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Narrative Literature Review: Digital-based Post-Operative Pain Management Innovation

Nurul Imam[1], Pradita Ayu Fernanda[2], Khalifatus Zuhriyah Alfianti[3], Eka Mei Dianita[4], Ni Putu Diah Ayu Rusmeni[5]

[1] *Sekolah Tinggi Ilmu Kesehatan William Booth, Indonesia*
[2] *ITS PKU Muhammadiyah Surakarta, Indonesia*
[3] *Fakultas Kesehatan, Universitas Gresik, Indonesia*
[4] *Sekolah Tinggi Ilmu Kesehatan Pemkab Jombang, Indonesia*
[5] *Sekolah Tinggi Ilmu Kesehatan Buleleng, Indonesia*

Correspondence should be addressed to:
Nurul Imam
bungimam.ru@gmail.com

Abstract:
Effective postoperative pain management is a key element in patient recovery after surgery, but often standard protocols do not take advantage of the potential of real-time data and digital technology for more responsive therapy adjustments. The aim of this study was to identify the latest innovations in digital-based postoperative pain management. A literature review examined the use of digital technology in postoperative pain management, focusing on smartphone apps, wearable devices, and real-time data analytics for monitoring patient pain with the keywords "Pain Management AND Digital Postoperative" OR "Digital Health AND Pain Management" AND "Technology" OR "Information Systems". The year of the source of the literature taken is 2019-2024. Database searches use Scopus, Pub Med, Sage Journal, and Google Scholar. The findings of this review suggest that the integration of digital technology in postoperative pain management can improve the personalization of care by allowing for more accurate and responsive therapy adjustments to changes in patients' pain conditions. Data-Based Approaches in the Digital Era are Virtual Reality (VR), PASHA Application (pain assessment, stimulating and healing application), A wireless intelligent PCA (Wi-PCA) AI (Artificial Intelligence), Cell Phone Application, Wearable Devices, Mhealth, NeuroCuple, LINE, Digital Intervention Group, The Panda App and A Digital Application. Wearable apps and devices effectively monitor pain and enable real-time therapy adjustments. Digital-based innovation can be used as an alternative nursing intervention for post-operative pain management.

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INTRODUCTION

In recent decades, innovations in postoperative pain management have seen significant advancements, along with technological advances and increased understanding of pain mechanisms. Effective postoperative pain management is a crucial aspect of postoperative patient recovery, as poorly managed pain can hinder the healing process, increase the risk of complications, and reduce the patient's quality of life (Mackey, 2018). In today's digital era, data-driven approaches are increasingly taking center stage in various medical fields, including in postoperative pain management. The integration of information technology and data analysis in clinical practice offers opportunities to design more personalized and evidence-based strategies, as well as improve the effectiveness of pain management (Mulyani et al., 2019). Postoperative pain management is a critical aspect of the postoperative patient's recovery process, significantly

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affecting the quality of life and speed of recovery. Pain that is not managed properly can lead to long-term complications, interfere with physical function, and decrease patient satisfaction with health services. Various conventional methods, such as the use of analgesics and regional anesthesia techniques, often have limitations in terms of effectiveness and potential side effects. Along with the development of digital technology, data-driven approaches are beginning to emerge as innovative alternatives in managing postoperative pain (Camp, 2022).

Postoperative pain management is very broad, covering different types of surgical procedures and varying degrees of pain intensity. According to data from the World Health Organization (WHO), postoperative pain that is not treated effectively can affect up to 80% of postoperative patients, potentially inhibiting the recovery process and increasing the duration of hospitalization. In addition, this problem has an impact on health resources, adds to the financial burden, and affects the quality of care provided by medical personnel. Smart technology is defined as an electronic or automated device or system that is connected and interconnected with the internet that is responsive and/or reactive to real-time data input. Utilizing smart technology is the next step in optimizing personalized and precise treatment in patients with pain (Johnson et al., 2021), by using data obtained from various sources, such as electronic medical records, wearable devices, and digital health applications, healthcare providers can gain deeper insights into pain patterns and patient responses to various interventions. This data-driven approach allows for real-time early identification and adjustment of pain therapy, providing a more comfortable and safe postoperative experience for patients (Kwon, 2021).

The shift in pain management shows the development from traditional methods to the integration of digital technology. Initially, pain management approaches were based on clinical experience and standard guidelines that may be less responsive to the patient's individual needs. However, with advances in technology, big data, and advanced analytics, tools are now available to monitor and assess pain in real-time. This approach allows for more precise monitoring and more effective therapy adjustments based on individual patient data (Kwon, 2021; Smith, 2023). Digital innovation can enhance the accessibility and effectiveness of pain management, enabling patients to receive necessary information and support in real-time, which contributes to their satisfaction. Furthermore, the data generated from digital applications can be utilized for further research, allowing for evaluation and improvement of clinical practices in post-operative pain management.

Innovative data-driven in the digital age offers promising prospects in postoperative pain management. For example, the use of digital sensors and mobile apps allows for continuous monitoring of the patient's pain level and response to analgesic therapy. This data can be analyzed using machine learning algorithms to provide more timely therapeutic recommendations tailored to the patient's specific condition. With the implementation of data-driven solutions, it is hoped that postoperative pain management can be carried out more effectively, minimize the risk of complications, and improve overall patient recovery outcomes (Yang, & Zhang, 2020). By highlighting recent technological advancements and case studies, it is hoped that readers will be able to understand how data and technology play an important role in improving pain management strategies, as well as identify the challenges and opportunities that exist in their application in daily clinical practice. The purpose of this study was to identify innovations in postoperative pain management through a data-driven approach in the digital age.

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METHOD

This research was conducted by searching for literature published in the last 5 years (2019-2024). Literature searches are conducted in the United Kingdom. The articles obtained were selected from several indexed electronic databases such as Scopus, Pub Med, Sage Journal, and Google Scholar.

Inclusion and Exclusion Criteria

Inclusion criteria review of this article Innovation in Postoperative Pain Management: A Data-Driven Approach in the Digital Age. The inclusion criteria for reviewing articles are limited to publications between 2019-2024 and in the United Kingdom. The articles taken are from the last 5 years with a research design of Randomized Control Trial, Observational Study. There are 11 articles that meet the inclusion and exclusion criteria out of 677 articles found in the Scopus, Pub Med, Sage Journal, and Google Scholar databases.

RESULT

Study Selection

The total number of articles identified is 677 articles. Then, the articles were checked for duplication and filtering, resulting in 603 articles. The articles were filtered based on title identification, leaving 70 articles. To test the feasibility of the abstract, an assessment was carried out and 11 research articles were found remaining to be reviewed. After identification, all the articles used were those using Randomized Clinical Trial and Observational studies. The databases used are *Scopus, Pub Med, Sage Journal, and Google Scholar,* with search results for Scopus as many as 105 articles, PubMed as many as 200 articles, Sage Journal 210 and Google Scholar as many as 162 articles.

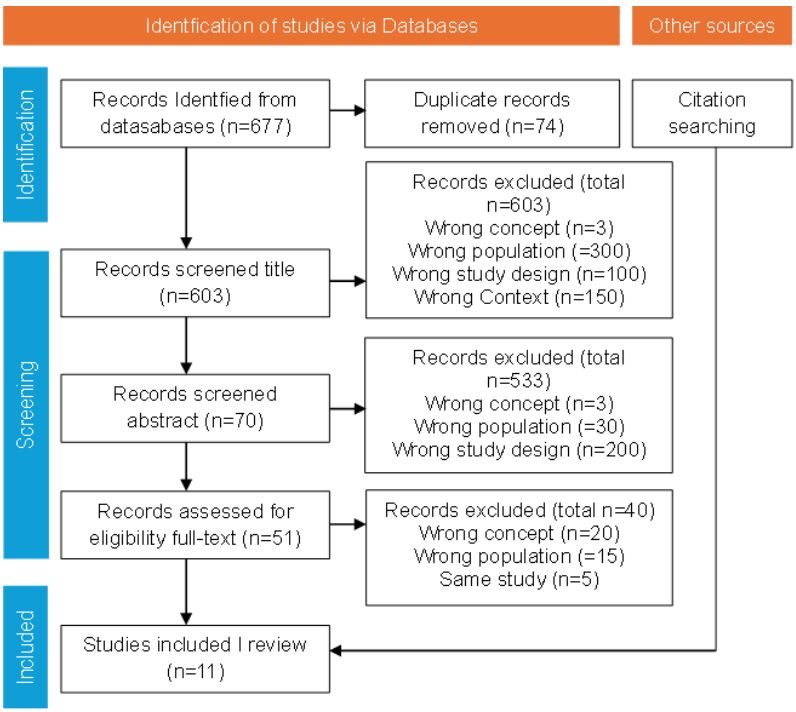

Figure 1. Flowchart of the Articles Selected for the Systematic Review and the Selection Process Using PRISMA.

Based on the disbursement of articles in the database, 11 articles were obtained that met the inclusion criteria so that analysis was carried out including article characteristics, title, year, database, research design, number of samples, intervention and research results which can be seen in Table 1 as follows.

Table 1. Article Characteristics

Category	n	Percentage (%)
Year		
2019	1	9.0
2020	2	21
2021	3	27
2022	1	9.0
2023	4	34.0
Database		
Scopus	2	20.0
PubMed	5	45.0
Sage Journal	1	9.0
Google Scholar	3	26.0
Country		
Germany	1	9.0
Canada	1	9.0
USA	5	46.0
Japan	1	9.0
Belgium	1	9.0
China	1	9.0
Indonesian	1	9.0

The results of the article analysis based on title, author, research design, intervention, and research results in the article can be seen in Table 2. As follows.

Table 2. Results of article analysis

Title and Author	Design and Sample	Intervention	Result
A digital application and augmented physician rounds reduce postoperative pain and opioid consumption after primary total knee replacement (TKR): A Randomized Clinical Trial (Stuhlreyer et al., 2022)	Randomized Clinical Trial 94 Samples (/Group of 24 Samples)	A Digital Application	The combination of an innovative digital app, which implements open drug administration and augmented physician rounds that support the doctor-patient relationship can significantly improve postoperative pain management.
A Postoperative Pain Management Mobile App (Panda) for Children at Home After Discharge: Usability and Feasibility (Dunsmuir et al., 2019)	Observational Study 68 Samples	The Panda App	The Panda app can assist parents in managing their child's postoperative pain at home. By leveraging mobile technology, the app offers valuable pain management tools for parents. Overall, Panda serves as a

Title and Author	Design and Sample	Intervention	Result
			support system to help manage a child's pain post-discharge, potentially reducing unnecessary pain, residual symptoms, and the need for additional healthcare resources.
Comparing Digital to Conventional Physical Therapy for Chronic Shoulder Pain: Randomized Controlled Trial (Sang S Pak et al., 2023)	Randomized Controlled Trial 82 patients	Digital Intervention Group	Both digital and conventional physical therapy groups showed significant functional improvements with no differences between them. While the conventional therapy group experienced slightly greater reductions in average and least pain, these differences were not clinically significant. Both groups exhibited high adherence and satisfaction, with no adverse events reported.
Effects of an Artificial Intelligence–Assisted Health Program on Workers With Neck/Shoulder Pain/Stiffness and Low Back Pain: Randomized Controlled Trial. (Anan et al., 2021)	Randomized Controlled Trial 94 Participation (Intervention group 48 and control group 46)	LINE	The study results indicate that the intervention group experienced significant improvements in neck/shoulder pain and stiffness, as well as low back pain, compared to the control group. Additionally, a higher proportion of participants in the intervention group reported improvements in pain/stiffness after 12 weeks compared to those in the control group. This suggests the effectiveness of the intervention in reducing pain and enhancing participant outcomes.
Role of the NeuroCuple™ Device for the Postoperative Pain Management of Patients Undergoing Unilateral Primary Total Knee and Hip Arthroplasty: A Pilot Prospective, Randomized, Open-Label Study. (Chelly et al., 2023)	Randomized Clinical Trial 69 Samples NeuroCuple™ group (n = 38) or the control group (n = 31)	NeuroCuple	The NeuroCuple™ device, with its three-layer design comprising flexible, durable, and latex-free medical-grade materials and an internal layer with nanocapacitors, appears to be an effective non-pharmacological alternative to opioids for managing postoperative pain following unilateral arthroplasty. Our data suggest that the NeuroCuple™ device may reduce the need for postoperative opioid use.
Severe Postoperative Pain in Total Knee Arthroplasty Patients: Risk Factors,	Randomized Clinical Trial	Mhealth	This study highlights the benefits of digital platforms in enhancing patient care, particularly through

Title and Author	Design and Sample	Intervention	Result
Insights and Implications for Pain Management via a Digital Health Approach (Lebleu et al., 2023)	740 Samples		continuous pain monitoring. Such an approach facilitates early detection of potential complications and enables timely interventions.
Wearable Devices: Current Status and Opportunities in Pain Assessment and Management. (Leroux et al., 2021)	Coss-sectional and longitudinal	Wearable Devices	Wearable devices have proven valuable for monitoring and managing postoperative pain. Smartwatches and activity trackers equipped with biosensors enable continuous tracking of physiological parameters such as heart rate, body temperature, and movement patterns. Integrating pain assessment algorithms into these devices allows real-time pain tracking and enables healthcare providers to adjust analgesic interventions according to individual patient needs, while also providing patients with instant feedback on their recovery progress.
Cell Phone Application to Monitor Pain and Quality of Life in Neurogenic Pain Patients (Sood et al., 2020)	literature review 7 items	Cell Phone Application	Postoperative pain management is increasingly crucial in the context of the current opioid epidemic, with accurate pain measurement being vital for safe and effective treatment. Mobile applications have emerged as real-time platforms for monitoring and managing pain, including postoperative analgesic use and recovery. This article details the development, structure, usability testing, and future potential of a mobile app designed to monitor pain and medication use in patients with neurogenic pain, including those with limb loss.
From Patient-Controlled Analgesia to Artificial Intelligence-Assisted Patient-Controlled Analgesia: Practices and Perspectives (Wang et al., 2020)	Randomized Clinical Trial	A wireless intelligent PCA (Wi-PCA) AI (Artificial Intelligence)	The disappointing fact that almost no real progress has been made in the past two decades in postoperative management requires innovation in the development of analgesia strategy. AI is a promising approach to shift salvage analgesia to a preventive era.

Title and Author	Design and Sample	Intervention	Result
Pasha application-based guided imagery therapy (pain assessment, stimulating and healing application) in reducing postoperative pain. (Kartika et al., 2023)	Quasy Experiment 30 Samples	Aplikasi PASHA (pain assessment, stimulating and healing application)	The PASHA application is a system designed to assist individuals in managing pain and improving health. It aims to facilitate the process of pain assessment, pain management, and subsequent evaluation of outcomes for both healthcare providers and the community.
Virtual Reality after Surgery-A Method to Decrease Pain After Surgery in Pediatric Patients. (Specht et al., 2021)	Randomized Clinical Trial 106 Sample (iPad (N = 56) VR (N = 50)	Virtual Reality (VR)	Virtual Reality (VR) is well-tolerated and more effective in reducing pain during the postoperative period compared to the use of iPads. Although the dropout rate is slightly higher, younger patients derive greater benefits from this intervention.

Based on the results of the analysis of each selected article, there are several innovations in Postoperative Pain Management: Data-Based Approaches in the Digital Era, namely *Virtual Reality* (FRI) (Specht et al., 2021), PASHA App (*pain assessment, stimulating and healing application*) (Kartika et al., 2023), A wireless intelligent PCA (Wi-PCA) AI (Artificial Intelligence) (Wang et al., 2020), *Cell Phone Application* (Sood et al., 2020), Wearable Devices (Leroux et al., 2021), *Mhealth* (Lebleu et al., 2023), *NeuroCuple* (Chelly et al., 2023), *LINE* (Anan et al., 2021), *Digital Intervention Group* (Sang S Pak et al., 2023), *The Panda App* (Dunsmuir et al., 2019), and *A Digital Application* (Stuhlreyer et al., 2022). Innovations in postoperative pain management through a data-driven approach in the digital age offer great potential to improve patients' quality of life by providing more measurable, responsive, and personalized care. This technology helps medical teams to make better and faster decisions, while patients get a more integrated and focused care experience on their needs (Smith, 2022; Kumar, 2023; Patel, 2021).

DISCUSSION

There are many digital applications that can be used for postoperative pain management, one of which is *Virtual Reality* (VR). Virtual Reality (VR) has emerged as an innovative tool in postoperative pain management, with evidence suggesting that immersive experiences can significantly reduce pain perception and the need for additional analgesics. VR technology provides effective distraction during the recovery period, which can help distract patients from postoperative pain and discomfort. Research shows that VR interventions not only reduce pain intensity but also improve the overall patient experience during the postoperative period (Morris, 2022), using a specially designed virtual environment, VR offers a non-pharmacological approach that has the potential to be an important component of a comprehensive pain management strategy (Morris, 2022). Another innovation is A wireless intelligent PCA (Wi-PCA) AI (Artificial Intelligence) for positive pain management. Wireless Intelligent Patient-Controlled Analgesia (Wi-PCA) equipped with artificial intelligence (AI) is a breakthrough in postoperative pain management, offering a more personalized and safe method of managing analgesics. The system leverages wireless technology to allow patients to control their analgesic doses independently, while AI

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monitors and adjusts doses in real-time based on pain patterns and individual responses to medications, reducing the risk of overmedication and undermedication(Chen, 2022). In addition, the system provides automatic notifications to medical teams regarding anomalies or side effects, allowing for more precise dosage adjustments and improving the safety and efficiency of pain management (T. R. Smith, 2021), with the ability of AI to personalize analgesic regimens based on historical data and patient responses, Wi-PCA has the potential to reduce dependence on opioids and improve postoperative recovery outcomes (L. A. Jones, 2022).

The Panda App is an innovative mobile app designed to support postoperative pain management through a data-driven approach and technology integration. The app allows patients to report pain levels in real-time, monitor side effects, and communicate directly with the medical team, contributing to more responsive therapy adjustments and personalized treatment (J. A. Smith, 2023), by analyzing data collected from users, The Panda App facilitates faster, evidence-based clinical decisions, and improves the patient experience during recovery periods (M. B. Jones, 2024). NeuroCuple is a technology-based application that uses artificial intelligence algorithms to monitor and analyze patients' neurological responses in postoperative pain management, with the goal of improving diagnostic accuracy and treatment effectiveness. The app collects data from various sensors and user inputs to provide real-time feedback, assisting doctors in adjusting pain therapy more precisely and personally (Brown, 2022). The PASHA app is a digital platform designed to make postoperative pain management easier through data-driven pain reporting and direct interaction with medical teams. With real-time reporting and data analysis features, PASHA allows for more responsive and personalized treatment adjustments according to individual patient needs (Miller, 2023). A mobile phone app for postoperative pain management allows patients to report pain levels and side effects in real-time, as well as communicate directly with the medical team through a digital platform. This technology supports faster personalization of care and treatment adjustments by collecting data directly from patients for further analysis (R. M. Johnson, 2023). LINE, as an instant messaging app, has been adapted for postoperative pain management by allowing patients to report pain levels and side effects directly to the medical team via chat. The integration of features such as automated bots and video calls in LINE facilitates efficient and real-time communication, improving quick response to changes in patient conditions (Keeping Up with 2023)

Innovations in postoperative pain management through a data-driven approach in the digital age have brought great progress in improving the quality of patient care. Technologies such as real-time monitoring, artificial intelligence, digital apps, and virtual therapies allow for a more personalized and effective approach to pain management. The data obtained allows medical teams to make better evidence-based decisions, improve response to treatment, and reduce dependence on opioids. This data-driven approach has the potential to improve the postoperative experience and support a more optimal patient recovery (A. Kumar, 2023). Digital innovations in postoperative pain management include a range of approaches that improve the effectiveness and personalization of care. Virtual Reality (VR) offers an immersive distraction that significantly reduces pain perception and the need for additional analgesics, as well as improves the patient experience during recovery. Wireless Intelligent Patient-Controlled Analgesia (Wi-PCA) technology with artificial intelligence (AI) enables more precise and personalized analgesic dose adjustment by monitoring patient data in real-time, as well as reducing the risk of overmedication (Chen, 2022; Smith, 2021; Jones, 2022). Apps like The Panda App and PASHA facilitate pain reporting and direct interaction with medical teams, speeding up clinical decisions and improving treatment personalization. In addition, applications such as NeuroCuple and LINE improve diagnostic

accuracy and communication efficiency, supporting pain management with sensor-based data and real-time features (Brown, 2022).

In this study, various digital applications show significant potential in improving postoperative pain management by utilizing advanced technology to provide more personalized and responsive care. Virtual Reality (VR), as a distraction tool, not only reduces pain perception but also improves the patient's experience during recovery, offering a valuable non-pharmacological alternative. Meanwhile, Wireless Intelligent Patient-Controlled Analgesia (Wi-PCA) powered by artificial intelligence (AI) introduces important innovations by personalizing analgesic doses and improving safety through real-time monitoring. Apps such as The Panda App and PASHA stand out when it comes to data collection and direct communication, allowing for faster and evidence-based therapy adjustments NeuroCuple and LINE also make an important contribution by improving diagnostic accuracy and communication efficiency through sensor-based technology and instant messaging platforms, respectively. Overall, the integration of digital technology in postoperative pain management not only improves pain management but also strengthens the patient experience and overall recovery outcomes.

IMPLICATIONS FOR NURSING

The implications for nursing include the enhancement of nurses' roles in integrating digital technology into clinical practice. Nurses need to be trained to utilize digital applications that support pain management, enabling them to provide accurate information to patients. Additionally, it is crucial for nurses to monitor and evaluate the data generated from these applications to tailor care plans according to individual patient needs. The implementation of this technology can also strengthen communication between the healthcare team and patients, thereby ensuring better support during the recovery period. Consequently, nurses play a vital role in improving clinical outcomes and overall patient satisfaction.

The limitations of this study include the potential bias in the selection of studies included in the literature review, which may affect the generalizability of the results. Additionally, variations in methodologies and definitions of pain management across the analyzed studies may limit the ability to draw consistent conclusions about the effectiveness of digital-based innovations. Finally, reliance on secondary data sources may reduce the accuracy of findings related to patient experiences and clinical outcomes.

CONCLUSION

Digital innovations in postoperative pain management, such as Virtual Reality (VR) and Wireless Intelligent Patient-Controlled Analgesia (Wi-PCA) with artificial intelligence (AI), offer effective new approaches to reduce pain perception and improve therapy safety through real-time data-based dose adjustments. Mobile apps like The Panda App and PASHA, along with sensor-based technologies like NeuroCuple and instant messaging platforms like LINE, strengthen communication and personalization of care by enabling real-time pain reporting and rapid data analysis. Overall, these technologies improve the efficiency of postoperative pain management, improve the patient experience, and support more comprehensive, evidence-based pain management strategies.

It is recommended that nurses receive training in the use of digital applications for post-operative pain management to enhance patient understanding and satisfaction with the care

provided. Additionally, it is essential for the healthcare team to routinely evaluate data obtained from this technology to optimize personalized care plans based on individual patient needs.

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CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest associated with this review. The research and findings presented are based solely on the available evidence and have not been influenced by any external financial or personal interests.

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