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Consensus Summary on the Clinical Application of Patient-Controlled Analgesia for Pain Management in China

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Abstract

Patient-Controlled Analgesia (PCA) has been shown to alleviate neurological damage and inflammatory stress response, and reduce acute pain. The implementation of PCA requires specialized PCA pumps, which have undergone continual development and improvement over the past 30 years. With the rapid advancement of computer-network-intelligent technologies in clinical medicine, China has research and development an intelligent 8Analgesic pumps system, named Artificial Intelligence PCA (Ai-PCA). This system significantly enhances the precision, reliability, and safety of PCA pain management. However, challenges remain due to the significant individual differences in pain perception, the variety of analgesic drug administration schemes, and the less than satisfactory treatment satisfaction. Experts in anesthesiology and pain medicine have been invited to compile the “Consensus summary on the clinical application of patient-controlled analgesia for pain management in China;” to provide guidance for clinical physician.

Keywords

Analgesia patient-controlled, Pain, Postoperative, Standardization, Consensus

Introduction

The consensus, spearheaded by Guangzhou First People's Hospital and authored on behalf of the Expert Working Group of the Chinese Society of Anesthesiology, involved 46 experts nationwide who participated in voting via a Tencent QR code-based questionnaire system. The voting process was used to establish the strength of recommendations for the Expert Consensus on the Clinical Application of Patient-Controlled Analgesia. The results showed that 100% of the experts participated in the QR code-based voting, selecting either "agree" or "disagree." Three experts (6.5%) abstained by selecting "unknown" or "unsure" for certain options. However, after the voting, all experts (100%) agreed to endorse the results generated through this QR code-based voting process for the Expert Consensus on the Clinical Application of Patient-Controlled Analgesia. In 2020, the International Association for the Study of Pain (IASP) revised its definition of pain. The updated definition states: “Pain is an unpleasant sensory and emotional experience associated with, or resembling that associated with, actual or potential tissue damage” [1]. Pain is inherently a subjective experience, influenced to varying degrees by biological, psychological, and social factors. Pain can be categorized into acute pain and chronic pain. Almost all surgical procedures result in tissue and nerve damage as well as inflammatory responses, which subsequently activate nociceptors and produce varying degrees of pain. Pain stress may lead to a series of disturbances and dysfunctions in respiratory, circulatory, endocrine, and metabolic functions, thereby affecting surgical outcomes and postoperative recovery [2]. Patient-controlled analgesia (PCA) is a technique in which healthcare providers preset the dosage of analgesic medication based on the patient's pain level and physical condition using a PCA device. This allows patients to manage their own pain, potentially alleviating stress and inflammatory responses caused by surgical trauma, thereby reducing perioperative discomfort and accelerating postoperative recovery [3-10].

Origin and Development of PCA

In the early 1970s, Sechzer introduced the principle of demand-based analgesia for PCA, which allows patients to self-administer analgesics by pressing a bolus button on a PCA pump, adjusted to their pain level and need, based on the medication prepared by healthcare providers. With the integration of computer technology and medicine, Grasbus produced the first PCA pump (The Cardiff Palliator) in 1976 [11].

The concept of PCA was introduced to mainland China in 1993, and electronic analgesia pumps were implemented in 1994. The PCA pump administers analgesics through a microcomputer-controlled infusion pump with a safety control system. Anesthesiologists pre-program the dosage and regimen, and patients can self-administer the medication by pressing a button when they experience pain. Over the past 30 years, the development of PCA pumps has evolved with technological advancements, and the introduction of intelligent PCA pumps, driven by computer technology, has significantly improved the precision, reliability, and safety of PCA treatment [12].

Definition and Advantages of PCA

Definition of PCA

PCA refers to a specialized micro-infusion device controlled by a computer, connected to the patient through tubing, which continuously delivers analgesics at a specified rate. The device is usually equipped with a self-controlled button, allowing patients to increase the dose when they experience heightened pain. Anesthesiologists adjust the continuous infusion rate, single bolus dose, and lockout time [13].

Types of PCA pumps

There are three commonly used PCA pumps in clinical practice: disposable mechanical infusion pumps, electronic programmable infusion pumps, and network-managed (smart) infusion pumps [14].

Advantages of PCA

PCA is primarily used in the management of acute and chronic pain, including postoperative pain, labor pain, cancer pain, and pain management for critically ill adult patients [15-18]. Following the principle of "pain relief on demand," PCA addresses the analgesic needs of different patients at varying times and pain intensities, making it an effective tool to reduce the individual variability of pain management and increase patient satisfaction [19].

Consensus Development Methods and Basis

Relevant literature on PCA technology, clinical applications, and perioperative management were retrieved from PubMed, Embase, Web of Science, Chemical Abstracts Service (CAS), Wan fang Data, China National Knowledge Infrastructure (CNKI), Chinese Core Journals, Chinese Science Citation Database, and EBSCO Academic databases. The search period was from database inception to March 1, 2024. Using evidence-based medicine and combining years of clinical experience, the group consisting of experts from anesthesiology and pain medicine departments across the China organized by the Chinese Society of Anesthesiology engaged in multiple discussions and revisions to finalize this expert consensus.

Additionally, the numerical rating scale (NRS) [20], visual analogue scale (VAS) [21], and the grade of recommendations assessment, development, and evaluation (GRADE) tool for evidence grading [22] were used (Table 1). Combining existing national and international guidelines and expert consensus, the "Expert Consensus on the Standardized Clinical Application of Patient-Controlled Analgesia" was drafted, with evidence quality categorized into four levels: High (A), moderate (B), low (C), and very low (D). Recommendations were classified as strong or weak (Table 1), with consensus strength determined by expert voting via a Tencent scan code questionnaire (support = 100% for "strong consensus," support ≥ 80%

Table 1: Grading of evidence quality based on NRS/VAS and GRADE.

Items	Specific description	Study type
Evidence quality grading		
High (A)	Very confident that the true effect is close to the estimated effect.	Randomized controlled trials (RCTs)
Moderate (B)	Moderately confident in the effect estimate; the true value is likely to be close to the estimate, but differences may exist.	High-quality secondary observational studies Randomized controlled trials (RCTs) downgraded by one level
Low (C)	Limited confidence in the effect estimate; the true value may differ from the estimate.	Observational studies upgraded by one level Randomized controlled trials (RCTs) downgraded by two levels
Very Low (D)	Little confidence in the effect estimate; the true value is likely to be substantially different from the estimate.	Observational studies Randomized controlled trials (RCTs) downgraded by three levels
Recommendation Strength		
Strong Recommendation	NRS/VAS score 4–6: Moderate pain, affecting sleep but still possible to sleep; 7–10: Severe pain, preventing sleep. Clearly demonstrates that the benefits outweigh the risks or vice versa.	_
Weak Recommendation	NRS/VAS score 0: No pain; 1-3: Mild pain, not affecting sleep; Benefits and risks are uncertain or evidence, regardless of quality, shows that benefits and risks are approximately equal.	_

for "consensus," support ≤ 60% for "no consensus," and support = 0% for "rejection of recommendation"). This paper provides evaluations and recommendations regarding PCA drug regimens, clinical PCA settings, and adverse reaction management.

PCA Analgesic Medications

Opioids

Postoperative PCA often requires opioid medications, including the fentanyl class, such as fentanyl, sufentanil, remifentanil, and alfentanil; other opioid analgesics include morphine, hydromorphone, dezocine, oxycodone, pentazocine, butorphanol, buprenorphine, and nalbuphine [23-27].

Non-steroidal anti-inflammatory drugs (NSAIDs)

NSAIDs, which provide analgesic and antipyretic effects, are commonly used according to the patient's analgesic needs. Non-selective COX inhibitors such as flurbiprofen axetil injection are commonly used, and continuous PCA infusion is currently possible with flurbiprofen axetil [28,29]. Ketorolac injections can also be placed in the PCA pump for patient-controlled intravenous analgesia (PCIA) [30].

Local anesthetics

Long-acting local anesthetics commonly used include ropivacaine, bupivacaine, levobupivacaine, and liposomal bupivacaine. Short-acting local anesthetics such as lidocaine are also used. Epidural multimodal analgesia typically requires combining local anesthetics with opioids. For peripheral nerve blocks, local anesthetics are generally used without an opioid combination [31-36].

Adjuvant analgesics

Common adjuvant analgesics for PCA include dexmedetomidine, esketamine, dexamethasone, ondansetron, and droperidol, which can be selected for clinical use; however, antiemetics are not recommended for inclusion in the PCA pump [37-39]. Other adjunctive medications include acetaminophen, duloxetine, gabapentin, and pregabalin, which must be administered orally and not via PCA [40-42]. The characteristics of commonly used opioid analgesics are detailed in Table 2 [43].

Common Clinical Applications of PCA

PCIA

Common opioid analgesics for PCIA: PCIA typically involves the use of potent opioids, supplemented by NSAIDs, ketamine, and antiemetics. Commonly used analgesics exhibit the following relative potency: Morphine 10 mg ≈ fentanyl 0.1 mg ≈ sufentanil 0.01 mg ≈ hydromorphone 1 mg ≈ tramadol 100 mg ≈ pethidine 100 mg ≈ butorphanol 2 mg ≈ oxycodone 10 mg ≈ dezocine 10 mg. The pharmacokinetics and pharmacodynamics of different PCIA drugs determine variations in parameters such as single dose and lockout time [18,20,23,24,27,44-50]. Postoperative PCIA can employ multimodal approaches, including pre-emptive analgesia and preventive analgesia [51]. These approaches align with the concept of ERAS, promoting the development of traditional PCA [52].

Indications for PCIA: PCIA is indicated for moderate to severe postoperative pain, particularly in patients unable to tolerate oral medications. It is suitable for analgesia in all body regions and is appropriate for adults with ASA I-III classifications and pediatric patients

Table 2: Characteristics of commonly used opioid analgesics in clinical practice.

Opioid	Onset time (min)	Elimination half-life (h)	Plasma protein binding rate	Pharmacological action
Morphine	5~10	3~4	26%~36%	A pure opioid receptor agonist, morphine activates μ, κ, and δ receptors, leading to analgesia, respiratory depression, euphoria, and addiction.
Fentanyl	1~2	2~4	80%	A μ-opioid receptor agonist, primarily metabolized in the liver with a significant first-pass effect.
Sufentanil	1~3	13	91%~93%	A highly selective μ-opioid receptor agonist, with 7-10 times higher affinity for μ-receptors than fentanyl, offering good hemodynamic stability.
Hydromorphone	1~3	2~3	8%~19%	A full opioid agonist with relative selectivity for μ-opioid receptors, without the analgesic ceiling effect seen with morphine.
Butorphanol	3~5	3~4	80%	Acts as both an agonist and antagonist at μ receptors, with its primary metabolite activating κ receptors, interacting with CNS receptors for analgesia.
Oxycodone	2~3	3.5	45%	A dual agonist at μ and κ receptors, with relative selectivity for μ receptors but can bind to other opioid receptors at higher doses.

(age ≥ 6 months), provided there is no preoperative cough, expectoration, or significant abnormalities in cardiac, pulmonary, hepatic, or renal function. PCIA can also be used for the maintenance of severe cancer pain, management of refractory cancer pain, and effective control of breakthrough pain [18,20,23,24,27,44-50].

Absolute contraindications for PCIA: (1) Coma or altered consciousness; (2) Cognitive impairment preventing proper understanding and use of PCA technology; (3) Severe obstructive sleep apnea syndrome; (4) Patient refusal [17,53].

Relative contraindications for PCIA: (1) Systemic infection, heart or lung failure, coagulopathy, or severe hepatic and renal insufficiency; (2) Acute upper gastrointestinal bleeding or obstruction leading to a risk of reflux and aspiration; (3) Conscious patients unable to operate the "self-control" button due to physical limitations; (4) Psychiatric disorders, including sleep apnea [54].

Advantages of PCIA: PCIA offers broad indications, is applicable to adults and children, and can be used for analgesia across all body regions. Its clinical use is widespread, often involving potent μ-opioid receptor agonists, partial agonists, or agonist-antagonists [54]. Due to the high toxicity and addiction potential of pethidine, as well as its resistance to naloxone, pethidine is not recommended for analgesia in PCIA patients [55].

Disadvantages of PCIA: There is considerable variability in analgesic efficacy among individuals, and increasing PCIA drug dosages is associated with an increased risk of side effects such as nausea, vomiting, dizziness, pruritus, excessive sedation, respiratory depression, and hypotension.

Assessment of PCIA analgesic efficacy: Assessment can be performed using the NRS, VAS, Verbal Rating Scale (VRS), Wong-Baker Faces Pain Rating Scale, and Bruggrmann Comfort Scale (BCS) for comfort level, and Ramsay Sedation Score for sedation level. Other commonly used tools include the McGill Pain Questionnaire (MPQ) and the analgesic quality index (AQI) for Ai-PCA systems. Side effects such as nausea, vomiting, pruritus, and dizziness are monitored and recorded during routine follow-up assessments.

Epidural PCA (PCEA)

Anesthetic drugs for PCEA: Epidural PCA typically requires a combination of opioids and long-acting local anesthetics for analgesia. The use of local anesthetics and opioids in the epidural space provides a synergistic analgesic effect, allowing for the reduction of local anesthetic concentrations and opioid dosages. Opioids directly act on opioid receptors in the spinal cord, producing analgesic effects, which, compared to intravenous and oral administration, reduces the risk of opioid-related side effects and potential complications [20,56-58]. PCEA can offer effective and prolonged segmental analgesia [59,60].

Indications for PCEA: (1) All patients undergoing epidural anesthesia can receive postoperative PCEA. Guidelines recommend PCEA after thoracic and abdominal surgeries; (2) Trauma patients, including those not requiring surgery, such as patients with rib fractures, can benefit from epidural analgesia, which alleviates pain during respiratory movements and may reduce the incidence of atelectasis and pulmonary inflammation; (3) Patients with pain syndromes [61].

Contraindications for epidural PCA: (1) Patient refusal; (2) Patients with coagulopathy or those currently undergoing or about to receive anticoagulant therapy; (3) Patients with bacteremia or local infection at the epidural puncture site; (4) Patients with altered consciousness or psychiatric disorders; (5) Patients with spinal deformities or spinal cord disorders (relative contraindication); (6) Patients with increased intracranial pressure or central nervous system diseases; (7) Patients in shock with severely compromised cardiovascular function; (8) Lack of qualified acute pain service personnel.

Advantages of PCEA: (1) Facilitates early mobilization; (2) Reduces pulmonary complications; (3) Decreases the incidence of deep vein thrombosis; (4) Shortens the recovery time of gastrointestinal function; (5) Reduces stress response and the occurrence of myocardial ischemia caused by pain; (6) Promotes graft survival after lower limb vascular surgery; (7) Reduces bladder spasms after prostate and hypospadias surgeries; (8) Use of spiral-reinforced wire catheters during epidural puncture helps reduce catheter breakage and the risk of nerve injury [62].

Disadvantages of PCEA: Some adverse effects and complications related to PCEA are associated with epidural puncture and catheter placement, such as epidural hematoma, spinal canal infection, and post-dural puncture headache. Others are related to the use of analgesic solutions (opioids and local anesthetics) [32]. With the increasing use of minimally invasive surgeries, which are associated with reduced pain intensity, PCEA has not become widely adopted for thoracic and abdominal surgeries. Recent literature suggests that PCEA prolongs hospital stays for thoracic surgery patients, whereas abdominal surgery patients benefit more from PCEA [63].

Assessment of PCEA analgesic efficacy: Pain assessment for PCEA follows the same objective methods as for PCIA [34]. In addition, the modified Bromage scale is used to evaluate the degree of motor block, while the Frankel grading system assesses the extent of spinal cord injury. Patient comfort with analgesia is evaluated using the AQI [36,37].

Other PCA administration routes

Subcutaneous PCA (PCSA): PCSA involves the insertion of a fine catheter under the skin at a designated site, allowing for the administration of opioids through a PCA pump. The absorption of the drug through subcutaneous tissue occurs slowly, resulting in a delayed onset of analgesia. Despite this drawback, PCSA offers several advantages, including enhanced safety and minimal side effects. However, the primary limitation remains the slow onset of pain relief.

Subarachnoid PCA (S-PCA): S-PCA involves the placement of a specially designed catheter directly into the subarachnoid space following a spinal puncture to facilitate analgesic delivery [9]. There are two forms of S-PCA: (1) A dedicated catheter can remain in the subarachnoid space for up to 48 hours, making it suitable for pain management in the lower limbs or abdomen. Exceeding this duration may lead to spinal cord irritation and hyperthermia, both of which resolve upon catheter removal. (2) A novel catheter made from thermoplastic polyurethane (TPU) can be placed in the subarachnoid space, with the drug reservoir implanted subcutaneously. The PCA pump delivers medication via a needle that punctures the reservoir, and in CP mode, this catheter can remain in place for 1 to 3 years, making it ideal for long-term pain management in cancer patients. The primary advantage of S-PCA is its rapid onset and potent analgesic effect; however, the major drawback is the elevated risk of severe infection. Therefore, strict aseptic techniques are essential throughout the procedure to minimize infection risk.

PCEA following subarachnoid injection: In the context of combined spinal-epidural anesthesia, the dura mater is punctured, creating a small opening that allows medication to seep into the subarachnoid space. Under these circumstances, PCEA remains a safe and effective option [64,65].

Target-controlled infusion PCA (TCI-PCA): Target-controlled infusion (TCI), when integrated with PCA, is referred to as TCI-PCA. For example, when a patient activates the bolus button for remifentanil, an intelligent intravenous infusion system semi-automatically adjusts the target drug concentration, swiftly achieving the desired plasma or effect-site concentration. The primary advantage of TCI-PCA is its rapid onset; however, the duration of analgesia tends to be relatively short. Studies have demonstrated the effectiveness of intravenous remifentanil TCI-PCA for labor analgesia [66].

Peripheral nerve block PCA (PNB-PCA): Ultrasound-guided PNB or continuous peripheral nerve block (CPNB) involves the administration of local anesthetic solutions through intermittent injections or continuous catheter infusion for PCNA. This approach is effective not only for managing pain in major surgeries of the upper and lower limbs but also for providing perioperative analgesia in patients undergoing abdominal, plastic, urological, gynecological, thoracic, and trauma surgeries [67].

Multimodal analgesia combined with PCA:

(1) PCA administration modes

1) LCP mode: Loading dose + continuous dose + PCA (LCP for short), where an initial loading dose is followed by continuous dosing, with the patient pressing the PCA button when pain is experienced. **2) CP mode**: Continuous dosing + PCA, where a baseline dose of the drug is continuously delivered, and the patient presses the bolus button when experiencing pain. **3) P mode:** Pure PCA self-control throughout the analgesic period, where the patient presses the PCA button when pain occurs. The use of a loading dose helps maintain the minimum effective analgesic concentration (MEAC) required by the patient. With an appropriately chosen loading and continuous dose, the plasma concentration is more easily maintained within MEAC across different age groups without overdose. When PCA is configured using equivalent doses, there is no statistical difference in analgesic efficacy between long-acting opioid PCA without background dosing and the LCP mode, though the duration differs. Drug selection should be based on the extent of surgical trauma to ensure standardized management [68].

(2) PNB + PCIA multimodal administration

Long-acting local anesthetics such as ropivacaine can be used for PNB either preoperatively or postoperatively in the PNB+PCIA mode. This approach significantly reduces the need for analgesic medications. Using ultrasound-guided liposomal bupivacaine for PNB provides more complete and long-lasting postoperative analgesia, facilitating early functional rehabilitation and contributing to rapid postoperative recovery [69].

Pre-PCA Assessment and Patient-Family Education

Preoperative assessment

The safe and effective management of Patient-Controlled Analgesia (PCA) requires an interdisciplinary Acute Pain Service (APS) team composed of physicians, pharmacists, and nurses. Before initiating PCA, the physician should assess the patient's American Society of Anesthesiologists (ASA) classification, body mass index (BMI), type of surgery, and blood transfusion status and accurately evaluate postoperative pain using the NRS. Additionally, the physician must select the appropriate analgesic pump and consider factors that may influence the effectiveness of postoperative PCA. The physician provides orders, the nurse implements them, and the APS ensures accurate medication preparation, continuous assessment of

analgesic efficacy, and dynamic monitoring for adverse reactions. Team members must be well-versed in the PCA management process, including patient selection, comprehensive identification and assessment of high-risk patients, formulation of PCA medication regimens, dose adjustments during use, and monitoring and management of adverse effects. Effective communication among team members is essential to achieve optimal pain control outcomes and prevent complications [70,71].

Preoperative education

For cognitively alert patients who can comprehend the information provided by healthcare professionals, preoperative education is critical. Repeated instruction can enhance patients' understanding and retention of information. The educational content should include (1) The importance of postoperative pain relief, (2) The principles and safety of the PCA pump, and (3) Key points regarding its use. Proper education by the physician is crucial for both patients and family members to ensure the safe use of PCA. Before initiating PCA analgesia, it is essential to communicate with the patient and their family, providing a detailed explanation of the advantages and safe use of the PCA pump tailored to their varying occupations and educational backgrounds. Training should emphasize the correct use of the device and clearly state that neither the patient nor family members should adjust PCA parameters independently. Specifically, only the patient or an authorized individual should press the PCA button to prevent accidental harm [72].

Structure of Artificial Intelligence PCA (Ai-PCA)

Ai-PCA system is a pain management pump that integrates the Internet of Things (IoT) and artificial intelligence (AI) technologies. It was approved for registration by the National Medical Products Administration in May 2011. The Ai-PCA consists of an intelligent analgesia terminal (including an intelligent infusion driving device and a disposable drug reservoir), a base station (used for data transmission), and a central analgesia monitoring station (equipped with analgesia management software on a computer, tablet, or smartphone) [73].

Base station

The base station serves as the foundational equipment for network setup, data reception, and transmission. It is equipped with a wireless module, an RS232 serial port at the bottom, a rubber antenna on the right side of the case, and status indicator lights on the front panel. The base station is a plug-and-play device. It acts as a key unit in the analgesia information system communication network, collecting data from the intelligent analgesia terminal and transmitting it to the central analgesia monitoring station [74].

Central analgesia monitoring station

The central monitoring station is responsible for analyzing and processing the data uploaded from the analgesia terminal. Operators can monitor the use of the analgesia terminal through the central station, which automatically generates postoperative follow-up records and PCA documentation. Hospitals are required to comply with the announcement issued by the National Medical Products Administration (CFDA) regarding the "Medical Device Classification Catalog" (No. 104 of 2017). Departments must also adhere to the national requirement that the "Analgesia Infusion Information Collection System" be registered as a Class III medical device [75].

PCA Standardized Management System

PCA standardized operational management

The anesthesia department implements the management model of a "Cloud Ward" or "Virtual Pain Unit (VPU)," adhering to a system of full participation, comprehensive control, and overall quality assurance [76]. Physicians from the APS are responsible for preoperative visits, where they inform patients about pain management strategies [77]. In compliance with the "Notice on Strengthening the Management of Narcotic Drugs and Category I Psychotropic Substances in Medical Institutions" (National Health Medical Issue 2020-13), anesthesiologists are not permitted to handle drugs independently. According to the "Law of the People's Republic of China on Practicing Physicians," the anesthesia department must establish an order-based system, with APS physicians issuing electronic orders. Nurses are responsible for preparing analgesic medications under supervision, and infusion pump parameters are automatically entered through the smart order system to enhance efficiency and prevent manual entry errors [78]. Due to the complexity and diversity of PCA formulations, a dual-verification system should be used in clinical practice to strengthen the Analgesia Quality Index (AQI) and improve the overall effectiveness of PCA. The workflow for Ai-PCA management is shown in Figure 1 [79].

APS operates 24 hours a day, 7 days a week, ensuring that all patients receiving pain treatment are managed by the on-duty APS physician, who addresses alarms and other issues as they arise. The APS team maintains dedicated application forms, registration logs, and routine nursing records. APS physicians conduct daily rounds 1 to 3 times, during which they assess VAS scores, Behavioral Comfort Scale (BCS) comfort scores, sedation levels, monitor SpO_2, and check the functionality of PCA pumps. Additionally, anesthesiologists and nurses

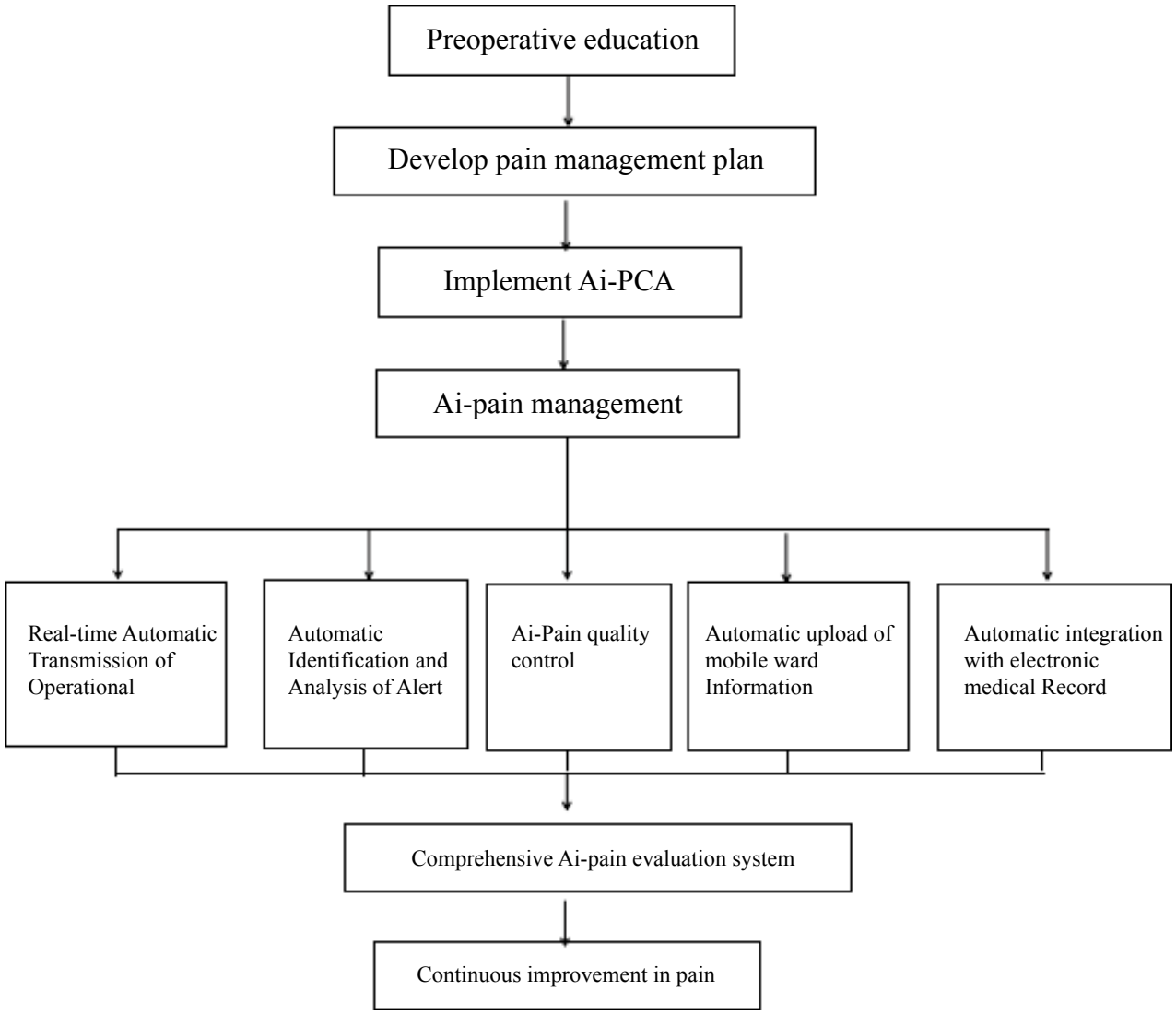

Figure 1: Flowchart of Ai-PCA operation.

perform afternoon rounds to evaluate the analgesic effects of PCA, identify any adverse reactions, and respond to questions regarding pain management. A VAS score of ≤ 3 indicates effective analgesia, while a score of ≥ 4 and/or the presence of adverse reactions necessitates timely symptomatic treatment, contributing to Enhanced Recovery After Surgery (ERAS) [80]. A three-level quality control management model alongside the anesthesia department management workflow is illustrated in Figure 2.

Quality control management of the intelligent analgesia system

An integrated platform for multi-modal evaluation, recording, and querying has been established, enabling real-time remote management and monitoring of the analgesia terminal. After the APS nurse removes the catheter and discontinues the pump, the intelligent analgesia pump is placed into an intelligent residual volume disposal robot, which automatically registers, disposes of, and disinfects the residual medication [81].

Standardization of PCA data collection: Postoperative follow-up and patient PCA records are an essential part of the surgical patient's medical record system. During the patient's pain management process, medical data is collected from the source in a standardized format to ensure comprehensive and accurate data capture. This guarantees the consistency of data collection, storage, processing, analysis, extraction, and application.

Standardization of real-time PCA tracking: The system automatically collects postoperative pain management information from patients and generates medical records. This enables quality control and real-time tracking throughout the entire pain management process. By objectively recording changes in the patient's condition in real time, it reduces the risk of missing important information during busy periods, thus aiding in accurate analysis and decision-making. Additionally, it prevents errors that may arise when physicians retrospectively fill in the records, thereby improving overall efficiency.

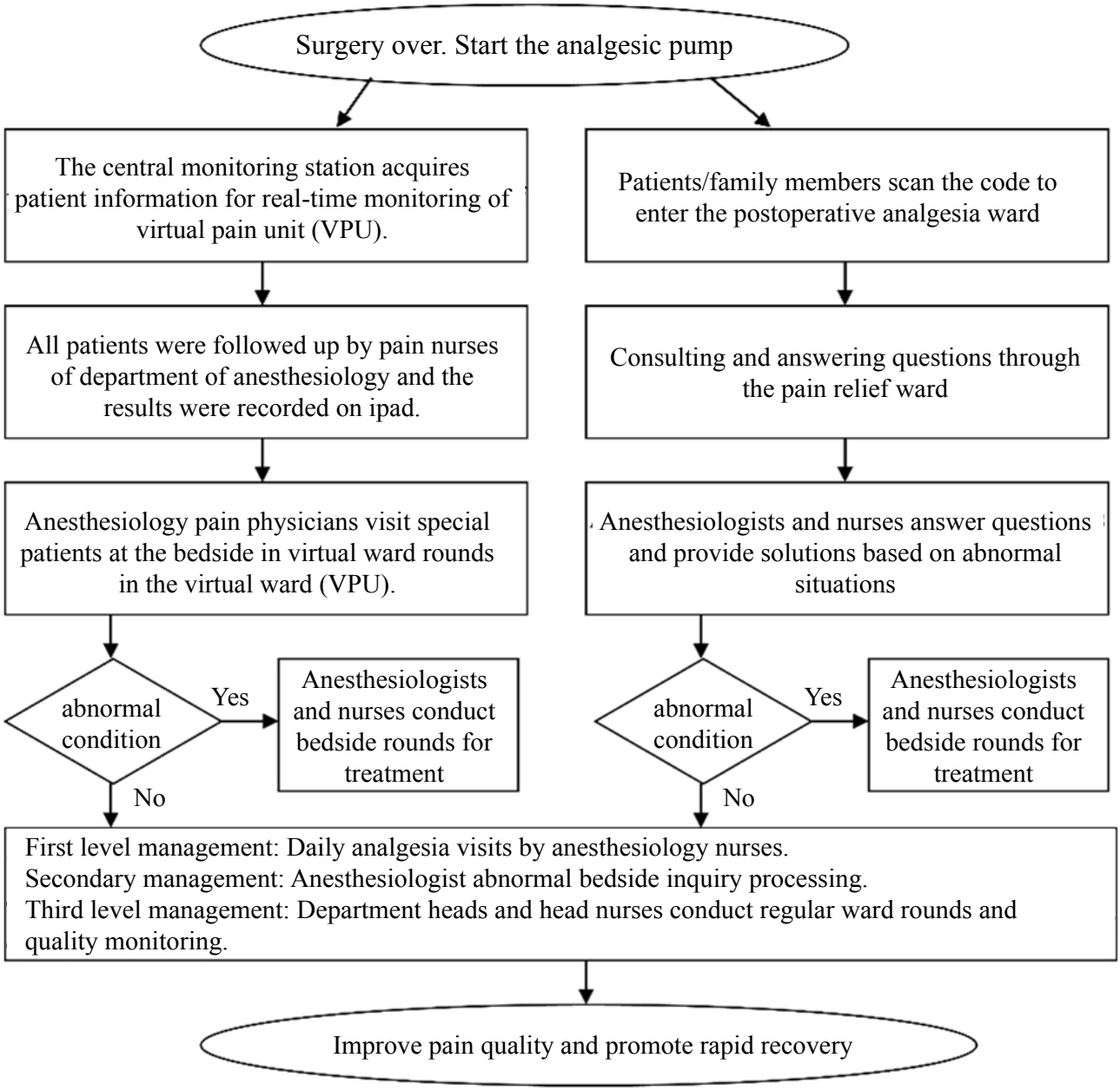

Figure 2: Management flow chart of the anesthesiology department.

Digitalization of PCA information storage: The system utilizes computer database storage technology to record, process, and store information related to the patient's pain management. The intelligent analgesia system allows on-demand retrieval of relevant medical data, which can be transferred to data mining software such as SPSS or SAS for macro-level analysis and scientific research. This provides strong support for managing medical practices related to patient analgesia, enabling the reproduction of PCA processes and the analysis of analgesic outcomes.

Intelligent quality control of PCA: The anesthesia department follows a pain management model characterized by full participation, continuous control, and comprehensive quality assurance. Using AQI software, the system analyzes key metrics such as the frequency of PCA button presses, evaluation rates, occurrence rates of various alarms, response times to critical alarms, medication utilization rates, and completeness of patient information. These indicators comprehensively reflect the technical proficiency of the medical staff, the thoroughness of patient assessments, the accuracy of medical orders, and the standardization of management practices. Departments typically select a 24-hour AQI display to provide a visual reflection of analgesic quality, and the PDCA (Plan-Do-Check-Act) cycle is used to continuously improve issues identified by the AQI. Additionally, comparative analyses of AQI data from different departments and hospitals help assess the quality of pain management and promote ongoing improvements in care [82].

Typical PCA Formulations

Recommended PCIA methods for postoperative patients

Recommended opioids for PCIA [83-85]: Morphine, sufentanil, and hydromorphone are the recommended strong opioids for PCIA (evidence level: B; recommendation grade: strong; consensus rate: 100.0%).

μ-Receptor partial agonist-antagonist for PCIA [87-89]: The use of μ-receptor partial agonist-antagonist drugs for PCIA is recommended (evidence level: B; recommendation grade: strong; consensus rate: 80%).

Fentanyl for PCIA [90]: Fentanyl is recommended for PCIA (evidence level: C; recommendation grade: weak; consensus rate: 37.2%).

Oxycodone for PCIA [49,91,92]: Oxycodone is recommended for PCIA (evidence level: C; recommendation grade: weak; consensus rate: 60.0%).

NSAIDs for PCIA [93]: The use of flurbiprofen axetil as an adjunctive analgesic during PCIA is recommended (evidence level: B; recommendation grade: strong; consensus rate: 86%).

Adjuvant analgesic medications for PCIA [94,95]: Dexmedetomidine and esketamine are recommended as adjuvant analgesic drugs during PCIA (evidence level: B; recommendation grade: strong; consensus rate: 97.7%) [4,19,23,49,56,57,81-110].

Combination of adjuvant drugs for PCIA [4,23]: Dexamethasone, droperidol, ondansetron, azasetron, and tropisetron are recommended as adjuvant drugs during PCIA to prevent opioid-induced nausea and vomiting (evidence level: B; recommendation grade: strong; consensus rate: 93.0%).

Other adjuvant drugs for PCIA [96]: Gabapentin and pregabalin are recommended as adjuvant medications during PCIA (evidence level: C; recommendation grade: weak; consensus rate: 16.3%).

Recommended PCEA methods for postoperative patients

Single-pump PCEA [56,57,97-109]: In the Single-pump PCEA model, strong opioids are administered using an LCP mode. The loading dose for titration is set at 5 ml per dose, with a continuous infusion of 0.5 ml per hour and a PCA bolus dose of 1 ml per activation, featuring a lockout interval of 10 to 15 minutes. The maximum allowable safety dose within one hour is capped at 15 ml. Strong opioids such as sufentanil, hydromorphone, and long-acting local anesthetics, including 0.2% ropivacaine and 0.2% levobupivacaine, are recommended for PCEA (evidence level: B; recommendation grade: strong; consensus rate: 95.3%).

Dual-pump PCEA: The dual-pump method is recommended internationally. Pump A continuously infuses 0.2% ropivacaine at 8-12 ml/h. When the analgesic effect of the local anesthetic is insufficient, Pump B is connected via a three-way valve to a venous catheter for 0.1% morphine PCIA [110-112]. Domestically, a dual-pump method is recommended where Pump A infuses 0.2% ropivacaine at 4-6 ml/h continuously. If the analgesia from the local anesthetic is insufficient, the patient can press the control button, and Pump B delivers 0.01% morphine PCEA via an epidural catheter. The LP model is used, with a loading (titration) dose of 5 ml/dose and a PCA bolus dose of 1-2 ml/dose, with a lockout interval of 15-20 minutes, enhancing analgesic effects [61,113,114]. However, when the local anesthetic exceeds 8 ml/h for more than 6 hours, patients often experience significant numbness in both legs. Patients have reported that this numbness is more uncomfortable than pain, prompting a request to stop the pump. Therefore, the dosage recommended domestically is significantly lower than that used internationally. Dual-pump analgesia is recommended for postoperative patients (evidence level: C; NRS/VAS score of 4-10: Weak; consensus rate: 60%).

PNB + PCEA [115-117]: The combination of PNB and PCEA is recommended for postoperative analgesia in patients (evidence level: B; NRS/VAS score of 4-10; recommendation grade: strong; consensus rate: 95.3%).

Recommended approaches for labor analgesia

PCIA for labor analgesia [118]: PCIA is recommended for labor analgesia in parturients (evidence level: C; NRS/VAS score of 4-10: Recommendation grade: weak; consensus rate: 16.3%).

PCEA for labor analgesia [119]: PCEA is strongly recommended for labor analgesia in parturients (evidence level: A; NRS/VAS score of 6-10: Recommendation grade: strong; consensus rate: 100%). cancer pain.

TCI-PCA for labor analgesia [120]: TCI-PCA is recommended for labor analgesia in parturients (evidence level: C; NRS/VAS score of 4-10: Recommendation grade: Weak; consensus rate: 18.6%).

Recommended approaches for angina pectoris

PCIA for angina pectoris [47]: PCIA is recommended for patients with angina pectoris (evidence level: B; NRS/VAS score of 4-10: Recommendation grade: weak; consensus rate: 74.4%).

PCEA for angina pectoris [121,122]: PCEA (T5-6) is recommended for patients with angina pectoris to significantly relieve paroxysmal chest pain or discomfort caused by myocardial ischemia due to insufficient coronary blood supply (evidence level: B; NRS/VAS score

of 6-10: Recommendation grade: Strong; Consensus rate: 86.0%).

Recommended approaches for cancer pain

PCIA for moderate cancer pain [19,109,110,123-125]: PCIA is strongly recommended for moderate cancer pain using an on-demand administration model (evidence level: B; recommendation grade: strong; consensus rate: 95.3%).

PCIA with pethidine [126]: Pethidine is not recommended for PCIA in cancer pain management (evidence level: D; recommendation grade: not recommended; consensus rate: 0%).

PCEA for severe cancer pain [127]: For severe cancer pain, a multidimensional evaluation should be conducted before starting PCA. After titration with a strong μ-opioid receptor agonist, patient consent should be obtained, and treatment should begin with a low dose. Efficacy and adverse reactions should be dynamically assessed during titration, and parameters should be adjusted accordingly (evidence level: B; recommendation grade: strong; consensus rate: 86%).

S-PCA for refractory cancer pain [128]: For patients with severe refractory cancer pain in the lower abdomen and lower limbs, especially those unable to lie flat or with intense pain and a strong desire for relief, S-PCA with long-acting local anesthetics may be used after obtaining informed consent (evidence level: C; recommendation grade: strong; consensus rate: 60.5%).

PCSA for moderate refractory cancer pain [129]: PCSA with strong μ-opioid receptor agonists is recommended for patients with moderate refractory cancer pain (evidence level: C; NRS/VAS score of 4-10: recommendation grade: weak; consensus rate: 58.1%).

PNB + PCIA for surgical patients [130,131]: PNB combined with PCIA is recommended for appropriate surgical patients (evidence level: B; NRS/VAS score of 4-10: Recommendation grade: strong; consensus rate: 97.7%).

Recommended approaches for severe pain management in adult critical care patients

PCIA for severe chest pain in acute myocardial infarction (AMI) patients [24]: PCIA is recommended for adult critical care patients experiencing severe chest pain during an AMI (evidence level: B; NRS/VAS score of 4-10: Recommendation grade: weak; consensus rate: 60.5%).

PCIA with NSAIDs for severe chest pain in AMI patients [132]: The use of NSAIDs for pain relief in adult critical care patients with severe chest pain due to AMI is recommended (evidence level: C; NRS/VAS score of 4-10: Recommendation grade: weak; consensus rate: 16.3%).

PCIA with morphine for shock patients [133]: Morphine is recommended for pain relief in patients suffering from shock (evidence level: C; NRS/VAS score of 4-10: Recommendation grade: weak; consensus rate: 32.6%).

PCIA for patients with acute abdomen [134]: On-demand analgesia is strongly recommended for patients with moderate to severe pain and a clear diagnosis of acute abdomen (evidence level: B; NRS/VAS score of 4-10: Recommendation grade: strong; consensus rate: 95.3%).

PCEA for patients with acute abdomen [135]: PCEA is recommended for pain relief in patients with severe pain and a clear diagnosis of acute abdomen (evidence level: B; NRS/VAS score of 4-10: Recommendation grade: strong; consensus rate: 81.4%).

PCEA for acute severe pancreatitis [136]: Opioids are recommended for pain relief in patients with acute severe pancreatitis (evidence level: B; NRS/VAS score of 4–10: recommendation grade: strong; consensus rate: 90.7%).

PCIA/PCEA for postoperative severe pain [137,138]: Opioids are routinely recommended for postoperative pain management in severe pain cases (evidence level: B; NRS/VAS score of 4-10: Recommendation grade: strong; consensus rate: 97.7%).

PCIA for post-craniotomy pain [139,140]: PCIA is recommended for pain management in patients after cranial surgery (evidence level: C; NRS/VAS score of 4-10: recommendation grade: weak; consensus rate: 62.8%).

Considerations for PCA formulations

Before selecting multimodal analgesia drugs for postoperative PCA, a thorough assessment of the patient's pain is required. Due to variations in patient ASA scores, types of surgery, and the nature of postoperative pain, the pharmacological effects of the drugs, combination regimens, PCA pump types, analgesic routes, and administration modes will differ. Therefore, PCA outcomes vary, and a standardized pain management approach is not advisable. Treatment should be tailored to individual patients and local circumstances, with objective evaluation and accurate determination of multimodal pain management strategies [20,27].

Monitoring and Management of Adverse Reactions to PCA

Adverse reactions and monitoring of PCIA

Adverse reactions of PCIA: Postoperative PCA adverse reactions can significantly impact patient satisfaction. The adverse reactions of PCIA are primarily

associated with the side effects of analgesic drugs, including excessive sedation, respiratory depression, nausea and vomiting, constipation, and, in some cases, pruritus and urinary retention [23]. PCIA optimizes opioid administration by minimizing the pharmacokinetic and pharmacodynamic variability between individuals. Respiratory rate is a routine parameter for monitoring respiratory depression, but SpO_2 monitoring should be utilized whenever possible.

Adverse reactions of PCEA: Epidural analgesia may cause complications and adverse reactions, some of which are related to epidural puncture and catheter placement. Adverse reactions include respiratory depression, excessive sedation, hypotension, nerve injury, unilateral lower limb numbness with weakness, or lower limb motor dysfunction. Other adverse reactions may include postoperative nausea and vomiting, pruritus, drowsiness, dizziness, and urinary retention [141,142].

Device or operation-related adverse reactions of PCA: Adverse reactions due to improper puncture technique or equipment use, such as bleeding or infection, are rare. Errors in pump programming, device malfunction, tampering with parameters, or family members pressing the PCA button on behalf of the patient may lead to drug overdose, resulting in serious adverse reactions like respiratory depression. Therefore, patients should be closely monitored for vital signs, particularly respiratory depression and changes in consciousness, during the first 24 hours of PCA initiation or after any dosage adjustment [143].

Adverse reactions of ultrasound-guided PNB + PCA: Ultrasound-guided PNB is a safe and effective postoperative analgesic technique. However, nerve blocks still carry risks of bleeding, infection, and nerve injury [20,27].

Management of adverse reactions

Respiratory depression: Respiratory depression is the most life-threatening adverse reaction. If the respiratory rate drops below 8 breaths/min, the patient's status, skin color, and airway patency should be immediately checked. For drowsy patients, respiratory patterns should be observed, and 0.1-0.4 mg of naloxone should be administered intravenously. In cases of mild airway obstruction, where the patient is easily aroused, they should be encouraged to choose the most suitable position to maintain airway patency [144].

Shivering: Postoperative muscle shivering may occur due to the side effects of morphine. Local application of a hot water bottle should be avoided. It is important to differentiate shivering from postoperative fever or infusion reactions and monitor whether the shivering is followed by an increase in body temperature [145].

Lower limb numbness with weakness: Lower limb numbness accompanied by weakness is a potential side effect of local anesthetics. This condition may arise from the displacement of the epidural catheter tip toward the nerve roots, excessive dosages of analgesics, or unilateral diffusion of the local anesthetic. Slowing the infusion rate can help alleviate these symptoms [146]. Typically, limb numbness resolves quickly after catheter removal and does not require special treatment. It is essential to implement precautionary measures and provide patient education to prevent falls during the use of the analgesic pump.

Urinary retention: Urinary retention is a common adverse reaction of opioid analgesics. Most patients using PCA pumps postoperatively are catheterized, and it is recommended that catheter removal should be timed after discontinuation of the analgesic pump [147].

Drowsiness: Some patients using PCA pumps may experience drowsiness. Patients should be easily roused, and nurses should frequently wake the patient, closely monitoring their respiratory rate, rhythm, depth, skin, lips, and nail bed color. Anesthetists should be informed to determine whether the analgesic dosage needs to be reduced [148]. During periods of drowsiness, nurses should enhance monitoring, raise bed rails, and educate caregivers to ensure patient safety, preventing falls, accidental catheter removal, or burns.

Hypotension: Hypotension may be associated with changes in body position, insufficient blood volume, or peripheral vasodilation caused by anesthetics. If necessary, the use of a PCA pump is paused, blood volume is replenished, and vasopressors are administered as needed [149].

Pruritus: Pruritus, induced by morphine-triggered histamine release, typically affects the head and neck, but may also spread to other body parts. Mild pruritus usually resolves within 1-2 days. For severe cases, patients should avoid scratching, and antihistamines such as diphenhydramine or promethazine can be administered. Nalmefene can be used for pruritus prevention [150].

Inhibition of bowel movements: Opioid analgesics used in PCA pumps, such as morphine and fentanyl, commonly inhibit bowel movements. Nurses should monitor patients' bowel sounds, gas passage, and bowel movements. In abdominal surgery patients, symptoms such as abdominal distension, delayed gas passage, postoperative nausea, or vomiting may occur [151]. If no gas passage occurs within 3 days postoperatively, patients should be encouraged to increase activity, such as turning over or engaging in bedside mobility, and abdominal hot compresses may help stimulate bowel movements. Severe abdominal distension may require continuous gastrointestinal decompression or rectal

gas evacuation as prescribed. Patients capable of eating should be encouraged to consume vegetables and fruits, like bananas, to aid bowel movements.

Chronic postsurgical pain (CPSP): Ineffectively controlled acute postoperative pain may lead to CPSP, particularly in patients with acute critical illness or those infected with COVID-19 prior to surgery. Studies have shown an increasing trend in CPSP incidence among postoperative patients with a history of COVID-19 infection and long COVID syndrome [152].

Psychological care: Optimal analgesic effects from PCA can only be achieved when combined with psychological care. Medical staff should provide reassurance and encouragement to boost the patient's confidence in overcoming pain. Patients should be taught relaxation techniques, distraction strategies, and emotional adjustment, employing a combination of traditional Chinese and Western medicine approaches to proactively control pain [153].

Recommendations for the management of adverse reactions

During PCA administration, close monitoring is required, along with psychological care to help patients relax. Acupuncture and traditional Chinese medicine should be used as complementary treatments when necessary [154]. Recommendations for the management of adverse reactions (evidence level: B; recommendation grade: Strong; consensus rate: 100%).

Scope of the Expert Consensus

This *Expert Consensus on the Standardized Clinical Application of Patient-Controlled Analgesia* applies to adults and s and not to children, as the management and service of acute pain in younger children have unique characteristics [155].

Outlook

The development of PCA for pain management exemplifies the rapid advancement of clinical medicine in China. From its initial introduction to independent innovation, Ai-PCA has significantly enhanced the precision, reliability, and safety of pain management practices [156]. As AI continues to progress at an unprecedented rate, with technologies like Sora emerging following the release of ChatGPT 4.0 in 2024, PCA technologies must evolve to keep pace with these advancements, fostering further innovation and refinement in intelligent systems. The future of intelligent healthcare promises more standardized, safer, more effective, and higher-quality pain management services. By aligning the development of PCA with intelligent healthcare, we can ensure high-quality, standardized pain management [136,157,158]. This alignment will propel the fields of anesthesiology and pain medicine towards a future characterized by standardized, high-quality care driven by intelligent healthcare solutions [159,160].

Disclosure

The full version of this consensus was originally published in Chinese in Chinese Journal of Pain Medicine (Aug 2024, 20:484-508). This is the summary of the full report in English. There is no copyright issue for this consensus summary in English.

Conflict of Interest Statement

None.

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