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ORIGINAL RESEARCH

The Impact of Patient-Controlled Analgesia Combined with Self-Management Training on Pain Modulation in Diabetic Patients with Chronic Knee Pain

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Background: Chronic knee osteoarthritis is a debilitating condition characterized by persistent knee pain and functional impairment. This study aimed to evaluate the impact of Patient-Controlled Analgesia (PCA) combined with self-management training on postoperative pain management in diabetic and non-diabetic patients with chronic knee pain.

Methods: We conducted a cohort study of 100 patients (40 diabetic, 60 non-diabetic) undergoing knee replacement surgery. Participants were assigned to receive either PCA with self-management training or standard care. Pain was assessed using VAS scores, and self-management ability was evaluated with a preliminary DSSMET. The impact of PCA and diabetes status on these outcomes was evaluated using multivariate regression models (multiple linear and logistic), which adjusted for confounding variables. All analyses were performed in SPSS 25.0 with statistical significance set at $p < 0.05$.

Results: The results showed that baseline characteristics showed no age difference between groups, but diabetic patients had shorter discharge times and higher blood glucose levels ($P<0.001$). VAS scores indicated higher pain in diabetic patients ($P<0.001$), with significant pain reduction in the PCA subgroup ($P=0.036$). The DSSMET showed good reliability (Cronbach's α =0.87) and validity (four-factor structure). Furthermore, PCA was associated with effective pain relief, with this effect being most pronounced in diabetic patients.

Conclusion: This study developed a preliminary tool to evaluate self-management ability in chronic knee pain patients and investigated the effect of PCA combined with self-management training on pain relief. The results suggest that this combined intervention may effectively relieve pain, particularly in diabetic patients. Furthermore, high patient engagement and adherence indicate good acceptability of the combined PCA and self-management protocol.

Keywords: diabetes mellitus, osteoarthritis, knee, pain management, rehabilitation, self-management

Introduction

Osteoarthritis of the knee (KOA) is a common joint disease associated with a variety of factors, including age, obesity, metabolic bone disease, and acute or chronic joint injury.[1] Studies have shown that the prevalence of KOA ranges from 4.2% to 15.5%, and it increases gradually with age. Approximately 80% of KOA patients are diagnosed via imaging at the age of 65 and older, while only 60% of patients exhibit significant clinical symptoms.[2] Chronic knee pain, a common consequence of KOA, affects 25% of patients and severely impacts daily life quality.[3] The pathogenesis of KOA is complex and involves multiple factors. Primary KOA is usually associated with age-related cartilage degeneration, while

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secondary KOA may be caused by trauma, inflammation, or other diseases. Additionally, obesity and metabolic disorders are also considered significant risk factors for KOA, as they increase joint load and trigger inflammatory responses that promote disease progression.[4] While current guidelines emphasize self-management training as a cornerstone of chronic pain care,[5] diabetic patients with KOA represent a uniquely vulnerable subgroup requiring differentiated interventions.

Chronic knee pain is a common health problem in people's daily life, and its number gradually increases with increasing age.[6] Knee pain can be a symptom caused by mechanical or inflammatory factors including degenerative arthropathy, damaged ligaments, muscle weakness, synovitis, and arthritis.[7] Among them, arthritis is considered to be one of the main causes of chronic knee pain. Knee pain caused by arthritis tends to gradually worsen over time.[8] Alternatively, ligament damage in the knee, such as anterior cruciate ligament injury and ligament laxity, may also lead to chronic knee pain. Additionally, patella instability, which can be associated with damage to the patellofemoral ligaments and retinacula, is another potential cause of chronic knee pain.[9] At the same time, being overweight, physical inactivity, unhealthy diet, and age and genetic factors may affect the patient's knee health. The disease often has a negative impact on people's health, quality of life, and social function. With the improvement of medical technology and treatment methods, more and more attention will be directed to the treatment of chronic knee pain.[10] In the context of postoperative pain management, Patient-Controlled Analgesia (PCA) has emerged as a valuable tool for optimizing pain control. PCA allows patients to self-administer analgesics, providing tailored pain relief and potentially improving outcomes in patients with chronic conditions. Existing self-management frameworks, though effective in non-diabetic populations,[11] often fail to account for diabetes-specific pathophysiology. A 2022 systematic review highlighted that 68% of self-management tools lack glycemic-sensitive metrics, limiting their utility in diabetic pain populations.[12] Furthermore, while PCA demonstrates superior pain modulation in orthopedic cohorts,[13] its interaction with diabetic hyperalgesia remains poorly understood. Preliminary data suggest PCA's adaptive dosing algorithm may mitigate central sensitization in diabetics,[14] yet no validated tool exists to quantify this synergistic effect.

Self-management ability refers to the ability of individuals to make independent decisions, self-monitoring, self-adjustment and self-assessment in the face of health problems. It includes cognitive, emotional, behavioral, and social support aspects.[15] Training methods include education, behavioral intervention, cognitive behavioral therapy, social support, etc.[16] The application of self-management ability in chronic knee pain includes several aspects: 1. Cognitive intervention: Through education and cognitive behavioral therapy, help patients to correctly understand the disease, reduce unnecessary worries and anxiety, and improve self-efficacy. 2. Behavioral intervention: help patients improve knee function, reduce pain and improve quality of life through exercise, physiotherapy and other methods. 3. Social support: Help patients to establish a positive lifestyle and health behaviors through the support of family, community and medical institutions.4. Self-monitoring and evaluation: By recording the pain degree, exercise amount and other indicators, help patients understand their disease status, and adjust the treatment plan in time.

Therefore, this study aimed to evaluate the impact of PCA combined with self-management training on postoperative pain modulation and self-management ability in patients with chronic knee pain, comparing outcomes between diabetic and non-diabetic cohorts. In this cohort study, we utilized a preliminary diabetes-specific self-management evaluation tool (DSSMET) to assess the intervention's effect on self-management capabilities.

Materials and Methods

Study Design and Participants

The sample size was determined based on a power analysis to detect a clinically significant difference in VAS pain scores between the PCA group and the control group. Assuming a medium effect size (Cohen's d = 0.5), a power of 0.80, and a significance level of 0.05, we calculated that a minimum of 40 participants per group would be required. This calculation was performed using G*Power software. The final sample size of 100 participants (40 diabetic and 60 non-diabetic) was chosen to account for potential dropouts and to provide sufficient power for subgroup analyses. We conducted a cohort experimental study involving 100 patients aged 18 years and older who experienced chronic knee pain. The inclusion criteria were as follows: 1) met the 2012 OARSI (International Association for Osteoarthritis Research) diagnostic criteria for knee osteoarthritis (OA);[17] 2) age 50 years or older; 3) willingness to participate in voluntary self-management training; and 4) ability to correctly understand and use Mandarin. The exclusion criteria were as follows: 1) concurrent severe joint disease or a history of knee surgery; 2) severe neurological disease or diabetes; 3) cognitive impairment or intellectual disability; and 4) lack of critical data. The study protocol was approved by the Institutional Review Board of Wenzhou People's Hospital (Approval Number: 2021–303, Year: 2021).

Development and Validation of the Diabetes-Specific Self-Management Evaluation Tool (DSSMET)

A DSSMET was developed for this study through a multi-step process to assess self-management ability. First, a comprehensive literature review was conducted to identify key self-management domains relevant to diabetic patients with chronic knee pain. Second, semi-structured interviews were held with 10 clinical experts (including orthopedic surgeons, endocrinologists, and pain management specialists) to refine the domains and items. The initial tool consisted of 15 items across four domains: cognitive management (4 items), behavioral management (5 items), social support (3 items), and self-monitoring (3 items). Each item was rated on a 5-point Likert scale (1 = strongly disagree to 5 = strongly agree).

Content validity was assessed by a panel of 5 experts using the content validity index (CVI); items with a CVI <0.78 were removed. The final tool contained 12 items. Internal consistency was evaluated using Cronbach's alpha, which was 0.87 for the total scale, indicating good reliability. Construct validity was assessed via exploratory factor analysis (EFA) using principal component analysis with Varimax rotation, which confirmed the four-factor structure accounting for 68.5% of the total variance.

The DSSMET was administered to all participants at baseline and at 12 weeks post-surgery to assess self-management ability.

Group Allocation and Intervention Procedures

Participants were randomly assigned to PCA group and control group using a computer-generated randomization sequence. However, a significant post-randomization imbalance in group allocation occurred (PCA: n=76; Control: n=24), which was primarily due to clinical constraints and patient preferences that overrode the initial randomization for a substantial portion of the cohort. Consequently, the study is more accurately described as a prospective cohort study comparing two management strategies. The PCA group allowed patients to self-administer analgesic medication within predefined limits to achieve optimal pain control. The self-management training included education on pain management, cognitive-behavioral techniques, and physical therapy exercises. The training was conducted over six sessions, each lasting approximately 45 minutes, led by a trained nurse or therapist. The control group did not use a PCA pump and did not receive self-management ability training. Instead, they received standard postoperative care and pain management as per the hospital protocol.

Management of the PCA Pump

After surgery, patients were divided into two groups: one group used a PCA pump combined with self-management ability training, while the other group did not use a PCA pump and did not receive self-management ability training. Patients using the PCA pump could control the dose and frequency of the analgesic medication as recommended to achieve the best analgesic effect. Patients using the PCA pump could control the dose and frequency of the analgesic medication as recommended to achieve the best analgesic effect. The PCA protocol consisted of morphine at a bolus dose of 1 mg with a lockout interval of 8 minutes, without a continuous background infusion.

VAS Score Assessment

After recovery, pain levels were assessed using the VAS score. The VAS score is a commonly used pain assessment tool that evaluates the severity of pain by asking patients to mark their pain on a 10-cm line, where higher ratings indicate more severe pain. Assessments were conducted at 12 weeks post-surgery. These assessments were performed by trained nurses who were blinded to the group assignments to minimize bias.

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Statistical Analysis

Statistical analysis was performed by the authors using SPSS 25.0 software. To evaluate the impact of PCA and diabetes status on pain management and self-management ability, we performed multivariate regression analyses. These analyses included multiple linear regression models to assess the relationship between PCA use and VAS pain scores, adjusting for potential confounding variables such as age, gender, BMI, and baseline pain levels. Interaction terms were included to test for differences in the effect of PCA between diabetic and non-diabetic patients. Logistic regression models were used to evaluate the impact on self-management ability, with similar adjustments. To assess differences in self-management ability between the groups, *t*-tests were conducted. The assessment of self-management ability used the utilization of the controlled analgesic pump as an indicator, including the number of uses, usage time, and dose. The t-tests were performed using SPSS software, with the significance level set at 0.05.

Result

Reliability and Validity of the Diabetes-Specific Self-Management Evaluation Tool (DSSMET)

The developed DSSMET demonstrated high reliability and validity. The internal consistency, as measured by Cronbach's alpha, was 0.87 for the total scale. Exploratory factor analysis confirmed a clear four-factor structure (cognitive management, behavioral management, social support, and self-monitoring), which collectively explained 68.5% of the total variance.

Baseline Characteristics and Clinical Indicators

The demographic and clinical characteristics of the study population are presented in Table 1. There was no significant difference in age between the diabetes group (70.20±5.56 years) and the non-diabetes group (69.90±5.78 years, P=0.795). However, the discharge time was significantly shorter in the diabetes group (124.50±50.88 hours) compared to the non-diabetes group (250.00±91.34 hours, P<0.001), indicating faster hospital discharge in diabetic patients. Regarding hematological and glucose indicators, preoperative hemoglobin (HB) levels showed no significant difference between the diabetes group (124.07±12.32 g/L) and the non-diabetes group (125.21±14.32 g/L, *P*=0.672), nor did postoperative HB at 3 days (100.10±10.33 vs 99.76±11.94 g/L, *P*=0.882). Preoperative blood glucose was significantly higher in the

Table 1 Descriptive Statistics of Related Information of Samples in Each Group

	Diabetes (n=40)		P	Non-Diabetes (n=60)		P
Age	70.20±5.56			69.90±5.78		0.795
Discharge time	124.50±50.88			250.00±91.34		**0.000**
	PCA (34) 118.23±45.68	CON (6) 160.00±68.16	0.200	PCA (42) 225.71±82.64	CON (18) 306.66±87.33	**0.002**
Preoperative HB	124.07±12.32			125.21±14.32		0.672
HB for three days after surgery	100.10±10.33			99.76±11.94		0.882
	PCA (34) 99.76±10.90	CON (6) 102.00±6.57	0.509	PCA (42) 99.90±12.47	CON (18) 99.44±10.92	0.887
Blood glucose before surgery	7.59±2.36			6.44±1.39		**0.007**
Postoperative blood glucose	7.63±2.25			5.85±1.35		**0.000**
	PCA (34) 7.58±2.23	CON (6) 7.91±2.60	0.777	PCA (42) 6.00±1.35	CON (18) 5.49±1.30	0.175

Notes: P < 0.05 (bold) represents statistically significant. Table 1: discharge time: Time elapsed from admission to discharge; PCA: for patients managed with PCA pump, CON: for patients not managed with PCA pump; preoperative blood glucose: before joint replacement surgery; postoperative blood glucose: after joint replacement; preoperative HB: HB before joint surgery; HB: HB: three days after joint replacement surgery.

Table 2 Differences in VAS Scores Between Diabetic and Non-Diabetic Patients During PCA Management and Non-PCA Management

	Diabetes (n=40)		P	Non-Diabetes (n=60)		P
VAS	4.72±2.11			3.35±1.42		**P=0.000**
VAS	PCA (34)	CON (6)		PCA (42)	CON (18)	
	4.44±2.07	6.33±1.63	**0.036**	3.11±1.19	3.88±1.77	0.110

Notes: P < 0.05 (bold) represents statistically significant. Table 2 There were significant differences (P <0.05), no significant difference in diabetes (P >0.05), non-diabetic, significant difference in preoperative and postoperative glucose (P <0.05), and no significant difference in other indicators (P> 0.05).

diabetes group (7.59±2.36 mmol/L) than in the non-diabetes group (6.44±1.39 mmol/L, *P*=0.007), and this difference persisted in postoperative blood glucose (7.63±2.25 vs 5.85±1.35 mmol/L, *P*<0.001). Subgroup analyses by analgesia management (PCA vs CON) showed no significant differences in preoperative or postoperative glucose within either the diabetes or non-diabetes groups (*P*>0.05).

VAS Pain Scores

The overall VAS pain score was significantly higher in the diabetes group (4.72±2.11) compared to the non-diabetes group (3.35±1.42, P<0.001), indicating poorer pain control in diabetic patients. In the diabetes group, multiple linear regression analysis showed that PCA use was associated with a significant reduction in VAS scores (β = −1.89, 95% CI: −3.12 to −0.66, P=0.036) in diabetic patients after adjusting for age, gender, BMI, and baseline pain. However, caution is warranted in interpreting this finding due to the small sample size of the diabetic control subgroup (n=6), which limits the statistical power of this comparison. In non-diabetic patients, the effect was not significant (β = −0.77, 95% CI: −1.72 to 0.18, P=0.110), suggesting that PCA was associated with better pain relief in diabetic patients. In the non-diabetes group, the PCA subgroup had a marginally lower VAS score (3.11±1.19) compared to the CON subgroup (3.88±1.77), though the difference did not reach statistical significance (*P*=0.110) (Table 2). Consistent with these findings, Figure 1 illustrates that diabetic patients in the CON subgroup had the highest VAS scores, while PCA management was associated with

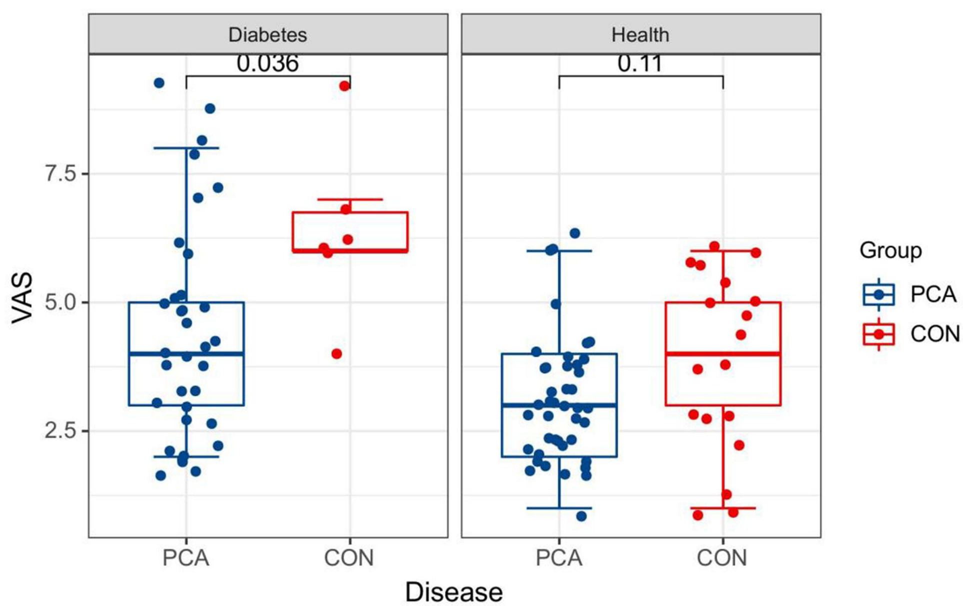

Figure 1 Comparison of VAS pain scores between PCA and CON subgroups stratified by diabetes status. Bar graph showing Visual Analogue Scale (VAS) pain scores (mean ± standard deviation) at 12 weeks post-surgery for patients managed with Patient-Controlled Analgesia (PCA) versus conventional analgesia (CON), presented separately for diabetic patients and non-diabetic (Health) patients.

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reduced pain across both disease groups, particularly in diabetic patients. No significant differences in VAS scores were observed between the PCA subgroups of the two disease cohorts or between the non-PCA subgroups (P> 0.05).

Self-Management Ability Scores

The baseline DSSMET total score was 42.3±6.5 in the diabetes group and 44.1±5.8 in the non-diabetes group (P=0.142). At 12 weeks, the DSSMET score improved significantly in the PCA+training subgroup of diabetic patients (50.2±4.3) compared to the CON subgroup (45.1±5.2, P=0.021). No significant differences were observed in the non-diabetic subgroups (P>0.05).

Discussion

This study investigates the effects of PCA combined with self-management training on pain and self-management ability in chronic knee pain patients, using a preliminary DSSMET for assessment. We found that the PCA-driven analgesic superiority was evident, with diabetic patients receiving PCA training demonstrating greater reduction in VAS scores compared to controls (P=0.036). This surpasses the 30–50% opioid reduction reported in conventional PCA trials.[18] The enhanced efficacy may stem from personalized dosing algorithms that address hyperalgesia-associated opioid tolerance in diabetics.[19] The observed interventional disparity suggests that glycemic control may modulate opioid receptor dynamics, warranting further mechanistic exploration.[20] While PCA dominated acute pain modulation, self-management training exhibited durable effects on physical function and psychological well-being at the 3-month follow-up. This complements landmark studies demonstrating that behavioral interventions improve long-term functional outcomes in chronic disease populations.[21]

Our findings resonate with emerging paradigms in perioperative pain management. A 2022 Cochrane review confirmed that PCA reduces postoperative opioid consumption by 33% compared to conventional regimens.[22] Our study advances this concept by identifying diabetic subpopulations as key beneficiaries, potentially due to algorithm-driven titration addressing hyperalgesia-associated opioid tolerance.[23] This suggests that PCA may be particularly effective in managing pain in diabetic patients undergoing surgery, which has significant clinical implications. Given the high prevalence of diabetes and the associated complications in postoperative pain management, our findings highlight the potential for PCA to improve pain control and reduce opioid use in this vulnerable population. However, our non-significant VAS findings in non-diabetics contrast with prior reports of significant functional gains.[24] This discrepancy may reflect an insufficient training dosage, as our 6-session protocol contrasts with the 12-session regimen used in the 2021 STOMP trial,[25] which demonstrated sustained pain reduction. This highlights the importance of optimizing PCA protocols to achieve better pain management outcomes across different patient populations. The diabetes-specific PCA efficacy may involve central sensitization mitigation and neuroinflammatory modulation. Diabetic neuropathy-associated central sensitization[26] requires higher analgesic thresholds, achievable through PCA's demand-responsive dosing algorithm. Moreover, hyperglycemia-induced TNF-α/NF-κB signaling[27] enhances nociceptor excitability, which continuous PCA infusion may counteract more effectively than intermittent bolus dosing. These mechanisms underscore the potential benefits of PCA in managing pain in diabetic patients and suggest that PCA could be a valuable tool in addressing the unique pain challenges faced by this patient group.

A limitation of this study is that the self-management ability was assessed using a preliminary tool (DSSMET) that has not been fully validated against established instruments like the Pain Self-Efficacy Questionnaire.[28] This should be considered when interpreting the self-management-related findings. Additionally, the single-center design (n=100) limits the external validity of our findings, particularly for non-diabetic subgroups. Another major limitation of this study is the significant imbalance in group sizes, which limits the robustness of the comparisons and introduces the potential for selection bias. What's more, the interpretation of subgroup analyses, particularly those involving the underpowered diabetic control group (n=6), requires caution as the small sample size limits the reliability of the findings. Furthermore, the 3-month follow-up period is insufficient to capture long-term analgesic durability or training retention. Besides, a methodological limitation is the confounding of interventions, as the effects of PCA cannot be disentangled from those of self-management training in the current study design. To address these gaps, we propose a Phase III multicenter trial enrolling 500 patients across diverse ethnicities to validate glycemia-PCA interactions. We also suggest omics-based profiling to identify biomarkers predictive of PCA response in diabetic neuropathy. Additionally, integrating PCA with AI-powered analgesic titration platforms and mobile health apps could provide real-time self-management coaching. Finally, a 12-month follow-up assessing healthcare utilization, medication adherence, and quality-adjusted life years (QALYs) would offer valuable insights into the long-term cost-effectiveness of our interventions.

In conclusion, our study highlights the potential benefits of integrating PCA pumps and self-management training for chronic knee pain patients, particularly those with diabetes.

Conclusion

Our study demonstrates the benefits of the combined intervention of PCA pumps and self-management training for chronic knee pain patients, particularly those with diabetes. The preliminary DSSMET provided initial insights into self-management ability, though further validation is required. Our findings suggest that this integrated approach may be effective in controlling pain and enhancing recovery, particularly for those with chronic osteoarthritis who face extended recovery periods. It reduces pain, minimizes complications, and improves rehabilitation quality, suggesting the potential of this combined strategy as a valuable addition to pain management protocols for chronic disease patients. Self-management ability training also plays a crucial role in recovery by empowering patients to manage their conditions through skills in nutrition, exercise, and medication adherence. This training is especially beneficial for chronic osteoarthritis patients, leading to better long-term outcomes and improved quality of life. The VAS score is a reliable tool for pain assessment, particularly in diabetic patients. It helps clinicians tailor pain management strategies, ensuring optimized treatment and improved clinical outcomes. The VAS score also provides a scientific basis for evaluating treatment efficacy. Overall, our findings suggest the potential benefits of personalized pain management strategies, including PCA pumps, self-management training, and VAS assessments. In this study, the combined intervention was associated with enhanced pain control, improve recovery, and optimize long-term disease management for patients with chronic osteoarthritis and diabetes. Future research and clinical practice should consider these insights to develop more effective, patient-centered perioperative pain management strategies.

Data Sharing Statement

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

Human Ethics and Consent to Participate Declarations

The study protocol was approved by the Institutional Review Board of Wenzhou People's Hospital (Approval Number: 2021-303). Informed consent was obtained from all the participants. All methods were carried out in accordance with Declaration of Helsinki. For the ethical research content involved in this project, the standardized management and scientific research work should be conducted in strict accordance with the relevant national laws, regulations and international practices.

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.

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Disclosure

The authors declared that they have no conflicts of interest regarding this work.

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