

PAEDIATRIC ANAESTHESIA

Digital health interventions for postoperative recovery in children: a systematic review

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Abstract

Background: Digital health interventions offer a promising approach for monitoring during postoperative recovery. However, the effectiveness of these interventions remains poorly understood, particularly in children. The objective of this study was to assess the efficacy of digital health interventions for postoperative recovery in children.

Methods: A systematic review was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, with the use of automation tools for searching and screening. We searched five electronic databases for randomised controlled trials or non-randomised studies of interventions that utilised digital health interventions to monitor postoperative recovery in children. The study quality was assessed using Cochrane Collaboration's Risk of Bias tools. The systematic review protocol was prospectively registered with PROSPERO (CRD42022351492).

Results: The review included 16 studies involving 2728 participants from six countries. Tonsillectomy was the most common surgery and smartphone apps (WeChat) were the most commonly used digital health interventions. Digital health interventions resulted in significant improvements in parental knowledge about the child's condition and satisfaction regarding perioperative instructions (standard mean difference=2.16, 95% confidence interval 1.45–2.87; $z=5.98$, $P<0.001$; $I^2=88\%$). However, there was no significant effect on children's pain intensity (standard mean difference=0.09, 95% confidence interval –0.95 to 1.12; $z=0.16$, $P=0.87$; $I^2=98\%$).

Conclusions: Digital health interventions hold promise for improving parental postoperative knowledge and satisfaction. However, more research is needed for child-centric interventions with validated outcome measures. Future work should focus development and testing of user-friendly digital apps and wearables to ease the healthcare burden and improve outcomes for children.

Systematic review protocol: PROSPERO (CRD42022351492).

Keywords: child health; digital technology; mobile applications; patient data; postoperative recovery; wearable electronic devices

Editor's key points

- The detection of postoperative complication in children is reliant on subjective reports from parents and burdensome clinic visits and questionnaires. With the emergence of digital health interventions, objective quantification of postoperative recovery is feasible.
- In this systematic review, the authors found that digital health technologies resulted in significant improvements in parental knowledge about the child's condition and satisfaction regarding perioperative instructions but not in children's pain intensity.
- Future research should prioritise child-centric digital health interventions, incorporating validated outcome measures and addressing privacy concerns associated with health data collection.

Postoperative recovery is a crucial phase in the treatment of children who have had surgery. The recovery period is often associated with pain, discomfort, and anxiety, which can impact the physical and psychological well-being of the child. Fortunately, very few children who undergo surgery will experience a serious adverse event.¹ The safety of modern-day surgery can largely be attributed to careful monitoring for complications with return to baseline function being considered an integral component of high-quality postoperative care and Enhanced Recovery After Surgery protocols.^{1,2}

Because of the increase in same-day surgical procedures, suggestions for early mobilisation, and increasing demands on hospital resources, monitoring children's recovery is becoming increasingly difficult.³ Consequently, the detection of postoperative complications after discharge is largely reliant on subjective reports of parents and the use of traditional methods, such as routine questionnaires and clinic visits, which are a burden to patients and their families, costly, and potentially inaccurate.³ Children who have surgery can also find it difficult to articulate their postoperative symptoms and often rely on a parent to report their recovery progress.⁴

With the advent of digital health interventions, objectively quantifying recovery during postoperative recovery is now possible.⁵ Digital health interventions refer to mobile, sensor, and internet technologies that can be used to virtually treat patients and collect and share a person's health information. Digital health interventions may include mobile health and applications, electronic health records, telehealth and telemedicine, home monitoring, wearable devices, robotics, and artificial intelligence.⁶ In the context of post-anaesthesia recovery, digital health interventions have the potential to facilitate the early detection of clinical deterioration and complications and to support the accurate assessment of health outcomes.⁷ For anaesthetists, the use of digital health interventions can dramatically reduce the costs and patient burden associated with follow-up appointments and provide high-frequency objective data in real time.⁸ Research in adult postoperative recovery has shown that the utilisation of digital health interventions can lead to the early detection of postoperative complications, enhanced recovery, and the delivery of health care that aligns with patients' preferences.⁹

Digital health interventions offer several advantages for children and their families, such as remote monitoring of vital signs from home and reduced need for in-person clinic visits, with data sent in real time to healthcare providers.⁵ Digital health apps have supported children to report discomfort or complications associated with medical treatment and have aided in timely medical intervention.^{9,10} Additionally, digital health interventions have aided children to manage their medications,¹¹ and provide guidance for rehabilitation.¹² However, studies on the efficacy of digital health interventions for monitoring children's postoperative outcomes has received less attention in the literature.¹³

The aim of this review is to systematically synthesise and critically evaluate the literature to determine the effects of digital health interventions for measuring postoperative recovery in children.

Methods

This systematic review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines¹⁴ and incorporated automation tools from the Systematic Review Accelerator (SRA).^{15–17} The systematic review protocol was prospectively registered with PROSPERO (CRD42022351492).

Information sources and search strategy

The following databases were searched by the first author (KP) from database inception through to September 2022: the Cumulative Index to Nursing and Allied Health Literature (CINAHL), Embase, PubMed, Cochrane CENTRAL, and Web of Science. Two specialist health librarians provided support to refine the search strategy. A senior information specialist (JC) with expertise in systematic review automation tools provided support with screening and searching the literature.¹⁶ The search was originally designed in PubMed and translated for use in the other databases using the Polyglot Search Translator.¹⁷ Search strategies for all databases are listed in [Supplementary File 1](#).

Study selection and eligibility criteria

We aimed to find, assess, and synthesise all randomised controlled trials (RCT) or non-randomised studies of interventions (NRSI) that met the selection criteria.

Population

The review encompassed research focusing on children and adolescents (0–18 yr, mean sample age ≤ 18 yr) who were recovering from surgical procedures. Studies were also eligible if they involved parents of children or adolescents. Excluded from consideration were studies involving children or adolescents with a mean sample age > 18 yr and cases unrelated to surgical recovery, such as those involving sedation for minor procedures.

Intervention

This review considered digital health interventions aimed at monitoring the postoperative recovery of children and were defined as interventions that were delivered virtually, utilising mobile phones, the internet, telemedicine, or electronic devices.⁶ Studies were excluded if the interventions did not meet

the criteria of digital health interventions, such as traditional in-person clinic visits.

Comparator

Included in the review were RCT and NRSI studies. NRSI studies were defined as quantitative studies that assessed the impact of an intervention without using random assignment of individuals or groups. Eligible NRSI studies include prospective cohort studies, case-control studies, controlled before-and-after studies, and interrupted time-series studies that incorporated a control group.¹⁸ Control groups could feature groups receiving no treatment, groups following standard care procedures, or those undergoing alternative interventions. Studies lacking a clear and defined comparison group were excluded.

Outcome

Studies were included if the outcomes included child-related outcomes, parent-related outcomes, or both, relevant to postoperative recovery, including pain, physical function, psychological well-being, and physiological recovery.¹⁹ Excluded from the review were research studies where the outcomes were not relevant to postoperative recovery or where measurements extended beyond the defined postoperative recovery period (>3 months). No studies were excluded based on publication date or language.

Data collection process

All retrieved records were uploaded into Covidence from Endnote X9 after duplicate records were removed using the SRA Deduplicator.¹⁵ The titles, abstracts, and full-text papers of potentially eligible records were screened by the first author (KP) and a second reviewer independently. Any disagreements were resolved after consultation and discussion with the authorship team until consensus was reached.

Data extraction and risk of bias assessment

We extracted data from individual studies based on characteristics of interest including (a) study setting and design, (b) participants, (c) intervention characteristics, (d) surgical condition assessed, (e) length of intervention, (f) measures, and (g) parent/child outcomes. Two review authors were involved in the data extraction and coding (JA and KP) and any disagreements encountered were resolved through discussion and consensus among the authors. Main outcomes were pain, physical function, and psychological and physiological recovery. The quality of individual RCT studies was assessed independently by JA and KP using the Cochrane Collaboration's Risk of Bias (RoB) tool for randomised trials,²⁰ and the risk of bias in randomised trials tool (RoB2) was used to generate the risk of bias graphs.²¹ For the NRSIs, the ROBINS-I tool²² was used to assess for potential risk of bias. However, we were unable to assess the publication bias for the RCTs included in the review as the number of studies did not meet the recommended minimum threshold of 10.²³

Results

Study selection

The five databases searched yielded 3420 records and 2671 records were screened by title and abstract after the removal

of duplicates. A total of 44 full-text records were assessed for eligibility. After full-text screening a total of 16 studies were included in this review. Figure 1 provides a summary of the selection process and Table 1 details the characteristics of included studies.

Study characteristics

From studies published to date, our search yielded 16 articles involving 2728 participants from six countries (China, k=8; Canada, k=3; Korea, k=2; United States of America, k=1; Switzerland, k=1; and Italy, k=1) that focused on the use of digital health technologies for postoperative recovery in children. The included studies assessed a variety of, but inconsistent, outcomes related to paediatric surgical procedures and postoperative care. These outcomes include parents' knowledge and anxiety,^{24–30} compliance with postoperative care instructions,³¹ disease knowledge and quality of life for parents and children,³² nutritional status of infants,³³ pain and bleeding,^{24,29,34–36} sleep patterns,^{24,37} postoperative complications,^{24,26,27,30,34,36,37} and follow-up adherence.³¹

The interventions included mobile applications such as telehealth education, smartphone text messaging, postoperative phone calls, WeChat, and the 317-Nursing app. The studies that included a WeChat intervention all featured the messaging app that facilitated real-time patient-provider communication. The 317-Nursing app is a customised app in the WeChat platform and was to obtain patient information and fill in follow-up questionnaires. Commercial activity trackers and digital photography were also utilised to monitor recovery time and emergency room visits.

The 16 studies included in the review all used quantitative methods: eight RCT studies,^{26–28,30,32–34,38} and the other eight studies had an NRSI design.^{24,25,29,31,35–37,39} The included studies reported short-term post-test data collected within 4 weeks from the surgery except in three studies.^{27,31,32}

Population characteristics

The studies included in the review included children between the ages of 1 and 18 yr, with the majority of studies (k=9) including children under 4 yr (mean=1.86, standard deviation=0.94). Children had undergone surgical procedures for varied health conditions, with tonsillectomy being the most reported condition (k=4). Other conditions included hernia, cataract, orofacial cleft, and congenital heart disease, among others.

Intervention characteristics

The 16 studies included in this review used four main categories of technology-based interventions to monitor and capture outcomes related to child postoperative recovery: (a) smartphone apps (e.g. WeChat), (b) telehealth (e.g. phone calls and text messages), (c) actigraphy, and (d) photography. Half of the studies used smartphone apps, with six using the WeChat app to monitor children's recovery. Comparison groups in the reported studies were either treatment as usual (TAU, k=7) or a parallel intervention, mostly involving paper reading materials (k=6) or technology (k=3). Of the included studies, nine (k=9) had a post-surgery intervention onset and 10 (k=10) had interventions lasting 2 weeks or less.

Study measures

The studies included in this review aimed to explore the potential of various digital health interventions in improving perioperative care for paediatric patients and their families. Both child and parent outcome measures were administered at pre- and post-test assessment. Outcome measures assessed children's physical functioning (sleep disturbance, complications, adherence, and compliance), pain intensity, psychological outcomes (anxiety and sick role behaviour), and physiological recovery (quality of recovery, cortisol levels, and bleeding). For parents, parental knowledge of the child's condition, parental satisfaction, parental anxiety, emergency room visits, and parental care were reported. Studies used both validated and non-validated self-report and proxy measures to assess child and parent outcomes at pre- and post-test.

Use of diary

Five studies used diaries to record and report postoperative child and parent outcomes including adherence and compliance with instructions,³¹ emergency room visits,³⁹ child

sleep,³⁷ and pain intensity, medication use, and complications after surgery.^{34,36} These studies included children who had surgery for various conditions such as cataract, hypospadias, orofacial cleft, and tonsillectomy.

State trait anxiety inventory

This well-validated self-report instrument was used in two studies^{24,29} to measure parents' state (situational) anxiety regarding children's postoperative recovery after elective surgery or tonsillectomy.

Actigraphy

Actigraphs were used in two studies^{24,37} to monitor sleep characteristics of children who had either elective or orofacial cleft surgery.

Faces Pain Scale

Four studies used the Faces Pain Scale (FPS) in various forms, including the revised or modified validated versions of FPS, to

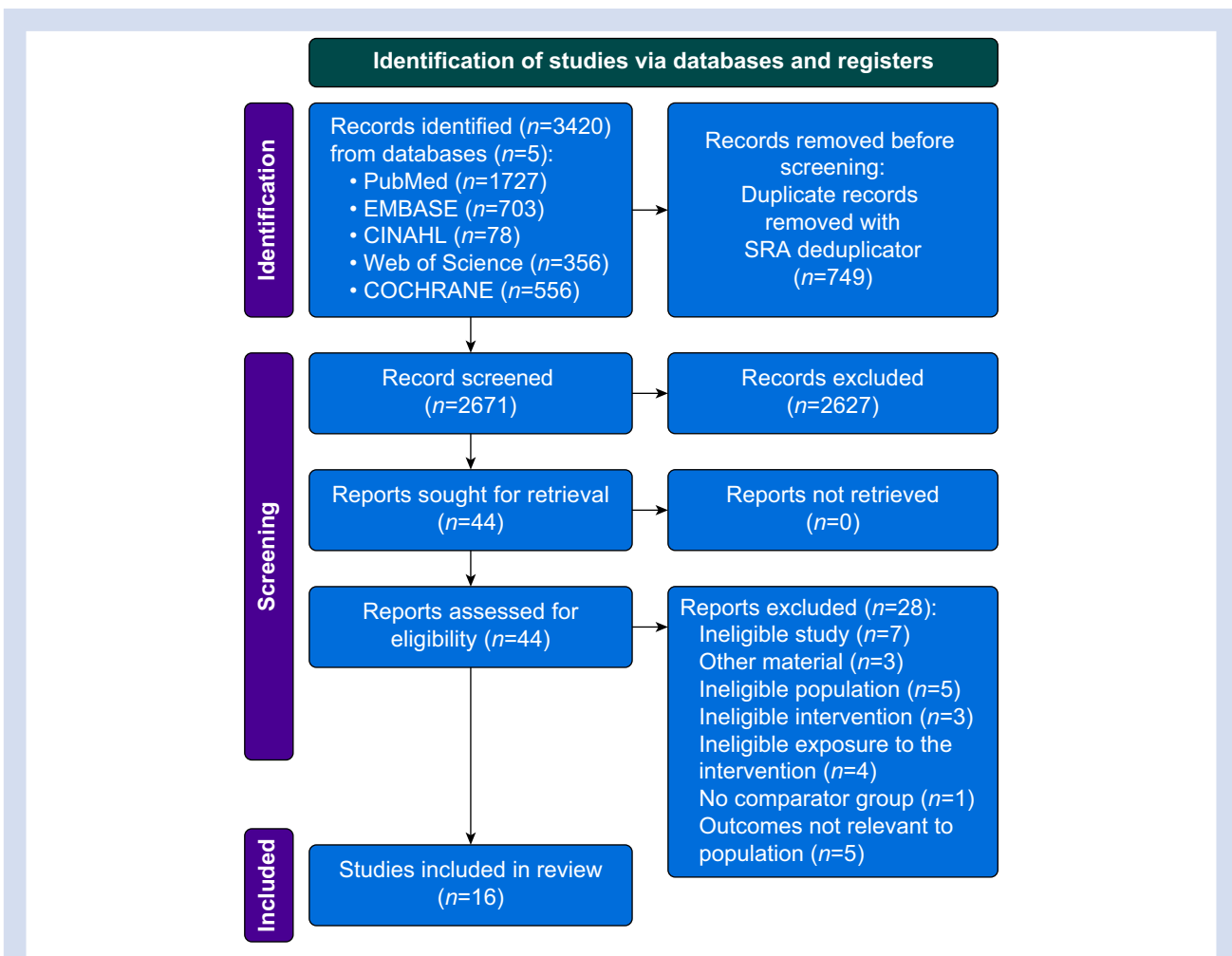


Fig 1. PRISMA 2020 flow diagram of included studies. SRA, Systematic Review Accelerator.

Table 1 Characteristics of included studies.

Study	Setting and design	Sample size (N) and mean child age (yr)	Intervention condition; allocation and technology	Comparison condition; allocation/ alternative intervention	Intervention onset and surgical condition	Postoperative assessment time and outcomes	Reporting of outcome measures	Statistically significant change/ group difference post-intervention
Chang and colleagues, 2018	China; NRSI	N=163 Age, M=2.1	n=75 WeChat messaging application	n=88 Standard clinic visit	Preoperative Cataract surgery	6 Months Adherence; compliance	Clinician	Yes, significantly higher in the intervention group.
Chua and colleagues, 2017	Canada; Cohort study	N=96 Age, M=2	n=81 Photography and email communication	n=15 Written information on surgery and postoperative care (leaflet)	Postoperative Hypospadias repair	1 Month Emergency room visits	Clinician Parent	No
Kain and colleagues, 2002	USA; NRSI	N=169 Age, M= 6.6	n=92 Actigraphy	n=77 Actigraphy data from a control group of healthy children in the community	Preoperative Outpatient elective surgery	5 Days Anxiety; pain; sleep disturbance	Parent	No
Kim and colleagues, 2021	Canada; NRSI	N=75 Age, M=1.9	n=31 Postoperative phone call	n=44 No postoperative phone call	Postoperative Urological surgery	2 Weeks Satisfaction with postoperative education; communication; parental anxiety	Parent	No, except for anxiety reduction in the intervention group.
Li and colleagues, 2019	China; RCT	N=127 Age, R=1–18	n=64 317-nursing mobile application program (WeChat)	n=63 Telephone	Preoperative Day surgery	24 h Quality of recovery from surgery	Parent	No
Liu and colleagues, 2018	China; RCT	N=418 Age, M=2.6	n=209 WeChat messaging application	n=209 Written information on surgery and postoperative care (leaflet)	Preoperative Hernia repair	7 Days Parental knowledge; complications	Parent	Yes, higher parental knowledge score and reduced complications in the intervention group.
Mueller and colleagues, 2014	Switzerland NRSI	N=57 Age, M=0.4	n=27 (OFC) Actigraphy	n=30 (normal) Actigraphy data from a control group of healthy children in the community	Preoperative Orofacial cleft repair	2 Weeks Cortisol; sleep pattern	Parent	No
Paquette and colleagues, 2013	Canada; RCT	N=45 Age, R=4–12	n=24 Telephone and brochure	n=21 Written information on surgery and postoperative care (brochure)	Postoperative Tonsillectomy	10 Days Pain intensity; analgesia; postoperative complication	Parent	No
Shen and colleagues, 2020	China; RCT	N=70 Age, M=0.4	n=35 WeChat messaging application	n=35 Telephone	Preoperative Congenital megacolon repair	6 Months Parental knowledge; defaecation; complications	Parent	Yes, enhanced the level of parental care knowledge, improved defaecation, reduced the occurrence of certain complications and reduced lost follow-up in the intervention group.

Continued

Table 1 Continued

Study	Setting and design	Sample size (N) and mean child age (yr)	Intervention condition; allocation and technology	Comparison condition; allocation/alternative intervention	Intervention onset and surgical condition	Postoperative assessment time and outcomes	Reporting of outcome measures	Statistically significant change/group difference post-intervention
Tiozzo and colleagues, 2021	Italy; NRSI	N=487 Age, M=6.4	n=179 App (smartphone)	n=308 Paper pencil	Postoperative Day surgery	5 Days Pain intensity	Parent Child	Yes, intervention group (app) group reported higher pain intensity.
Xie and colleagues, 2021	China; RCT	N=80 Age, M=1.7	n=40 WeChat messaging application	n=40 Written information on surgery and postoperative care (education card)	Postoperative Ventricular septal defect repair	3 Months Parental knowledge and quality of life (QoL); mental state	Parent	Yes, better parental knowledge, QoL, emotion control, 'worry', and 'family communication' in the intervention group.
Xin and colleagues, 2019	China; NRSI	N=670 Age, R=4–12	n=341 Postoperative phone call	n=329 Standard clinic visit	Postoperative Tonsillectomy	2 Weeks Pain intensity; postoperative complication	Parent	Yes, less pain intensity; bleeding; constipation and better fluid intake in early session but not final session in the intervention group.
Yang and colleagues, 2016	Korea; RCT	N =61 Age, R=3–7	n=27 Mobile instant messenger	n=34 Written information on surgery and postoperative care	Preoperative Tonsillectomy	7 Days Parental knowledge; child anxiety, sick-role behaviour	Parent Child	Yes, better parental knowledge and child anxiety in the intervention group.
Yu and colleagues, 2019	Korea; NRSI	N=52 Age, R=3–7	n=27 Mobile instant messenger	n=25 Written information on surgery and postoperative care	Postoperative Tonsillectomy	7 Days Parental knowledge; anxiety; bleeding frequency; pain intensity	Parent	Yes, for parental knowledge and anxiety in the intervention group.
Zhang and colleagues, 2020	China; RCT	N=74 Age, M=2.3	n=37 WeChat messaging application	n=37 Written information on surgery and postoperative care (leaflet)	Preoperative Congenital heart disease surgery	1 Month Parental knowledge; parental satisfaction; child complications	Parent	Yes, for parental knowledge and parental satisfaction; in the intervention group.
Zhang and colleagues, 2022	China; RCT	N=84 Age, M=3.3	n=42 WeChat messaging application	n=42 Written information on surgery and postoperative care (leaflet)	Postoperative Transthoracic device closure of ventricular septal defects	1 Month Parental care; infant nutritional status	Parent	Yes, in favour of the intervention group.

report pain intensity for children who had general/elective surgeries^{24,35} or for tonsillectomy.^{29,34,36}

Self-report and proxy report

Self-report questionnaires were used in five studies to assess parental anxiety,²⁵ child's quality of recovery from surgery,²⁶ parental knowledge, and complications^{26,27} and proxy measures of child anxiety and their sick role behaviour.²⁸ Details of study measures and outcomes are summarised in [Supplementary Table S1](#).

Risk of bias assessment

Figure 2 presents a summary of the risk of bias assessment for the eight RCTs included in the review. Visual summaries of risk of bias within and across the studies were generated using the online risk of bias visualisation tool for randomised trials (robvis-RoB2) and the scores are summarised in five domains. As shown in [Fig. 2](#), all eight RCTs were judged to have low risk of bias in the two domains of bias arising as a result of deviations from intended interventions and missing outcome data. Overall, there was a 25% high risk of bias in the included studies because of the randomisation process and measurement of the outcome. However, all the NRSIs included in the review were judged to have low risk of bias based on the 7-domain ROBINS-I criteria.

Intervention outcomes

Outcomes by digital health technology

The studies adopted diverse digital technologies to monitor varying outcomes for both child and parent measures.

WeChat

This application was used mostly in studies conducted in China to monitor parental knowledge of the child's condition and complications after surgery. Studies using WeChat^{26,27,30,32} reported statistically significant improvements in parental knowledge of postoperative care, reduction in parent anxiety, and reduced postoperative complications in the intervention groups relative to the parallel conditions.

Mobile instant messengers

Studies using mobile instant messengers (MIM)^{28,29} found statistically significant improvements in parental knowledge of the disease and anxiety for participants in the intervention group compared with the TAU conditions.

Phone calls

Telehealth education^{25,36} led to improved parental knowledge and satisfaction with care, while also reducing anxiety, complications, and rehospitalisation rates in the intervention group relative to the control group.

Smartphone app

The studies that used an app to monitor postoperative pain and quality of recovery^{35,38} found that these technologies improve communication between patients, families, and healthcare providers, however, there were no significant

differences in the postoperative outcomes between participants in the intervention and parallel conditions.

Actigraphy

The studies that used actigraphy to monitor sleeping patterns found that sleep disturbance was common after children's surgery.^{24,37} However, these studies demonstrated no significant difference in the sleep pattern between children in the intervention groups and those in the comparison group after surgery.

Digital photography

A pilot study comparing digital photography via email correspondence to traditional telephone communication³⁹ suggested that digital photography may be a preferred and effective method for assessing wound healing and communicating with parents and healthcare providers after hypospadias surgery. However, there were no significant differences between intervention and comparison groups for emergency room visits to check surgical wounds, indicating that the use of digital photography/e-mail communication technology was no better than the ordinary telephone conversation.

Child and parent outcomes

We summarised the overall findings of the 16 studies included in the review by child and parent outcomes.

Child outcomes

Of the 16 studies included in this review, three studies^{25,31,39} did not report on child outcomes and two studies included outcomes that were reported by the child.^{28,35} We summarised the findings of 13 studies that reported child outcomes to establish whether digital health technologies had a positive effect on the postoperative recovery for children. The results revealed that four of the 13 studies^{28,29,32,36} reported statistically significant outcomes for child outcome measures including quality of life, pain intensity, and anxiety, and two studies reported significant outcomes for defaecation²⁷ and nutritional status³³ in favour of the intervention condition relative to the comparison group. We noted that six studies^{24,26,30,34,37,38} did not find any significant difference between intervention and comparison conditions for any child outcome measures post-intervention. One study³⁵ that investigated a smartphone app to record child postoperative pain intensity reported a significant outcome, but in favour of the comparison group that used paper-and-pencil. Higher pain intensity scores were associated with being in smartphone app group.

Parent outcomes

Some of the included studies assessed parental outcomes including knowledge about the child's condition, quality of life, satisfaction with the quality of education about surgery, and anxiety. Five studies reported statistically significant results in favour of the intervention condition for parental knowledge about the child's condition^{26–30} and two studies found statistically significant results for satisfaction of the parent and family.^{25,30}

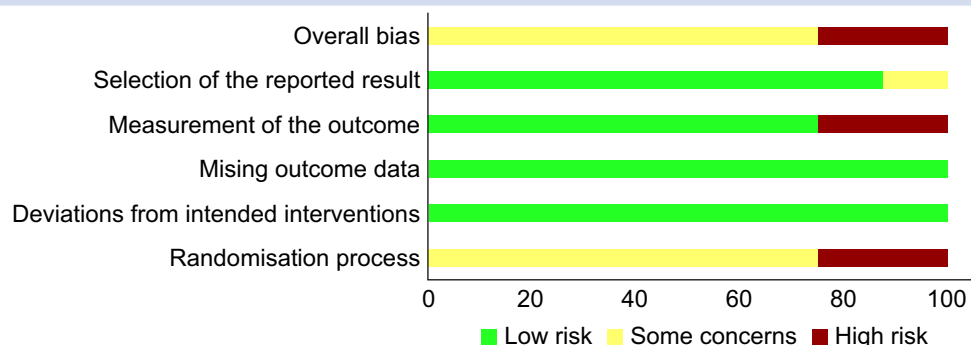


Fig 2. Risk of bias assessment of RCTs included in the review.

Intervention effect

Quantitative synthesis

Because of variable reporting of outcome data across different studies included in this review, it was only feasible to conduct a quantitative synthesis for data that were reported across studies assessing similar outcome measures. Only pain and parental knowledge of the child's condition and its management were reported in at least five studies. Therefore, we conducted quantitative synthesis of data based on the

post-intervention reported results (where means and standard deviations were available). We performed a meta-analysis using the Cochrane Collaboration's Review Manager Version 5.4 (2020), Copenhagen. We computed the standard mean differences (SMD) for continuous data, and the random effects model was used to estimate the overall intervention effect sizes.

We conducted a meta-analysis to compare digital health technologies with comparison conditions for children's pain intensity. Data from four studies^{29,34–36} that reported pain

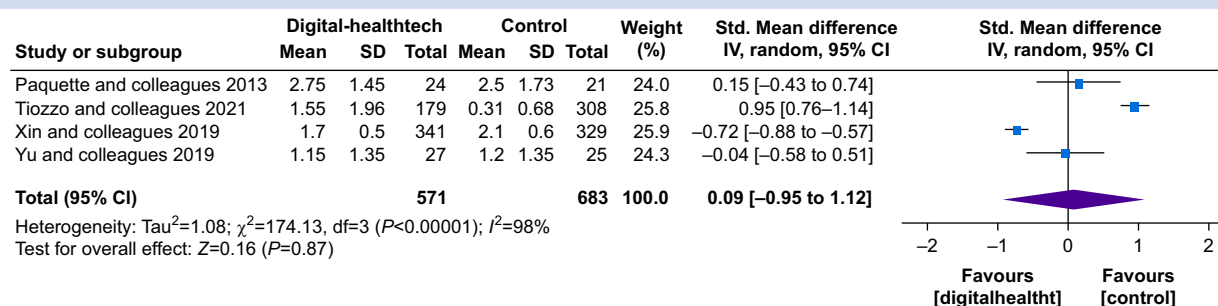


Fig 3. Forest plot results for pain intensity. CI, confidence interval; df, degrees of freedom; SD, standard deviation.

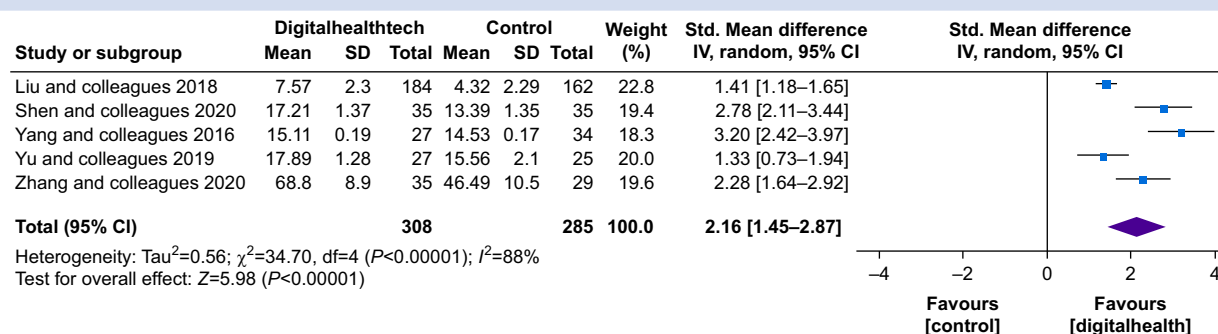


Fig 4. Forest plot results for parental knowledge of the child's condition.

intensity at post-intervention were pooled (as shown in Fig. 3), and the results of a random effects model revealed that there was no significant intervention (digital technology) effect on reducing pain intensity in children after surgery (SMD=0.09, 95% confidence interval [CI] - 0.95 to 1.12; $z=0.16$, $P=0.87$; $I^2=98\%$).

We then conducted a meta-analysis including five studies^{26–30} that had examined effects on parental knowledge of the child's condition/care to determine the overall pooled effect of digital health technologies relative to comparison conditions. The results of a random effects model revealed a significant effect in favour of the digital health technologies, as shown in Fig. 4 (SMD=2.16, 95% CI 1.45–2.87; $z=5.98$, $P<0.001$; $I^2=88\%$). However, a significant heterogeneity of $I^2=88\%$ was noted, which reflects between-study differences.

Discussion

The systematic review found that digital health technologies have the potential to improve postoperative monitoring for paediatric patients and their families. Evidence related to the efficacy of digital health technologies for postoperative recovery in children was synthesised from 16 articles involving 2728 participants from six countries, with inconsistent outcomes related to paediatric surgical procedures and postoperative monitoring. Child self-report data were notably limited in this systematic review, as only two studies incorporated children's self-reported postoperative outcome measures. The methodological quality of the included studies indicated a low risk of bias. However, it was only possible to conduct a meta-analysis on parent knowledge of their child's disease and pain intensity after surgery. Other outcome measures were inconsistent across studies and therefore were qualitatively summarised in the review. Overall, we found statistically significant effects for digital health interventions in the postoperative recovery period on parent knowledge but not for children's pain intensity.

The systematic review has indicated that digital health technologies have demonstrated effectiveness in improving various parental outcomes, including enhancing parental knowledge regarding their child's condition and its management, and reducing parental anxiety. These outcomes are particularly significant in supporting a child's postoperative recovery.⁴⁰ These review findings align with a prior systematic review, which reported that providing web-based preoperative information to parents of children undergoing elective surgery led to increased parental knowledge and greater satisfaction with post-discharge care.⁴¹ Although the benefits of enhancing parental knowledge in surgical care, such as reducing anxiety, shortening hospital stays, and minimising postoperative complications, are evident, further rigorous research is essential to establish potential links between these improvements and enhanced surgical recovery in children.^{42,43}

The size of the digital health intervention effect on child pain intensity was not found to be statistically significant (SMD=0.09, 95% CI -0.95 to 1.12) yet may be clinically important. The estimated digital health intervention effect could have been confounded by the methods of pain assessment. The four studies that reported pain intensity outcomes all utilised validated pain assessment tools yet relied on parent proxy rather than the child's self-report of pain.^{29,34–36} The one included study that also included the child self-report of pain after surgery found that pain intensity was higher when the rater was the child rather than the parent, suggesting pain

was being under-reported by parents.³⁵ Parental underestimation of pain has similarly been reported in paediatric pain studies with parents' estimates of pain severity after surgery only moderately correlated with the child's.^{44–46}

Pain intensity outcomes included in this systematic review could have further been impacted by the capacity to detect clinically significant differences in pain intensity in children receiving routine analgesia. Yu and Kim²⁹ reported a mean pain intensity score for the 7 days after tonsillectomy which may not account for pain fluctuations and non-detection of the moderate to severe pain typically experienced by children in the immediate postoperative period.⁴⁷ Xin and colleagues³⁶ reported that children experienced clinically significant pain early after tonsillectomy with mean pain scores higher in their control group at 1–3 days after operation, whereas the mean pain score at 7 and 14 days after operation were not different between the control and intervention groups. In the study by Paquette and colleagues,³⁴ children in the intervention group received more doses of analgesics than those in the control group ($P=0.002$) which could account for why there were no significant differences in parent-reported pain intensity scores.

The goal of postoperative recovery is to minimise or avoid postoperative complications which requires the monitoring of multiple domains of recovery.⁴⁸ This systematic review reported diverse, yet inconsistent domains of post-surgery recovery that were monitored, such as pain, physiological recovery, activities of daily living, sleep, postoperative complications, and psychological recovery.¹⁹ The inconsistency of outcomes measured in digital health interventions highlighted in this systematic review emphasise the need to routinely incorporate validated Patient/Proxy Reported Outcome Measures (PROMs) to effectively monitor the postoperative recovery of children.^{49,50}

This systematic review raises questions as to how digital health interventions can be more child-centric to capture the direct experiences of children's postoperative recovery. Digital health interventions have been demonstrated to be a reliable and acceptable way to obtain child-reported symptoms in real time^{51–53} and improving their self-efficacy in managing health conditions.^{54–58} The majority of the included studies ($n=4$) in this systematic review provided digital health interventions to the parent. The two studies that provided digital health interventions to the child were both actigraphy studies to objectively measure postoperative sleep patterns in children²⁴ and infants³⁷ and included only parent proxy outcome measures. Actigraphy is also being superseded by wearable technologies such as smartwatches and fitness trackers, which now offer advanced health monitoring capabilities such as pulse oximetry, heart rate variability, blood pressure, and galvanic skin conductance to measure moments of stress.^{5,8,59}

Healthcare technology is advancing rapidly, driving innovations in how patient-centred outcomes are collected and shared, improving efficiency, and alleviating pressure on healthcare services.^{60,61} The interventions included in this review required clinicians to perform follow-up reviews or monitor social media conversations, while parents had to engage in time-consuming activities such as completing a diary or survey, resulting in increased healthcare costs.⁶¹ Additionally, the studies did not effectively harness the potential of digital health interventions to capture patient data in real time, a capacity demonstrated by more recent research.⁶² It is worth noting that smartphone applications and wearable devices have emerged as a highly efficient, effective, and

appealing means of collecting patient-reported measures longitudinally, particularly among children.^{63,64}

Strengths and limitations

We included only RCTs and quasi-experimental studies in our analysis to ensure that the analysis reflected effect estimates for digital health interventions for postoperative monitoring that were formed from high-quality research. It is unclear if digital health interventions are effective for children because of lack of child self-report and diversity of child postoperative outcome measures included in the studies, which hinders the comparability of studies. It is notable that WeChat was the most widely used digital technology for managing and monitoring child postoperative recovery ($n=7/16$, 43.75%), and it demonstrated significant effectiveness in improving parental outcomes.^{26,27,30–33} However, it is important to highlight that all studies utilising WeChat were conducted in the same country, China, which indicates a relative lack of diversity in the types and usage of digital health technologies among the studies included in this review and may limit the generalisability of the findings to other regions and populations.⁶⁵ Notably, WeChat possesses all core functionalities including text, voice, and video messages found in non-Chinese apps in addition to its advanced features.⁶⁶ The wider acceptability and uptake of WeChat technology in China is linked with its multi-functionality features for app developers and end-user data privacy and protection.

Implications for clinical practice and research

This systematic review highlights the potential of digital health technologies to enhance postoperative monitoring for paediatric patients and their families. However, the effectiveness of digital health interventions for children remains uncertain because of a lack of child self-report and variations in outcome measures across the studies. There is a need for validated outcome measures for monitoring children's postoperative recovery that can inform future investigations of the efficacy of digital health interventions.

All the countries included in this systematic review have comprehensive and robust privacy laws for health data protection. However, the digitisation of healthcare has created an abundance of health data that fall between the cracks of current privacy regulations.⁶⁷ Existing laws designed to govern data privacy and security standards often do not extend to researchers engaged in digital health technology research with patients. Consequently, there is the potential for privacy and security threats to the extensive health-related data gathered.^{68,69} Most technology companies are privately owned, which amplifies their influence in acquiring, using, and safeguarding patient health information, posing privacy concerns related to the implementation of digital technologies in health and data security.⁷⁰ Balancing health information dissemination via digital technology and privacy protection is delicate. Privacy law effectiveness relies on enforcement, public awareness, and evolving technology. Maintaining equilibrium between patient privacy and leveraging data for healthcare enhancement is crucial. Unethical use of data through digital technologies, if not addressed proactively, can disrupt this balance.⁷¹

Conclusions

Although digital health technologies offer promise for enhancing postoperative monitoring, careful consideration is needed to ensure child-centeredness, validated outcome measures, and effective integration into clinical practice. Current interventions predominantly target parents, yet evidence supports the reliability and acceptability of child-reported symptoms in real time. The shift towards smart-watches and wearable technologies further emphasises the potential for child-centred data collection that minimise clinician and parental burden.

Authors' contributions

Conceptualisation: KP, PLA
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Search strategy: KP, AM, PLA, JC, JK, CK, AQ, BG
Literature search: KP, JK, CK, AQ
Formal analysis, data curation: KP, JA
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Declaration of interest

The authors declare that they have no conflicts of interest.

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Appendix A. Supplementary data

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