Dovepress
Taylor & Francis Group

REVIEW

Comprehensive Review on Personalized Pain Assessment and Multimodal Interventions for Postoperative Recovery Optimization

Jingying Xu[1,]*, Xiaona Liu[1,]*, Jinyan Zhao[1], Jingjing Zhao[2], Hao Li[1], Huanhuan Ye[2], Shuang Ai[2]

[1]Department of Rehabilitation Medicine, Joint Logistics Support Force No. 964 Hospital of People's Liberation Army of China, Changchun, Jilin, 130000, People's Republic of China; [2]Department of Outpatient, Joint Logistics Support Force No. 964 Hospital of People's Liberation Army of China, Changchun, Jilin, 130000, People's Republic of China

*These authors contributed equally to this work

Correspondence: Shuang Ai, Email 124793685@qq.com

Abstract: Postoperative pain management is an important determinant of patient recovery, as it directly influences rehabilitation efficiency, hospitalization duration, and the risk of postoperative complications. Despite its significance, traditional pain management strategies often fail to adequately address individual variability and the multidimensional nature of pain, thereby limiting their effectiveness. To address these limitations, we designed this comprehensive narrative review to systematically summarize relevant literature published between 2000 and 2024, from databases such as PubMed and Web of Science, with a particular focus on personalized pain assessment and multimodal interventions to optimize postoperative recovery. Personalized pain assessment, guided by the biopsychosocial model, captures the biological, psychological, and social dimensions of pain, offering a more comprehensive and individualized evaluation of patient needs. In parallel, multimodal interventions, which integrate pharmacological and non-pharmacological strategies, are designed to target multiple pain mechanisms simultaneously, thereby enhancing analgesic efficacy while minimizing adverse effects. Emerging evidence indicates that combining personalized pain assessment with multimodal interventions can significantly improve clinical outcomes, as demonstrated by reductions in postoperative pain scores by approximately 20–30%, shorter hospital stays by 1–2 days, and decreased opioid consumption by 25–40%. Notable clinical applications supporting these findings include the use of dynamic pain monitoring devices, virtual reality-based therapies, and prehabilitation programs to facilitate recovery. Building upon these findings, this review further discusses the theoretical foundations underlying personalized pain management, explores its clinical applications, and examines the practical challenges associated with its implementation. Additionally, future directions are proposed, including the development of AI-driven pain assessment tools, the promotion of interdisciplinary collaboration, and the establishment of standardized clinical protocols. Collectively, these advancements support the potential of personalized, multidimensional strategies to improve postoperative outcomes and enhance overall patient satisfaction.

Keywords: personalized pain assessment, multimodal interventions, postoperative recovery, pain management, enhanced recovery

Introduction
Background

Postoperative pain remains one of the most prevalent and challenging complications during the perioperative period, with up to 80% of patients experiencing postoperative pain and more than 50% reporting moderate to severe pain intensity.[1,2] Unrelieved acute postoperative pain is associated with an increased risk of developing persistent post-surgical pain (PPSP), a higher incidence of cardiovascular and pulmonary complications, impaired wound healing, and delayed rehabilitation.[3–5] Despite notable advances in pharmacological therapies and surgical techniques, traditional approaches to pain management continue to face substantial limitations, which include a predominant reliance on monotherapy, insufficient attention to individual variability in pain perception, suboptimal targeting of the multidimensional nature of

pain, and an increased risk of opioid dependence and associated adverse effects.[6–8] Moreover, traditional pain management methods rely too much on single-drug therapy, ignore the individual differences and multidimensional characteristics of pain, have limited analgesic effects, and have prominent problems of drug dependence and adverse reactions. To address these challenges, personalized pain assessment and multimodal intervention have gradually received attention.[9,10] In response to these challenges, individualized pain assessment and multimodal interventions have attracted increasing attention.

Objectives of the Review

In response to the identified challenges, this narrative review was undertaken with the following objectives: (1) to summarize the current status, challenges, and limitations associated with conventional postoperative pain management strategies; (2) to explore the theoretical foundations and clinical applications of personalized pain assessment and multimodal interventions; (3) to review emerging technologies and interdisciplinary approaches that facilitate personalized pain management; and (4) to propose future directions for clinical practice and research aimed at improving postoperative recovery outcomes.

Methodology and Scope

This review was conducted using a narrative synthesis approach. Relevant literature published between 2000 and 2024 was identified through systematic searches of PubMed, Web of Science, and Google Scholar, using keywords including "postoperative pain", "personalized pain assessment", "multimodal analgesia", "enhanced recovery", and "pain management innovations". The articles were selected based on their relevance to personalized assessment strategies, multimodal analgesic approaches, and postoperative recovery optimization. The review primarily focuses on adult and elderly patient populations undergoing major surgical procedures, such as orthopedic, abdominal, thoracic, and oncologic surgeries. Pain management strategies discussed include preoperative, intraoperative, and postoperative interventions. Studies focusing exclusively on pediatric populations, minor surgical procedures, or experimental pharmacological agents lacking clinical validation were excluded.

Theoretical Framework

Pain is a subjective and multidimensional experience, influenced by biological, psychological, and social factors. Traditional pain assessment methods, such as the Visual Analog Scale (VAS) and Numerical Rating Scale (NRS), primarily focus on quantifying pain intensity, but they often fail to capture the emotional, cognitive, and social dimensions of the pain experience.[11,12] Similarly, conventional single-drug analgesic approaches are limited by their focus on biological mechanisms alone, neglecting the substantial impact of psychological states and social contexts on pain perception and recovery. These limitations highlight the need for a more comprehensive and individualized framework for postoperative pain management.

In response to these challenges, the concept of personalized pain assessment and multimodal interventions has gained increasing recognition. Personalized pain assessment, grounded in the biopsychosocial model, systematically integrates biological factors (eg, pain intensity, inflammatory biomarkers), psychological factors (eg, anxiety, depression, coping strategies), and social factors (eg, family support, socioeconomic status) to provide a dynamic and comprehensive evaluation of the patient's pain experience.[13] Building upon this assessment, multimodal interventions combine pharmacological therapies, including opioids, non-steroidal anti-inflammatory drugs (NSAIDs), and local anesthetics, with non-pharmacological strategies, such as psychological interventions, physical rehabilitation, and emerging technologies like virtual reality, to achieve synergistic, multi-targeted analgesia.[14]

The theoretical framework guiding this review is thus primarily anchored in the biopsychosocial model, which conceptualizes pain as a complex phenomenon arising from the interplay of biological, psychological, and social factors. In addition to this model, the review draws on principles of multimodal analgesia, dynamic risk stratification, and patient-centered care, all of which emphasize individualized treatment pathways and holistic outcome optimization. Collectively, these frameworks support an integrated approach that aims not only to alleviate acute pain but also to reduce the risk of

persistent post-surgical pain, enhance postoperative recovery quality, shorten hospitalization duration, and optimize healthcare resource utilization.[15]

In summary, by critically examining personalized pain assessment models, multimodal intervention strategies, and interdisciplinary management approaches within this theoretical framework, the present review seeks to provide a comprehensive and practical reference for advancing postoperative pain management and improving patient recovery outcomes.

Current Status and Challenges in Postoperative Pain Management
Characteristics and Mechanisms of Postoperative Pain

Postoperative pain is a complex physiological and psychological phenomenon caused by surgical trauma (Figure 1). It is highly subjective, multidimensional and dynamically changing, and mainly involves the following two levels of mechanisms. In terms of physiological mechanisms, surgical trauma causes tissue damage and triggers an inflammatory response, leading to the release of large amounts of pro-inflammatory cytokines such as IL-6 and TNF-α. These cytokines activate peripheral nociceptors, transmitting pain signals through peripheral nerves to the central nervous system, where pain perception occurs.[16] If acute pain is not promptly managed, central sensitization may develop, characterized by excessive activation and neoplastic changes in spinal cord and brain pain pathways. This phenomenon leads to abnormal amplification of pain signals and may progress to chronic postoperative pain.[17] Furthermore, patients with advanced age, obesity, or diabetes experience increased challenges in pain management due to altered nerve sensitivity and drug metabolism rates.[18] Psychological and social factors also play a key role in postoperative pain. For example, preoperative anxiety, depression and other negative emotions, insufficient social support, or high financial pressure will also aggravate the patient's pain perception and delay functional recovery.[19] It can be seen that postoperative pain is a multidimensional experience caused by physical, psychological and social factors. A single pain management method is difficult to comprehensively solve this complex problem. Therefore, accurate identification of pain mechanisms and multidimensional intervention have become the key to improving postoperative pain management.

Limitations of Traditional Pain Management Approaches

Traditional management of postoperative pain relies primarily on pharmacotherapy, including opioids, NSAIDs, local anesthetics, and nerve block techniques. Although effective in relieving acute pain, there are obvious limitations. First, as the main analgesic drugs, opioids can easily induce tolerance and dependence. Long-term use can lead to side effects such as nausea, vomiting, constipation, and respiratory depression, especially in elderly patients.[20,21] In addition, opioid abuse has become a global public health challenge, limiting its long-term use.[22,23] NSAIDs play an important role in relieving inflammatory pain, but their long-term use may cause gastrointestinal damage, impaired renal function, and cardiovascular risks, and their application is limited, especially in elderly patients and patients with underlying diseases.[24,25] Secondly, although local anesthesia and nerve block technology have good analgesic effects, they rely on professional technology and equipment, and there are risks of complications such as infection and nerve damage.[26–28]
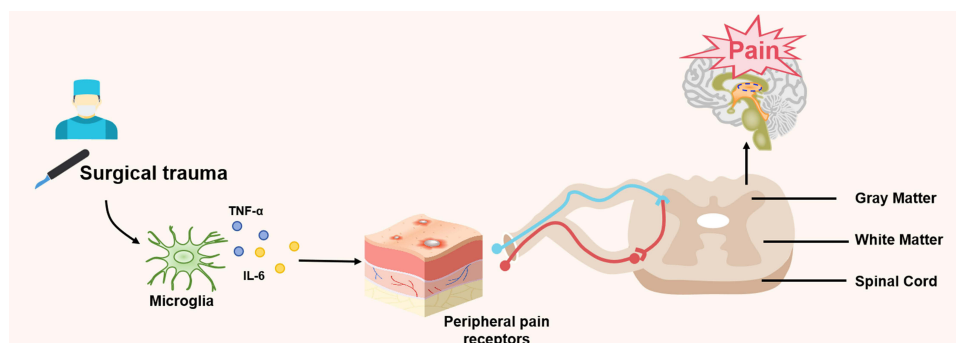

Figure 1 Mechanisms of Postoperative Pain.

Furthermore, single-drug therapies struggle to address the multidimensionality and complex mechanisms of pain. For example, for patients undergoing complex surgeries such as radical cancer surgery or joint replacement, the pain mechanism involves neuropathic, inflammatory and psychological factors, and it is difficult for a single drug to cover all sources of pain.[29,30] Finally, traditional pain management often adopts a fixed-dose "one-size-fits-all" solution, ignoring the individual needs of patients. For example, the drug metabolism rate of obese patients is significantly different from that of normal patients, while the drug clearance rate of elderly patients is reduced, and drug accumulation is more likely to occur.[31,32] Therefore, the traditional single-drug model cannot effectively solve the multidimensionality and individual differences of postoperative pain. New strategies that combine multidimensional pain assessment and multimodal intervention have become an important direction to solve this challenge.

Theory and Practice of Personalized Pain Assessment
Biopsychosocial Model: The Basis for Multidimensional Pain Assessment

The core concept of personalized pain assessment is based on the biopsychosocial model, which views pain as a complex multidimensional experience (Figure 2). This model emphasizes that pain is not only a perception process of physiological signals but is also profoundly affected by the patient's psychological state and social environment.[33,34] Specifically, the physiological dimension mainly focuses on the biological manifestations of pain, including inflammatory response, nerve conduction, and individual physiological and pathological characteristics. Although traditional pain assessment tools such as VAS and NRS can quickly quantify pain intensity, their single-dimensional limitations make it difficult to capture the multidimensional characteristics of pain.[35] In addition, biomarkers such as cortisol and C-reactive protein (CRP) provide an objective basis for pain assessment, especially showing important value in monitoring the stress response of acute pain and the inflammatory status of chronic pain.[36,37] In terms of psychological dimension, negative emotions such as anxiety and depression are closely related to pain perception, research shows that negative emotions
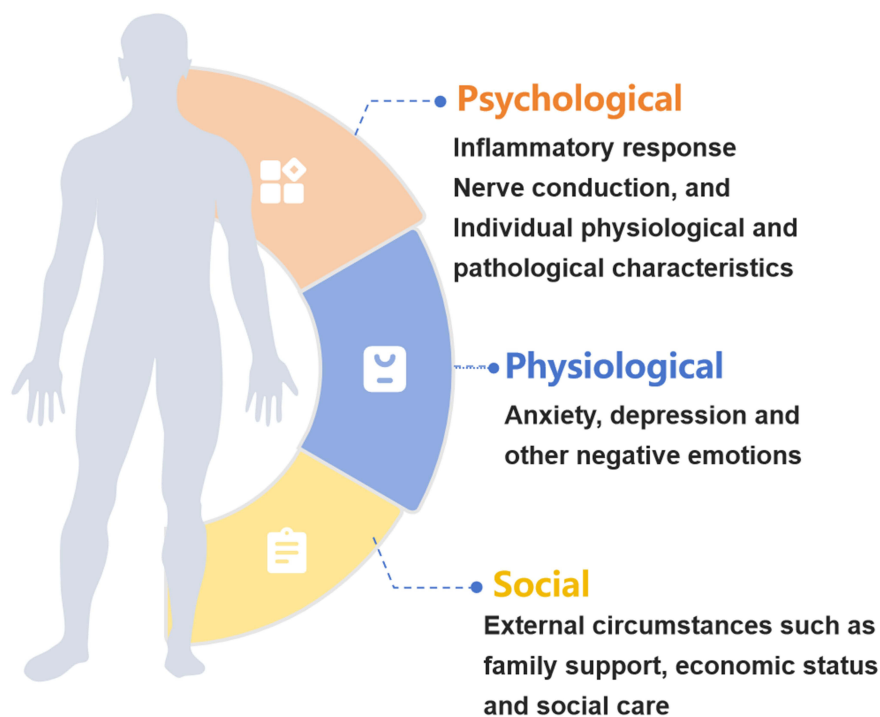
Figure 2 Biopsychosocial Model: the Basis for Multidimensional Pain Assessment.

can amplify pain signals and affect the persistence and recovery of pain. Commonly used clinical psychological assessment tools include the Hospital Anxiety and Depression Scale (HADS) and the Pain Catastrophizing Questionnaire (PCS), which are used to identify patients' emotional states and pain amplification tendencies.[38,39] In terms of social dimension, external environments such as family support, economic status and social care play an important regulating role in pain management. Good social support can enhance patients' pain tolerance and relieve anxiety and depression. Patients who lack a support system often higher pain scores and slower recovery.[40] Therefore, the biopsychosocial model provides a theoretical basis for multidimensional pain assessment. By comprehensively integrating physiological, psychological and social factors, it helps to achieve precision and systematization of personalized pain assessment.

Advancements in Pain Assessment Tools for Postoperative Pain Management

With the advancement of technology, pain assessment tools have evolved from single-dimensional metrics to multi-dimensional and dynamic evaluation systems, providing more accurate support for postoperative pain management. Unlike traditional single-score tools with inherent limitations, the McGill Pain Questionnaire (MPQ) offers a comprehensive assessment of pain by describing its sensory, emotional, and cognitive dimensions, thereby enriching clinical evaluation with more holistic information.[41] Similarly, PainDETECT, a screening tool specifically designed for neuropathic pain, integrates pain characteristics, self-reported scores, and psychological state to identify patients at high risk of chronic postoperative pain.[42] For instance, in patients undergoing joint replacement surgery, the preoperative application of PainDETECT allows precise identification of pain patterns, facilitating the development of personalized postoperative analgesic plans.[43] Furthermore, the introduction of artificial intelligence (AI) technology has driven the intelligent and dynamic transformation of pain assessment. AI models integrate preoperative patient history, pain scores, biomarkers, and psychological data to accurately predict postoperative pain risks and recommend individualized intervention strategies.[44] For example, preoperative imaging analysis found that patients with higher insular activity had higher postoperative pain scores, and a targeted analgesic program based on this finding significantly improved pain control and functional recovery.[45] Additionally, AI-enhanced dynamic monitoring devices, such as wearable technologies, are being increasingly utilized in clinical practice. These devices continuously track physiological indicators such as pain scores, heart rate variability (HRV), and galvanic skin response (GSR), providing real-time feedback on pain status. This enables early identification of pain exacerbation and timely adjustment of interventions.[46,47] In terms of clinical application, there is a trend toward improved patient satisfaction and early recovery in knee replacement patients through personalized pain assessment tools and dynamic monitoring devices.[48]

Thus, personalized pain assessment tools and clinical applications provide essential support for precise postoperative pain management, significantly improving the targeting and effectiveness of both assessments and interventions.

Application and Advantages of Multimodal Pain Interventions

Multimodal analgesia refers to the use of two or more analgesic agents or techniques that act through different mechanisms to provide superior pain control compared to single-modality therapies.[49] By simultaneously targeting multiple pain pathways, multimodal analgesia aims to enhance analgesic efficacy while minimizing the incidence of drug-related adverse effects. Its core components encompass both pharmacological (ie, opioids, NSAIDs, local anesthetics, and adjunctive agents such as α2-adrenergic agonists) and non-pharmacological (ie, physical therapies, such as cryotherapy, massage, and exercise rehabilitation, as well as psychological approaches, including cognitive-behavioral therapy and mindfulness-based therapies) interventions. By integrating pharmacological and non-pharmacological approaches, multimodal pain intervention targets multiple mechanisms of pain generation and transmission, significantly enhancing analgesic efficacy while reducing drug-related side effects. Opioids, such as morphine and oxycodone, are highly effective for controlling moderate to severe postoperative pain. However, their long-term use is associated with tolerance, dependency, and adverse effects, necessitating cautious dose selection and administration methods in clinical practice.[50] NSAIDs such as ibuprofen and diclofenac sodium reduce inflammation by inhibiting cyclooxygenase (COX), and have a good effect on relieving mild to moderate pain, but the potential damage to the gastrointestinal tract and kidney should be vigilant.[51] Local anesthetics, including lidocaine and bupivacaine, achieve pain relief by blocking nerve

conduction and are commonly used for nerve blocks and surgical site infiltration anesthesia. Recently, α2-adrenergic receptor agonists such as dexmedetomidine have gained prominence for their central analgesic and sedative effects, particularly in augmenting analgesia during complex surgeries like thoracoscopic procedures.[52]

In regard to non-pharmacological interventions, mindfulness-based therapy and group psychological support have been shown to alleviate preoperative anxiety and postoperative pain perception, enhancing patients' psychological adaptability.[53] Physical therapies, such as cryotherapy, massage, and exercise rehabilitation, improve local blood circulation and muscle function, thereby reducing postoperative pain and accelerating recovery.[54,55] Additionally, emerging technologies such as virtual reality (VR), telemedicine, and neuromodulation techniques are increasingly utilized in pain management. Studies indicate that VR effectively diverts patients' attention from pain through immersive virtual environments, significantly reducing postoperative pain scores and analgesic consumption.[56,57] Moreover, transcutaneous electrical nerve stimulation (TENS) and spinal cord stimulation (SCS) are widely applied in patients with moderate to severe pain. These neuromodulation techniques inhibit pain signal transmission, providing substantial pain relief.[58]

Collectively, the integration of pharmacological and non-pharmacological interventions achieves synergistic effects through multi-target and multidimensional approaches, significantly enhancing postoperative pain management outcomes. For example, in spinal surgery patients, the combination of local anesthetics, NSAIDs, mindfulness therapy, and VR effectively reduced pain scores and shortened recovery time. Therefore, multimodal pain interventions can be used to overcome the limitations of traditional monotherapy by providing a systematic and comprehensive solution for optimizing postoperative pain management. This strategy represents a significant advancement in enhancing patient outcomes and improving the quality of care in clinical settings.

Integration of Personalized Pain Assessment and Multimodal Interventions

In addition to emerging technologies such as artificial intelligence-driven predictive models and wearable dynamic monitoring devices, traditional methods such as patient-controlled analgesia (PCA) represent classical personalized treatment approaches in postoperative pain management.[59] PCA enables patients to self-administer predetermined doses of analgesics, typically opioids, according to their individual pain experiences and requirements.[59] By providing autonomy over pain control, PCA improves patient satisfaction, reduces fluctuations in analgesic plasma concentrations, and minimizes the risk of under- or over-treatment. Clinical evidence supports the efficacy of PCA in enhancing postoperative pain control, particularly after major surgeries.[60] Furthermore, other personalized interventions, such as individualized titration protocols for regional anesthesia, the use of patient-specific analgesic pathways based on genetic polymorphisms, and tailored non-pharmacological therapies based on psychological profiling, are gaining attention in the effort to optimize personalized postoperative pain management.[61] Together, these approaches complement AI-based innovations to provide comprehensive, patient-centered care. The following case studies highlight the clinical applications and benefits of this strategy in different patient groups.

Pain Management in Elderly Patients

Elderly patients face unique challenges in postoperative pain management, including physiological decline, slower drug metabolism, increased drug sensitivity, and risks of cognitive dysfunction such as postoperative cognitive dysfunction (POCD).[62] Studies have shown that elderly patients exhibit poorer tolerance to opioid analgesics, which increases the risk of accumulation and adverse reactions, such as delirium and respiratory depression.[63] Designing individualized pain management plans is therefore crucial for this population. A study focusing on elderly patients undergoing hip replacement demonstrated the effectiveness of a multimodal analgesic strategy, which included intraoperative local anesthesia, postoperative NSAIDs, and cognitive behavioral therapy (CBT). The results showed that the patient's pain score was significantly reduced after surgery, and the postoperative anxiety and depression improved. Moreover, cognitive function recovery is accelerated and the incidence of delirium is reduced.[64] Preoperative psychological interventions are also an essential component of pain management in elderly patients. A clinical trial demonstrated that preoperative psychological counseling and postoperative family support significantly reduced anxiety scores and enhanced pain tolerance.[65] Additionally, interventions such as mindfulness therapy and virtual reality VR distraction

techniques have proven effective in reducing postoperative pain scores, decreasing the need for analgesics, lowering complication rates, and accelerating recovery.[66]

In addition to psychological interventions, other preoperative strategies have also been shown to contribute to improved postoperative pain outcomes. Prehabilitation programs, including physical conditioning and respiratory exercises, can enhance physical resilience and reduce postoperative pain intensity.[67] Nutritional optimization, smoking cessation, and structured patient education regarding postoperative pain expectations have similarly demonstrated benefits in facilitating early recovery and reducing analgesic requirements.[68] Although a detailed evaluation of these modalities is beyond the scope of this review, recognizing their contribution further emphasizes the importance of a comprehensive preoperative optimization strategy.

Pain Management in Patients Undergoing Complex Surgeries

Complex surgeries, such as spinal fusion, thoracotomy, and major abdominal procedures, are often accompanied by severe postoperative pain, making pain management particularly challenging. Since pain involves inflammatory, neuropathic, and psychological factors, single-mode analgesic strategies are often insufficient. A comprehensive intervention combining multimodal analgesia with individualized assessment is essential. In spinal fusion surgeries, clinical studies have demonstrated that using preoperative imaging assessments and personalized pain prediction models to identify high-risk patients, combined with intraoperative administration of dexmedetomidine, local anesthesia, and NSAIDs, followed by postoperative physical therapy and psychological support interventions, can reduce complications, enhance patient experience, and shorten hospital stays.[69] For thoracotomy patients, postoperative pain is closely associated with respiratory depression, and inadequate management can lead to atelectasis and pulmonary infections. Relevant studies report that combined with multimodal analgesia programs (such as epidural analgesia, TENS and postoperative chest cold compress technology), patients' postoperative respiratory function was significantly improved, early mobility was improved, and the use of analgesics was reduced.[70,71] Additionally, real-time blood oxygen monitoring and pain score feedback help physicians dynamically adjust pain management plans, improving analgesic efficacy and reducing the risk of complications. Furthermore, VR technology has shown promising results in the postoperative management of complex surgical patients. A study of laparoscopic cholecystectomy surgery showed that mean preoperative anxiety scores were significantly lower in both VR groups compared with the control group (P < 0.001), and patients in both intervention groups also had significantly lower postoperative pain scores (P = 0.001).[72]

Postoperative Pain Management for Cancer Patients

Postoperative pain management for cancer patients is particularly complex. Pain often involves multiple mechanisms, such as surgical trauma, tumor compression, and neuropathic pain, and patients are often accompanied by psychological problems such as anxiety and depression. For this population, personalized pain assessment and multimodal analgesia have significant advantages. Studies on postoperative pain management in patients with colon cancer have shown that the combined use of intraoperative local anesthesia and postoperative non-pharmacological intervention (such as psychological support and physical therapy) can effectively relieve postoperative pain. Patients' postoperative pain scores were reduced, and the incidence of postoperative complications was reduced, and the study also pointed out that psychological intervention played an important role in patients' emotional regulation and pain tolerance during the postoperative recovery period.[73] A study of patients with gastric cancer showed that a multimodal analgesic regimen that combined local anesthesia (eg, transversalis fascia block) with NSAIDs and postoperative physical therapy improved the 24 h incidence of moderate-to-severe pain with exercise and rest. The pain scores were reduced and the duration of first rescue analgesia after gastric cancer surgery was prolonged.[74] For patients undergoing pancreatic cancer surgery, postoperative pain management is particularly critical due to the large surgical trauma and long recovery period. A multimodal regimen that combined preoperative nutritional receipt with postoperative pharmacologic analgesia showed[75] that patients with fast-track recovery had a significantly faster clinical course in terms of recovery of bowel function and complete enteral nutrition. In addition, postoperative hospital stays were significantly shorter for fast-track patients. Further, virtual reality technology has demonstrated benefits following cancer surgery. Patients with esophageal cancer, for instance, who got

VR distraction in addition to medication analgesia, experienced fewer pulmonary problems, quicker recovery periods, and lower postoperative pain scores.[76]

Pain Management for Special Populations

Special populations (such as children, newborns, patients with chronic pain, and patients with postoperative obesity) have unique needs in postoperative pain management, and the combination of personalized pain assessment and multimodal intervention is particularly important. Postoperative pain assessment and management are particularly difficult for neonates and infants, and non-pharmacological interventions have significant advantages for these patients. A study demonstrated that non-pharmacological interventions are significantly effective in neonatal pain management. Combining maternal presence and skin-to-skin contact (kangaroo care) with sucrose analgesia significantly reduces neonatal pain scores (as assessed by the Neonatal Infant Pain Scale, NIPS), crying duration, and stress responses. Additionally, massage therapy, non-nutritive sucking, and acupuncture are effective for mild to moderate pain, promoting weight gain, improving neurodevelopment, and providing adjunctive analgesia for invasive procedures.[77]

For patients with long-term chronic pain, postoperative pain management is particularly complex, and pain may become aggravated or chronic. Relevant literature reports that for patients with chronic pain undergoing total knee arthroplasty, multimodal analgesia combined with personalized medication management programs (including preemptive analgesia, neuraxial anesthesia, PCA and local infiltration analgesia, and oral opioids medications/non-opioid medications, etc), improves clinical outcomes and patient satisfaction, promotes knee recovery, and reduces patient opioid consumption and related adverse effects.[78] For obese patients, postoperative pain management faces challenges such as changes in drug metabolism rate and distribution volume. By combining wearable dynamic monitoring of pain indicators with individualized drug dose adjustment, studies have shown that obese patients get better pain relief and faster recovery.[79] On this basis, the combination of cold compress technology and low-intensity exercise therapy further accelerated the patient's postoperative recovery. In addition, obese patients often suffer from sleep apnea syndrome (OSA). Personalized analgesic programs need to pay special attention to the risk of respiratory depression and select short-acting opioids and multimodal non-opioid analgesic programs to minimize adverse reactions.[80]

In summary, by combining personalized pain assessment and multimodal intervention for different groups of people, these solutions provide a scientific and systematic solution for postoperative pain management, significantly improve the analgesic effect, accelerate functional recovery, and have important clinical application value.

Evaluation of International Guidelines on Personalized Pain Management and Multimodal Interventions

The standardization of personalized pain assessment and multimodal analgesic strategies is essential for their effective implementation in clinical practice.[81] In this regard, several international guidelines and consensus statements provide recommendations aimed at structuring postoperative pain management. For instance, the 2016 Clinical Practice Guideline jointly issued by the American Pain Society (APS),[6] American Society of Regional Anesthesia and Pain Medicine (ASRA),[61] and American Society of Anesthesiologists (ASA)[82] emphasizes the adoption of multimodal analgesia as a standard of care, advocating the combined use of pharmacological and non-pharmacological therapies to reduce opioid requirements and promote recovery. Similarly, ERAS protocols[83] recommend tailoring multimodal analgesia to individual patient profiles, while also stressing early mobilization and optimized anesthetic management. In addition, multidisciplinary statements from organizations such as the Association of Anaesthetists and the British Pain Society highlight the importance of individualized, goal-directed analgesia, particularly in vulnerable patient groups.

Although these guidelines advocate for multimodal and personalized approaches, they do not yet provide standardized pathways that fully integrate comprehensive biopsychosocial pain assessments into routine analgesic planning. Furthermore, variability in the implementation of personalized pain management strategies across institutions and regions remains a significant challenge.[84] Therefore, there is a need for international harmonization efforts to develop standardized, evidence-based protocols that systematically incorporate individualized pain assessments to improve the consistency of care, advance postoperative pain management practices, and optimize patient outcomes.

Current Limitations and Future Directions in Research

Research Limitations

Although the integration of personalized pain assessment and multimodal interventions has demonstrated significant advantages in postoperative pain management, several challenges continue to hinder its widespread adoption and practical application. First, the high cost of technology and the complexity of equipment limit its feasibility in primary healthcare settings. Real-time health monitoring devices and genetic polymorphism analysis, for instance, require advanced laboratory infrastructure and specialized personnel, posing significant barriers for resource-limited medical facilities.[85] Although portable monitoring devices offer the potential for broader use in primary care, their current high purchase and maintenance costs remain prohibitive for many institutions. Second, the lack of standardized protocols further restricts the practical application of existing technologies. Variability in assessment tools and management processes across different hospitals and regions impedes the adaptability, consistency, and generalizability of personalized pain management strategies.[86] Without uniform standards, it becomes difficult to implement these innovations on a larger scale. Finally, data privacy and ethical concerns represent critical barriers to the promotion of personalized management. The collection, storage, and transmission of sensitive health data necessitate robust privacy protection measures. However, many existing systems fall short in ensuring data security, thereby exposing patients to potential risks of data breaches and undermining trust in technology-driven pain management approaches.

Future Development Directions

To address these challenges, future research and practice should focus on technological innovation, interdisciplinary collaboration, intelligent data management, and large-scale implementation strategies to achieve the widespread application and continuous optimization of personalized pain management.

Technological Innovation and Cost Reduction

Technological innovation represents a primary driving force in advancing personalized pain management. However, to achieve widespread adoption, it is equally essential to reduce costs and improve accessibility. Future efforts should focus on the development of portable, simplified pain assessment tools and real-time monitoring devices that enhance usability and facilitate broader clinical integration. For example, the integration of mobile applications with wearable devices allows patients to upload real-time pain scores, physiological parameters, and other relevant metrics, thereby enabling continuous pain monitoring and dynamic feedback to healthcare providers. Clinical studies have demonstrated that the use of such technologies not only reduces patient readmission rates but also significantly improves the quality of postoperative recovery.[87] Additionally, addressing cost barriers is essential to ensure equitable access, and reducing the costs associated with new technologies requires concerted policy support. Governments and healthcare organizations can promote adoption in primary care settings by providing targeted subsidies, such as financial assistance for hospitals to procure portable devices and funding programs to support patients' use of mobile health monitoring systems. These initiatives are particularly important for overcoming the low penetration of health technologies in resource-limited areas. By simultaneously fostering innovation and ensuring affordability, these measures can expand the coverage and improve the quality of personalized pain management services.

Optimization of Multidisciplinary Collaboration Models

Managing complex postoperative pain requires a multidisciplinary collaboration model that integrates expertise across different clinical specialties. Pain management is no longer the sole responsibility of anesthesiologists and surgeons as it demands active involvement from psychologists, rehabilitation therapists, and nursing teams to address the multifaceted nature of postoperative pain. Thus, establishing standardized multidisciplinary pain management teams can provide structured workflows and formal communication mechanisms to enhance coordination and ensure that individualized pain management plans are efficiently implemented.[88] Clinical evidence highlights the benefits of such collaborative approaches. For instance, in burn patients, multidisciplinary management combining pharmacological analgesia, physical therapy, and psychological interventions has been shown to significantly improve both pain control and mental health outcomes.[89] Similarly, for patients with neuropathic pain, multidisciplinary interventions have demonstrated

effectiveness in enhancing postoperative pain control and promoting cognitive recovery.[24] These findings support the essential role of coordinated interdisciplinary efforts in optimizing postoperative outcomes.

To sustain and continuously improve multidisciplinary collaboration, healthcare institutions should prioritize regular team-based training sessions and case discussions to facilitate the sharing of best practices and accumulated clinical experiences. Furthermore, the integration of digital tools, such as shared electronic medical record platforms, can strengthen real-time information exchange across disciplines. Such technologies not only improve communication efficiency but also ensure the precise, consistent delivery of personalized pain management strategies.

Data-Driven Intelligent Management

Data-driven approaches to pain management are emerging as a key future direction, with AI and big data analytics playing central roles in enhancing the precision of pain assessment and intervention. By integrating multidimensional data, including pain scores, biomarkers, psychological status, and preoperative clinical histories, AI algorithms can model pain trajectories and generate personalized intervention strategies. For example, in postoperative breast cancer patients, the implementation of an AI-based pain management system was shown to significantly reduce both pain intensity and psychological distress.[90] Moving forward, future efforts should prioritize the development of interoperable data platforms that enable seamless integration and sharing of health information across hospitals and regions. Breaking down data silos will facilitate large-scale application of predictive models and support real-time clinical decision-making. Simultaneously, it is essential to establish robust data security frameworks and safeguard patient privacy. The standardization and regulatory oversight of health data usage will also be critical in ensuring the ethical and effective deployment of AI-driven technologies in pain management.

Large-Scale Promotion Strategies

The widespread adoption of personalized pain management, particularly in primary care settings and resource-limited areas, requires systematic and practical promotion strategies. First, strengthening the training of primary care providers is essential. Governments and healthcare institutions should develop and disseminate standardized pain management guidelines and toolkits to enhance providers' technical competencies. Implementing remote education programs and organizing regular training sessions can ensure that primary care practitioners are proficient in utilizing pain assessment tools and real-time monitoring devices.[91] Second, policy support is critical to facilitate the dissemination of relevant technologies. Financial subsidies and equipment procurement initiatives sponsored by governments can improve the accessibility of pain management technologies in rural and underserved regions. Notably, several countries have successfully expanded postoperative pain management coverage in primary care by introducing simplified health monitoring devices, thereby improving the reach and quality of care.[92,93] Lastly, intensifying public health awareness campaigns is vital to enhance patient understanding and acceptance of personalized pain management approaches. Community-based education and outreach programs can empower patients to engage actively in pain monitoring and management processes, thereby fostering broader adoption of personalized pain assessment methods and multimodal interventions.

Conclusion

Personalized pain assessment and multimodal interventions represent promising advancements for optimizing postoperative pain management. Research on multimodal analgesia combining pharmacological and psychological interventions provides strong evidence for improving both physical recovery and emotional well-being, and clinicians could be encouraged to adopt individualized, multimodal pain management strategies tailored to patients' biopsychosocial profiles, surgical types, and perioperative risks. In settings with resource limitations, simplified personalized approaches, such as patient stratification and basic multimodal pharmacologic regimens, may offer feasible alternatives.

Despite the promising results, critical knowledge gaps remain. High-quality, large-scale randomized controlled trials are needed to standardize personalized pain assessment frameworks, validate AI-based predictive tools, and clarify the long-term outcomes of emerging non-pharmacological interventions. Additionally, strategies to improve implementation feasibility, patient adherence, and interdisciplinary collaboration warrant further exploration.

In summary, personalized pain assessment and multimodal interventions provide a scientifically grounded, patient-centered pathway to optimize postoperative recovery. Future efforts focused on standardization, technological innovation, and evidence-based clinical integration would be essential to fully realize their potential impact.

Data Sharing Statement

The data used to support the findings of this study are available from the corresponding author upon request.

Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

Disclosure

The authors declare that they have no competing interests.

References

1. Apfelbaum JL, Chen C, Mehta SS, et al. Postoperative pain experience: results from a national survey suggest postoperative pain continues to be undermanaged. *Anesthesia Analg*. 2003;97:534–540. doi:10.1213/01.ANE.0000068822.10113.9E
2. Gan TJ, Habib AS, Miller TE, et al. Incidence, patient satisfaction, and perceptions of post-surgical pain: results from a US national survey. *Curr Med Res Opin*. 2014;30:149–160. doi:10.1185/03007995.2013.860019
3. Nett MP. Postoperative pain management. *Orthopedics*. 2010;33:23–26. doi:10.3928/01477447-20100722-60
4. Kehlet H, Jensen TS, Woolf CJ. Persistent postsurgical pain: risk factors and prevention. *Lancet*. 2006;367:1618–1625. doi:10.1016/S0140-6736(06)68700-X
5. Katz J, Seltzer Z. Transition from acute to chronic postsurgical pain: risk factors and protective factors. *Expert Rev Neurother*. 2009;9:723–744. doi:10.1586/ern.09.20
6. Chou R, Gordon DB, de Leon-Casasola OA, et al. Management of postoperative pain: a clinical practice guideline from the American Pain Society, the American Society of Regional Anesthesia and Pain Medicine, and the American Society of Anesthesiologists' Committee on Regional Anesthesia, Executive Committee, and Administrative Council. *J Pain*. 2016;17:131–157. doi:10.1016/j.jpain.2015.12.008
7. Dietz N, Sharma M, Adams S, et al. Enhanced Recovery After Surgery (ERAS) for spine surgery: a systematic review. *World Neurosurg*. 2019;130:415–426. doi:10.1016/j.wneu.2019.06.181
8. Tippireddy S, Ghatol D. Anesthetic management for Enhanced Recovery After Major Surgery (ERAS). In: *StatPearls*. StatPearls Publishing; 2023.
9. Hah JM, Bateman BT, Ratliff J, et al. Chronic opioid use after surgery: implications for perioperative management in the face of the opioid epidemic. *Anesthesia Analg*. 2017;125:1733–1740. doi:10.1213/ANE.0000000000002458
10. Kaye AD, Jones MR, Kaye AM, et al. Prescription opioid abuse in chronic pain: an updated review of opioid abuse predictors and strategies to curb opioid abuse: Part 1. *Pain Physician*. 2017;20:S93–s109. doi:10.36076/ppj.2017.s109
11. Wewers ME, Lowe NK. A critical review of visual analogue scales in the measurement of clinical phenomena. *Res Nurs Health*. 1990;13:227–236. doi:10.1002/nur.4770130405
12. Thong ISK, Jensen MP, Miró J, et al. The validity of pain intensity measures: what do the NRS, VAS, VRS, and FPS-R measure? *Scand J Pain*. 2018;18:99–107. doi:10.1515/sjpain-2018-0012
13. Edwards RR, Dworkin RH, Sullivan MD, et al. The role of psychosocial processes in the development and maintenance of chronic pain. *J Pain*. 2016;17:T70–92. doi:10.1016/j.jpain.2016.01.001
14. Alorfi NM. Pharmacological methods of pain management: narrative review of medication used. *Int J Gene Med*. 2023;16:3247–3256. doi:10.2147/IJGM.S419239
15. Tan M, Law LS, Gan TJ. Optimizing pain management to facilitate enhanced recovery after surgery pathways. *Can J Anaesthesia*. 2015;62:203–218. doi:10.1007/s12630-014-0275-x
16. Ji RR, Nackley A, Huh Y, et al. Neuroinflammation and central sensitization in chronic and widespread pain. *Anesthesiology*. 2018;129:343–366. doi:10.1097/ALN.0000000000002130
17. Costigan M, Scholz J, Woolf CJ. Neuropathic pain: a maladaptive response of the nervous system to damage. *Annu Rev Neurosci*. 2009;32:1–32. doi:10.1146/annurev.neuro.051508.135531
18. Domenichiello AF, Ramsden CE. The silent epidemic of chronic pain in older adults. *Prog Neuro Psychopharmacol Biol Psychiatry*. 2019;93:284–290. doi:10.1016/j.pnpbp.2019.04.006
19. Laganà AS, La Rosa VL, Rapisarda AMC, et al. Anxiety and depression in patients with endometriosis: impact and management challenges. *Int J Women's Health*. 2017;9:323–330. doi:10.2147/IJWH.S119729
20. Benyamin R, Trescot AM, Datta S, et al. Opioid complications and side effects. *Pain Physician*. 2008;11:S105–20. doi:10.36076/ppj.2008/11/S105
21. Colvin LA, Bull F, Hales TG. Perioperative opioid analgesia-when is enough too much? A review of opioid-induced tolerance and hyperalgesia. *Lancet*. 2019;393:1558–1568. doi:10.1016/S0140-6736(19)30430-1
22. Lyden J, Binswanger IA. The United States opioid epidemic. *Semin Perinatol*. 2019;43:123–131. doi:10.1053/j.semperi.2019.01.001

23. Kolodny A, Courtwright DT, Hwang CS, et al. The prescription opioid and heroin crisis: a public health approach to an epidemic of addiction. *Ann Rev Public Health*. 2015;36:559–574. doi:10.1146/annurev-publhealth-031914-122957

24. Hyland SJ, Brockhaus KK, Vincent WR, et al. Perioperative pain management and opioid Stewardship: a practical guide. *Healthcare*. 2021;9. doi:10.3390/healthcare9030333

25. Lee A, Cooper MG, Craig JC, et al. Effects of nonsteroidal anti-inflammatory drugs on postoperative renal function in adults with normal renal function. *Cochrane Database Syst Rev*. 2007;2007:Cd002765. doi:10.1002/14651858.CD002765.pub3

26. Albrecht E, Chin KJ. Advances in regional anaesthesia and acute pain management: a narrative review. *Anaesthesia*. 2020;75 Suppl 1:e101–e10. doi:10.1111/anae.14868

27. Horlocker TT. Complications of regional anesthesia and acute pain management. *Anesthesiol Clin*. 2011;29:257–278. doi:10.1016/j.anclin.2011.04.006

28. Graf BM, Martin E. [Peripheral nerve block. An overview of new developments in an old technique]. *Der Anaesthesist*. 2001;50:312–322. doi:10.1007/s001010170015

29. Tait RC, Zoberi K, Ferguson M, et al. Persistent post-mastectomy pain: risk factors and current approaches to treatment. *J Pain*. 2018;19:1367–1383. doi:10.1016/j.jpain.2018.06.002

30. Lingard EA, Riddle DL. Impact of psychological distress on pain and function following knee arthroplasty. *J Bone Joint Surg*. 2007;89:1161–1169. doi:10.2106/JBJS.F.00914

31. Corsonello A, Pedone C, Incalzi RA. Age-related pharmacokinetic and pharmacodynamic changes and related risk of adverse drug reactions. *Curr Med Chem*. 2010;17:571–584. doi:10.2174/092986710790416326

32. Cheymol G. Effects of obesity on pharmacokinetics implications for drug therapy. *Clin Pharmacokinet*. 2000;39:215–231. doi:10.2165/00003088-200039030-00004

33. Jensen MP, Turk DC. Contributions of psychology to the understanding and treatment of people with chronic pain: why it matters to ALL psychologists. *Am Psychol*. 2014;69:105–118. doi:10.1037/a0035641

34. Gatchel RJ, McGeary DD, McGeary CA, et al. Interdisciplinary chronic pain management: past, present, and future. *Am Psychol*. 2014;69:119–130. doi:10.1037/a0035514

35. Williamson A, Hoggart B. Pain: a review of three commonly used pain rating scales. *J Clin Nurs*. 2005;14:798–804. doi:10.1111/j.1365-2702.2005.01121.x

36. Haug SR, Marthinussen MC. Acute dental pain and salivary biomarkers for stress and inflammation in patients with pulpal or periapical inflammation. *J Oral Facial Pain Headache*. 2019;33:227–233. doi:10.11607/ofph.2007

37. Hänsel A, Hong S, Cámara RJ, et al. Inflammation as a psychophysiological biomarker in chronic psychosocial stress. *Neurosci Biobehav Rev*. 2010;35:115–121. doi:10.1016/j.neubiorev.2009.12.012

38. Hampton SN, Nakonezny PA, Richard HM, et al. Pain catastrophizing, anxiety, and depression in Hip pathology. *Bone Joint J*. 2019;101-b:800–807. doi:10.1302/0301-620X.101B7.BJJ-2018-1309.R1

39. Wood TJ, Gazendam AM, Kabali CB. Postoperative outcomes following total hip and knee arthroplasty in patients with pain catastrophizing, anxiety, or depression. *J Arthroplasty*. 2021;36:1908–1914. doi:10.1016/j.arth.2021.02.018

40. Ren H, Wang D, Ding Y, et al. Does social support moderate wound pain and health-related quality of life in patients with chronic wounds? A multicenter descriptive cross-sectional study. *J Wound Ostomy Cont Nurs*. 2021;48:300–305. doi:10.1097/WON.0000000000000767

41. Ngamkham S, Vincent C, Finnegan L, et al. The McGill Pain Questionnaire as a multidimensional measure in people with cancer: an integrative review. *Pain Manage Nurs*. 2012;13:27–51. doi:10.1016/j.pmn.2010.12.003

42. Freynhagen R, Tölle TR, Gockel U, et al. The painDETECT project - far more than a screening tool on neuropathic pain. *Curr Med Res Opin*. 2016;32:1033–1057. doi:10.1185/03007995.2016.1157460

43. Rienstra W, Blikman T, Dijkstra B, et al. Validity of the Dutch modified painDETECT questionnaire for patients with Hip or knee osteoarthritis. *Disabil Rehabil*. 2019;41:941–947. doi:10.1080/09638288.2017.1413429

44. Zeng S, Qing Q, Xu W, et al. Personalized anesthesia and precision medicine: a comprehensive review of genetic factors, artificial intelligence, and patient-specific factors. *Front Med*. 2024;11:1365524. doi:10.3389/fmed.2024.1365524

45. Bergeron D, Obaid S, Fournier-Gosselin MP, et al. Deep brain stimulation of the posterior insula in chronic pain: a theoretical framework. *Brain Sci*. 2021;11:639. doi:10.3390/brainsci11050639

46. Kumar S, Pandey D, Chandra S. Revolutionizing biofeedback and beyond: a journey through the evolving landscape of biomechanics. *Biochem Cell Arch*. 2023;23:1625–1639.

47. Chu YC, Chen SS, Chen KB, et al. Enhanced labor pain monitoring using machine learning and ECG waveform analysis for uterine contraction-induced pain. *BioData Min*. 2024;17:32. doi:10.1186/s13040-024-00383-z

48. Nathwani D, Shenoy R. Latest advances in robot-assisted knee arthroplasty. *Surg Technol Int*. 2021;39:331–337. doi:10.52198/21.STI.39.OS1423

49. O'Neill A, Lirk P. Multimodal Analgesia. *Anesthesiol Clin*. 2022;40:455–468. doi:10.1016/j.anclin.2022.04.002

50. Vadivelu N, Mitra S, Kaye AD, et al. Perioperative analgesia and challenges in the drug-addicted and drug-dependent patient. *Best Pract Res Clin Anaesth*. 2014;28:91–101. doi:10.1016/j.bpa.2014.02.003

51. Varrassi G, Pergolizzi JV, Dowling P, et al. Ibuprofen safety at the golden anniversary: are all NSAIDs the same? A narrative review. *Adv Ther*. 2020;37:61–82. doi:10.1007/s12325-019-01144-9

52. Bailard NS, Ortiz J, Flores RA. Additives to local anesthetics for peripheral nerve blocks: evidence, limitations, and recommendations. *Am J Health Syst Pharm*. 2014;71:373–385. doi:10.2146/ajhp130336

53. Wren AA, Neiman N, Caruso TJ, et al. Mindfulness-based virtual reality intervention for children and young adults with inflammatory bowel disease: a pilot feasibility and acceptability study. *Children*. 2021;8:368. doi:10.3390/children8050368

54. Gloth MJ, Matesi AM. Physical therapy and exercise in pain management. *Clin Geriatr Med*. 2001;17:525–35, vii. doi:10.1016/S0749-0690(05)70084-7

55. Kaye AD, Granier AL, Garcia AJ, et al. Non-opioid perioperative pain strategies for the clinician: a narrative review. *Pain ther*. 2020;9:25–39. doi:10.1007/s40122-019-00146-3

56. Wiederhold BK, Gao K, Sulea C, et al. Virtual reality as a distraction technique in chronic pain patients. *Cyberpsychol Behav Soc Netw*. 2014;17:346–352. doi:10.1089/cyber.2014.0207

57. Indovina P, Barone D, Gallo L, et al. Virtual reality as a distraction intervention to relieve pain and distress during medical procedures: a comprehensive literature review. *Clin J Pain*. 2018;34:858–877. doi:10.1097/AJP.0000000000000599

58. Wang EJ, Berninger LE, Komargodski O, et al. Painful diabetic neuropathy - spinal cord stimulation, peripheral nerve stimulation, transcutaneous electrical nerve stimulation, and scrambler therapy: a narrative review. *Pain Physician*. 2022;25:E1163–e73.

59. Momeni M, Crucitti M, De Kock M. Patient-controlled analgesia in the management of postoperative pain. *Drugs*. 2006;66:2321–2337. doi:10.2165/00003495-200666180-00005

60. Tai YH, Wu HL, Lin SP, et al. An investigation of the effect of patient-controlled analgesia on long-term quality of life after major surgery: a prospective cohort study. *J Chin Med Assoc*. 2020;83:194–201. doi:10.1097/JCMA.0000000000000241

61. Horlocker TT, Vandermeuelen E, Kopp SL, et al. Regional anesthesia in the patient receiving antithrombotic or thrombolytic therapy: American Society of Regional Anesthesia and Pain Medicine Evidence-Based Guidelines (Fourth Edition). *Reg Anesth Pain Med*. 2018;43:263–309.

62. Zhang L, Qiu Y, Zhang ZF, et al. Current perspectives on postoperative cognitive dysfunction in geriatric patients: insights from clinical practice. *Front Med*. 2024;11:1466681. doi:10.3389/fmed.2024.1466681

63. Del Tedesco F, Sessa F, Xhemalaj R, et al. Perioperative analgesia in the elderly. *Saudi J Anaesth*. 2023;17:491–499. doi:10.4103/sja.sja_643_23

64. Cheng CM, Chiu MJ, Wang JH, et al. Cognitive stimulation during hospitalization improves global cognition of older Taiwanese undergoing elective total knee and Hip replacement surgery. *J Adv Nurs*. 2012;68:1322–1329. doi:10.1111/j.1365-2648.2011.05842.x

65. van Dijk JFM, Zaslansky R, van Boekel RLM, et al. Postoperative pain and age: a retrospective cohort association study. *Anesthesiology*. 2021;135:1104–1119. doi:10.1097/ALN.0000000000004000

66. Louras M, Vanhaudenhuyse A, Panda R, et al. Virtual reality combined with mind-body therapies for the management of pain: a scoping review. *Int J Clin Exp Hypn*. 2024;72:435–471. doi:10.1080/00207144.2024.2391365

67. Du D, Li H, Xu Y, et al. Study on the effect of pain programmed care based on the concept of prehabilitation on the recovery of joint function and WHOQOL-BREF score in elderly patients after total hip arthroplasty. *Altern Ther Health Med*. 2023;29:618–623.

68. Tonnesen H, Lydom LN, Joensen UN, et al. STRONG for Surgery & Strong for Life - against all odds: intensive prehabilitation including smoking, nutrition, alcohol and physical activity for risk reduction in cancer surgery - a protocol for an RCT with nested interview study (STRONG-Cancer). *Trials*. 2022;23:333. doi:10.1186/s13063-022-06272-2

69. Debono B, Wainwright TW, Wang MY, et al. Consensus statement for perioperative care in lumbar spinal fusion: enhanced Recovery After Surgery (ERAS®) Society recommendations. *Spine J*. 2021;21:729–752. doi:10.1016/j.spinee.2021.01.001

70. Gottschalk A, Cohen SP, Yang S, et al. Preventing and treating pain after thoracic surgery. *Anesthesiology*. 2006;104:594–600. doi:10.1097/00000542-200603000-00027

71. Puntillo F, Giglio M, Varrassi G. The routes of administration for acute postoperative pain medication. *Pain Ther*. 2021;10:909–925. doi:10.1007/s40122-021-00286-5

72. Abbasnia F, Aghebati N, Miri HH, et al. Effects of patient education and distraction approaches using virtual reality on pre-operative anxiety and post-operative pain in patients undergoing laparoscopic cholecystectomy. *Pain Manage Nurs*. 2023;24:280–288. doi:10.1016/j.pmn.2022.12.006

73. Huang L, Zhang T, Wang K, et al. Postoperative multimodal analgesia strategy for enhanced recovery after surgery in elderly colorectal cancer patients. *Pain Ther*. 2024;13:745–766. doi:10.1007/s40122-024-00619-0

74. Dong W, Peng Y, Chen G, et al. 2-O-β-D-Glucopyranosyl-L-ascorbic acid, an ascorbic acid derivative isolated from the fruits of Lycium barbarum L. ameliorates high fructose-induced neuroinflammation in mice: involvement of gut microbiota and leaky gut. *Food Sci Hum Well*. 2024;13:241–253. doi:10.26599/FSHW.2022.9250020

75. Wichmann MW, Roth M, Jauch KW, et al. A prospective clinical feasibility study for multimodal "fast track" rehabilitation in elective pancreatic cancer surgery. *Rozhledy v chirurgii*. 2006;85:169–175.

76. Malik A, Elshazly T, Pokuri K, et al. Virtual reality for postoperative pain management: a review of current evidence. *Curr Pain Headache Rep*. 2024;28:1307–1319. doi:10.1007/s11916-024-01308-5

77. Hall RW, Anand KJ. Pain management in newborns. *Clin Perinatol*. 2014;41:895–924. doi:10.1016/j.clp.2014.08.010

78. Li JW, Ma YS, Xiao LK. Postoperative pain management in total knee arthroplasty. *Orthop Surg*. 2019;11:755–761. doi:10.1111/os.12535

79. Schug SA, Raymann A. Postoperative pain management of the obese patient. *Best Pract Res Clin Anaesth*. 2011;25:73–81. doi:10.1016/j.bpa.2010.12.001

80. Cozowicz C, Poeran J, Zubizarreta N, et al. Non-opioid analgesic modes of pain management are associated with reduced postoperative complications and resource utilisation: a retrospective study of obstructive sleep apnoea patients undergoing elective joint arthroplasty. *Br J Anaesth*. 2019;122:131–140. doi:10.1016/j.bja.2018.08.027

81. Hanna M, Montero Matamala A, Perrot S, et al. Delivery of multimodal analgesia to effectively treat acute pain: a review from Roma Pain Days. *Cureus*. 2022;14:e22465. doi:10.7759/cureus.22465

82. Vallejo MC, Kumaraswami S, Zakowski MI. American Society of Anesthesiologists 2023 guidance on neurologic complications of neuraxial analgesia/anesthesia in obstetrics. *Anesthesiology*. 2024;140:1235–1236. doi:10.1097/ALN.0000000000004967

83. Dong J, Lei Y, Wan Y, et al. Enhanced recovery after surgery from 1997 to 2022: a bibliometric and visual analysis. *Updates Surg*. 2024;76:1131–1150. doi:10.1007/s13304-024-01764-z

84. Fillingim RB. Individual differences in pain: understanding the mosaic that makes pain personal. *Pain*. 2017;158 Suppl 1:S11–S8. doi:10.1097/j.pain.0000000000000775

85. Chakraborty S. Democratizing nucleic acid-based molecular diagnostic tests for infectious diseases at resource-limited settings – from point of care to extreme point of care. *Sens Diagn*. 2024;3:536–561. doi:10.1039/D3SD00304C

86. Nelson TA, Anderson B, Bian J, et al. Planning for patient-reported outcome implementation: development of decision tools and practical experience across four clinics. *J Clin Transl Sci*. 2020;4:498–507. doi:10.1017/cts.2020.37

87. Vitali D, Olugbade T, Eccleston C, et al. Sensing behavior change in chronic pain: a scoping review of sensor technology for use in daily life. *Pain*. 2024;165:1348–1360. doi:10.1097/j.pain.0000000000003134

88. El-Boghdadly K, Levy NA, Fawcett WJ, et al. Peri-operative pain management in adults: a multidisciplinary consensus statement from the Association of Anaesthetists and the British Pain Society. *Anaesthesia*. 2024;79:1220–1236. doi:10.1111/anae.16391

89. Smith BW, Meyer WJ. Acute stress disorder and post-traumatic stress disorder in individuals suffering from burn injury. In: Kamolz L-P, Jeschke MG, Horch RE, Küntscher M, Brychta P, editors. *Handbook of Burns Volume 2: Reconstruction and Rehabilitation*. Cham: Springer International Publishing; 2020:3–13.

90. Chen VE, Greenberger BA, Shi Z, et al. Post-mastectomy and post-breast conservation surgery pain syndrome: a review of etiologies, risk prediction, and trends in management. *Transl Cancer Res*. 2020;9:S77–s85. doi:10.21037/tcr.2019.06.46

91. Wang D, Guo Y, Yin Q, et al. Analgesia quality index improves the quality of postoperative pain management: a retrospective observational study of 14,747 patients between 2014 and 2021. *BMC Anesthesiol*. 2023;23:281. doi:10.1186/s12871-023-02240-8

92. Aqajari SAH, Cao R, Kasaeyan Naeini E, et al. Pain assessment tool with electrodermal activity for postoperative patients: method validation study. *JMIR mHealth uHealth*. 2021;9:e25258. doi:10.2196/25258

93. Nelson G, Kiyang LN, Crumley ET, et al. Implementation of Enhanced Recovery After Surgery (ERAS) across a provincial healthcare system: the ERAS Alberta colorectal surgery experience. *World J Surg*. 2016;40:1092–1103. doi:10.1007/s00268-016-3472-7