherence to the intervention was suboptimal. Inadequate uptake, variability in implementation fidelity, and short follow-up periods may have further contributed to underestimating the true clinical impact of these tools. Interestingly, while reductions in complications were generally non-significant, such trends would be expected to influence the mean rather than the median length of stay, as complications typically extend hospital stays at the upper end of the distribution. These findings are notable given the consistent reductions observed in mean length of stay across studies, despite inconsistent effects on median values. This discrepancy warrants further investigation to better understand the mechanisms by which DHIs may affect clinical outcomes [46]. Furthermore, most interventions in the included studies targeted change at the patient level only, focusing on self-management, symptom tracking, and engagement with

recovery or follow-up care. Few studies [31], [32], [34] implemented interventions that also involved clinicians or hospital-level processes, limiting the potential for broader system-wide impact.

Evidence on patient reported outcomes following the use of a DHI is limited and mixed. Of the studies reporting on PROMS, only one study [36] reported the quality of recovery (QoR) and found statistically and clinically significant improvements over the first seven postoperative days, with an effect size suggesting a moderate to large benefit, while another found no difference in health-related quality of life (HR-QoL) at 12 months post-surgery [34]. Similarly, studies assessing patient satisfaction reported variable results, with two studies reporting statistically significant improvements in satisfaction [31], [32] while one observed no difference [33]. Differences in outcomes measures, timing of assessment and study design are likely to have contributed to these varied findings in patient reported outcomes. Short-term QoR and multi-item satisfaction scales may be more sensitive to intervention effects than generic HR-QoL measures or single-item satisfaction questions. Future research should use validated, standardised PROMs and satisfaction instruments at multiple timepoints to capture both short- and long-term effects and identify which DHI components are most effective. Clinically, these findings suggest DHIs can enhance immediate recovery experiences, even if long-term health status is unaffected.

Interventions that combined education with prompts or reminders and self-monitoring tended to demonstrate larger improvements in outcomes such as length of stay [30], [31] whereas interventions relying on education alone, without additional behaviour changes strategies in place, showed smaller or inconsistent effects [33], [35]. Tailoring interventions to individual patient characteristics and integrating them into existing clinical pathways also appeared to enhance engagement and effectiveness. As such, future DHIs should target specific, actionable behaviours and incorporate strategies that actively support behaviour change, rather than solely providing information.

Strengths and limitations of the review

This review has several methodological strengths. It was conducted in accordance with best-practice guidelines for systematic reviews, including adherence to PRISMA standards [21], and, where applicable, the SWiM guidelines for narrative synthesis [25]. A comprehensive search strategy was developed and executed with input from an experienced librarian, ensuring robust and inclusive retrieval of relevant literature. Screening, data extraction, and risk of bias assessments were performed independently by pairs of reviewers, with discrepancies resolved through consensus. Standardised and piloted data extraction forms were used to enhance consistency. The review also

employed gold standard tools for quality assessment, including ROB 2 for randomised trials and ROBINS-I for non-randomised studies, allowing for rigorous evaluation of methodological quality.

However, there are important limitations. The review was restricted to English-language publications, which may have introduced language bias and limited the global applicability of findings. Due to heterogeneity in study designs, outcome measures, and reporting, a meta-analysis was not feasible, and findings are based on narrative synthesis. The interpretation was also challenged by inconsistent terminology across studies, particularly in how adherence and patient behaviours were defined, described, and measured. Additionally, the overall number of high-quality studies was limited. Many included studies were at high or unclear risk of bias, most commonly due to deviations from intended interventions, missing outcome data, and selective reporting. Furthermore, several of the studies were not powered to detect clinical endpoints, potentially underestimating the true impact of the interventions.

Future Research

This review highlights several important considerations for future research. Given the above limitations, more high-quality randomised trials are needed which are powered to detect differences in the clinical outcomes of interest and which use more consistent measures and time-periods. Secondly, given no included studies reported any health economic findings, there is a clear need for high-quality studies evaluating the cost and cost-effectiveness of patient-directed digital health interventions delivered across the perioperative journey. Economic data is essential for hospital administrators and policymakers to make informed decisions about whether such interventions are feasible and sustainable at scale. Furthermore, future research should focus on intervention implementation. Even the most effective intervention will fail to deliver impact if it is not well integrated into existing clinical systems and workflows. Studies should explore which implementation strategies such as staff training, leadership support, and integration into electronic medical records or routine care pathways, are required to support uptake in real-world settings. Additionally, there is a need to better understand which specific behaviour change techniques (BCTs) are most effective in promoting adherence to perioperative guidelines. Many digital health interventions are complex and comprise multiple strategies and delivery channels, which makes it challenging to determine which specific elements are driving observed effects. Future research should aim to identify, test, and refine the most impactful BCTs, ideally using theory informed frameworks and transparent reporting of intervention components. Studies should also aim to clarify which intervention components are most effective for specific outcomes, assess both short- and long-term effects, and explore generalisability across different surgical populations, particularly

since many ERAS behaviours are relevant across a wide range of procedures. Finally, improving consistency in terminology and outcome reporting, particularly around adherence and patient-led ERAS behaviours, will enhance comparability across studies and support future evidence synthesis. Standardised definitions and reporting tools should be developed and adopted to improve the quality and utility of future research in this field.

CONCLUSIONS

Perioperative DHIs focusing on adherence to patient-led ERAS guidelines may improve recovery. This synthesis of RCT and non-RCT evidence found that use of DHIs could reduce the mean hospital length of stay and increase adherence to some patient-led ERAS behaviours, particularly mobilisation. Evidence for other clinical and patient reported outcomes, including readmissions, ED presentations, and health-related quality of life, remain limited and inconsistent.

Increases in mobilisation and decreases in length of stay can improve the overall patient experience and optimise hospital resource utilisation. As such, clinicians and hospitals should integrate these interventions thoughtfully, adapting interventions to local care pathways and individual patient needs, while recognising that their impact on broader clinical outcomes remains uncertain. Even modest improvements in recovery processes and patient reported outcomes can provide meaningful clinical and operational benefits. Future interventions should incorporate evidence-based behaviour change strategies within the DHI, and should be evaluated using high-quality RCTs using standardised, validated outcome measures across multiple timepoints. Studies should aim to clarify which intervention components are most effective for specific outcomes, assess both short- and long-term effects, and explore generalisability across different surgical populations, considering most of these ERAS behaviours are common to all surgeries. Consistent reporting of mean and median length of stay (and measures of variability, SD, IQR etc), adherence to ERAS behaviours, PROMs, satisfaction, complications, readmissions, and ED presentations will improve comparability and strengthen the evidence base.

REFERENCES

[1] D. Nepogodiev *et al.*, "Global burden of postoperative death," *The Lancet*, vol. 393, no. 10170, p. 401, Feb. 2019, doi: 10.1016/S0140-6736(18)33139-8.

[2] "Home - ERAS® Society." Accessed: May 28, 2025. [Online]. Available: https://erassociety.org/

[3] C. Temple-Oberle *et al.*, "Consensus Review of Optimal Perioperative Care in Breast Reconstruction: Enhanced Recovery after Surgery (ERAS) Society Recommendations," *Plastic & Reconstructive Surgery*, vol. 139, no. 5, pp. 1056e–1071e, May 2017, doi: 10.1097/PRS.0000000000003242.

[4] M. D. Tyson and S. S. Chang, "Enhanced Recovery Pathways Versus Standard Care After Cystectomy: A Meta-analysis of the Effect on Perioperative Outcomes," *European Urology*, vol. 70, no. 6, pp. 995–1003, Dec. 2016, doi: 10.1016/j.eururo.2016.05.031.

[5] L. Sattler, E. Puze, K. Sands, and W. Talbot, "Enhanced recovery pathways improve early outcomes and reduce length of stay in primary hip and knee arthroplasty: A systematic review of randomized controlled trials," *International Journal of Orthopaedic and Trauma Nursing*, vol. 57, p. 101186, May 2025, doi: 10.1016/j.ijotn.2025.101186.

[6] V. Kannan *et al.*, "Impact of 'Enhanced Recovery After Surgery' (ERAS) protocols vs. traditional perioperative care on patient outcomes after colorectal surgery: a systematic review," *Patient Saf Surg*, vol. 19, no. 1, p. 4, Jan. 2025, doi: 10.1186/s13037-024-00425-9.

[7] M. D. Iniesta *et al.*, "Impact of compliance with an enhanced recovery after surgery pathway on patient outcomes in open gynecologic surgery," *International Journal of Gynecological Cancer*, vol. 29, no. 9, pp. 1417–1424, Nov. 2019, doi: 10.1136/ijgc-2019-000622.

[8] K. Fagard *et al.*, "A systematic review of the intervention components, adherence and outcomes of enhanced recovery programmes in older patients undergoing elective colorectal surgery," *BMC Geriatr*, vol. 19, no. 1, p. 157, Dec. 2019, doi: 10.1186/s12877-019-1158-3.

[9] L. Li, J. Jin, S. Min, D. Liu, and L. Liu, "Compliance with the enhanced recovery after surgery protocol and prognosis after colorectal cancer surgery: A prospective cohort study," *Oncotarget*, vol. 8, no. 32, pp. 53531–53541, Aug. 2017, doi: 10.18632/oncotarget.18602.

[10] "Analysis of associated factors of early mobilization in colorectal cancer patients who underwent enhanced recovery after surgery pathway_CHINESE JOURNAL OF BASES AND CLINICS IN GENERAL SURGERY_The only official website." Accessed: Aug. 02, 2025. [Online]. Available: https://english.gensurg.cn/article/10.7507/1007-9424.202106124

[11] A. B. Stone *et al.*, "Barriers to and Facilitators of Implementing Enhanced Recovery Pathways Using an Implementation Framework: A Systematic Review," *JAMA Surg*, vol. 153, no. 3, p. 270, Mar. 2018, doi: 10.1001/jamasurg.2017.5565.

[12] E. A. Pearsall *et al.*, "A Qualitative Study to Understand the Barriers and Enablers in Implementing an Enhanced Recovery After Surgery Program," *Annals of Surgery*, vol. 261, no. 1, pp. 92–96, Jan. 2015, doi: 10.1097/SLA.0000000000000604.

[13] A. Balfour, J. Amery, J. Burch, and H. Smid – Nanninga, "Enhanced recovery after surgery (ERAS®): Barriers and solutions for nurses," *Asia-Pacific Journal of Oncology Nursing*, vol. 9, no. 7, p. 100040, Jul. 2022, doi: 10.1016/j.apjon.2022.02.002.

[14] M. Roy *et al.*, "Health Literacy Among Surgical Patients: A Systematic Review and Meta-analysis," *World j. surg.*, vol. 43, no. 1, pp. 96–106, Jan. 2019, doi: 10.1007/s00268-018-4754-z.

[15] N. C. English, B. A. Jones, and D. I. Chu, "Addressing Low Health Literacy in Surgical Populations," *Clin Colon Rectal Surg*, vol. 38, no. 01, pp. 026–033, Jan. 2025, doi: 10.1055/s-0044-1786389.

[16] D. Wang *et al.*, "Issues in patients' experiences of enhanced recovery after surgery (ERAS) : a systematic review of qualitative evidence," *BMJ Open*, vol. 13, no. 2, p. e068910, Feb. 2023, doi: 10.1136/bmjopen-2022-068910.

[17] F. J. Penedo, L. B. Oswald, J. P. Kronenfeld, S. F. Garcia, D. Cella, and B. Yanez, "The increasing value of eHealth in the delivery of patient-centred cancer care," *The Lancet Oncology*, vol. 21, no. 5, pp. e240–e251, May 2020, doi: 10.1016/S1470-2045(20)30021-8.

[18] M. Blumenau Pedersen, J. Saxton, S. Birch, B. Rasmussen Villumsen, and J. Bjerggaard Jensen, "The use of digital technologies to support home-based prehabilitation prior to major surgery: A systematic review," *The Surgeon*, vol. 21, no. 6, pp. e305–e315, Dec. 2023, doi: 10.1016/j.surge.2023.05.006.
[19] J. Min *et al.*, "345P The effect of early post-operative exercise on shoulder function in breast cancer patients: A randomised controlled trial," *Annals of Oncology*, vol. 34, p. S320, Oct. 2023, doi: 10.1016/j.annonc.2023.09.1074.
[20] J. Li, M. Davies, M. Ye, Y. Li, L. Huang, and L. Li, "Impact of an Animation Education Program on Promoting Compliance With Active Respiratory Rehabilitation in Postsurgical Lung Cancer Patients: A Randomized Clinical Trial," *Cancer Nurs*, vol. 44, no. 2, pp. 106–115, Mar. 2021, doi: 10.1097/NCC.0000000000000758.
[21] "PRISMA 2020 checklist — PRISMA statement." Accessed: Jun. 26, 2025. [Online]. Available: https://www.prisma-statement.org/prisma-2020-checklist
[22] "Covidence - Better systematic review management." Accessed: Jun. 26, 2025. [Online]. Available: https://www.covidence.org/
[23] S. Michie, M. M. Van Stralen, and R. West, "The behaviour change wheel: A new method for characterising and designing behaviour change interventions," *Implementation Sci*, vol. 6, no. 1, p. 42, Dec. 2011, doi: 10.1186/1748-5908-6-42.
[24] S. P. Hozo, B. Djulbegovic, and I. Hozo, "Estimating the mean and variance from the median, range, and the size of a sample," *BMC Med Res Methodol*, vol. 5, no. 1, p. 13, Apr. 2005, doi: 10.1186/1471-2288-5-13.
[25] M. Campbell *et al.*, "Synthesis without meta-analysis (SWiM) in systematic reviews: reporting guideline," *BMJ*, p. l6890, Jan. 2020, doi: 10.1136/bmj.l6890.
[26] "Risk of bias tools - Current version of RoB 2." Accessed: May 28, 2025. [Online]. Available: https://sites.google.com/site/riskofbiastool/welcome/rob-2-0-tool/current-version-of-rob-2
[27] "Risk of bias tools - RoB 2 for cluster-randomized trials." Accessed: May 28, 2025. [Online]. Available: https://sites.google.com/site/riskofbiastool/welcome/rob-2-0-tool/rob-2-for-cluster-randomized-trials
[28] "Risk of bias tools - ROBINS-I V2 tool." Accessed: May 28, 2025. [Online]. Available: https://www.riskofbias.info/welcome/robins-i-v2
[29] "GRADE Book." Accessed: Jun. 26, 2025. [Online]. Available: https://book.gradepro.org/
[30] D. Schlund *et al.*, "Value of an interactive phone application in an established enhanced recovery program," *Int J Colorectal Dis*, vol. 35, no. 6, pp. 1045–1048, Jun. 2020, doi: 10.1007/s00384-020-03563-5.
[31] P. Jayakumar *et al.*, "A Patient-Focused Technology-Enabled Program Improves Outcomes in Primary Total Hip and Knee Replacement Surgery," *JBJS OA*, vol. 2, no. 3, p. e0023, Sep. 2017, doi: 10.2106/JBJS.OA.16.00023.
[32] J. McDonall *et al.*, "Patient activation intervention to facilitate participation in recovery after total knee replacement (MIME): a cluster randomised cross-over trial," *BMJ Qual Saf*, vol. 28, no. 10, pp. 782–792, Oct. 2019, doi: 10.1136/bmjqs-2018-008975.
[33] J. Mata *et al.*, "A mobile device application (app) to improve adherence to an enhanced recovery program for colorectal surgery: a randomized controlled trial," *Surg Endosc*, vol. 34, no. 2, pp. 742–751, Feb. 2020, doi: 10.1007/s00464-019-06823-w.
[34] M. S. Vesterby *et al.*, "Telemedicine support shortens length of stay after fast-track hip replacement: A randomized controlled trial," *Acta Orthopaedica*, vol. 88, no. 1, pp. 41–47, Jan. 2017, doi: 10.1080/17453674.2016.1256939.
[35] S. L. Van Der Storm *et al.*, "Improving Enhanced Recovery after Surgery (ERAS): The Effect of a Patient-Centred Mobile Application and an Activity Tracker on Patient Engagement in Colorectal Surgery," *Surg Innov*, vol. 32, no. 1, pp. 5–15, Feb. 2025, doi: 10.1177/15533506241299888.

[36] A. S. K. Jones *et al.*, “Using animated visualization to improve postoperative mobilization: A randomized controlled trial.,” *Health Psychology*, vol. 38, no. 8, pp. 748–758, Aug. 2019, doi: 10.1037/hea0000761.
[37] “GRADE | Cochrane.” Accessed: Jun. 26, 2025. [Online]. Available: https://www.cochrane.org/learn/courses-and-resources/cochrane-methodology/grade
[38] M. N. Sarkies *et al.*, “Perioperative interventions to improve early mobilisation and physical function after hip fracture: a systematic review and meta-analysis,” *Age and Ageing*, vol. 52, no. 8, p. afad154, Aug. 2023, doi: 10.1093/ageing/afad154.
[39] S. Wolk, M. Distler, B. Müssle, S. Söthje, J. Weitz, and T. Welsch, “Adherence to ERAS elements in major visceral surgery—an observational pilot study,” *Langenbecks Arch Surg*, vol. 401, no. 3, pp. 349–356, May 2016, doi: 10.1007/s00423-016-1407-2.
[40] K. Åsberg and M. Bendtsen, “Perioperative digital behaviour change interventions for reducing alcohol consumption, improving dietary intake, increasing physical activity and smoking cessation: a scoping review,” *Perioper Med*, vol. 10, no. 1, Dec. 2021, doi: 10.1186/s13741-021-00189-1.
[41] M. I. Berrio-Valencia *et al.*, “Adherence to prehabilitation in adult surgical patients: a systematic review, meta-analysis, meta-regression, and qualitative synthesis,” *British Journal of Anaesthesia*, vol. 135, no. 3, pp. 582–593, Sep. 2025, doi: 10.1016/j.bja.2025.06.003.
[42] A. H. Lee, W. K. Fung, and B. Fu, “Analyzing Hospital Length of Stay: Mean or Median Regression?,” *Medical Care*, vol. 41, no. 5, pp. 681–686, May 2003, doi: 10.1097/01.MLR.0000062550.23101.6F.
[43] “Hospital costs and payments | Better Health Channel.” Accessed: Oct. 18, 2025. [Online]. Available: https://www.betterhealth.vic.gov.au/health/servicesandsupport/hospital-costs-and-payments?utm=
[44] “Spending on hospitals - Hospitals - AIHW.” Accessed: Oct. 18, 2025. [Online]. Available: https://www.aihw.gov.au/hospitals/topics/hospital-resources/spending?utm
[45] J. E. Squires, K. Sullivan, M. P. Eccles, J. Worswick, and J. M. Grimshaw, “Are multifaceted interventions more effective than single-component interventions in changing health-care professionals’ behaviours? An overview of systematic reviews,” *Implementation Sci*, vol. 9, no. 1, p. 152, Dec. 2014, doi: 10.1186/s13012-014-0152-6.
[46] K. M. Sauro *et al.*, “Enhanced Recovery After Surgery Guidelines and Hospital Length of Stay, Readmission, Complications, and Mortality: A Meta-Analysis of Randomized Clinical Trials,” *JAMA Netw Open*, vol. 7, no. 6, p. e2417310, Jun. 2024, doi: 10.1001/jamanetworkopen.2024.17310.

APPENDICES

1. PRISMA guidelines
2. Search strategy
3. Table of patient-led ERAS Behaviours
4. GRADE assessments
5. Risk of Bias tables for individual domains

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Appendix1.PRISMA2020checklist.docx
- Appendix2.SearchStrategy.docx
- Appendix3.TableofERASBehaviours.docx
- Appendix4.GRADEAssessments.docx
- Appendix5.Riskofbiastables.docx