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Review Article

Interpretation and Implementation Prospects of the Expert Consensus on Clinical Application for Patient-controlled Analgesia Based on Intelligent Analgesia Technology

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Abstract

The transition from conventional patient-controlled analgesia (PCA) to artificial-intelligence-assisted patient-controlled analgesia (Ai-PCA) represents an innovative model for analgesia management. Clinicians utilize AI-enabled PCA devices to deliver individualized analgesia according to patients' pain intensity and physical status. This review interprets the 2024 Chinese Expert Consensus on Clinical Application of Patient-controlled Analgesia, a landmark document for innovative analgesic strategies. We summarize the historical evolution of postoperative PCA and Ai-PCA, the rationale for consensus development, clinical implementation details, quality management frameworks, and future directions of Ai-PCA. Measures to improve Ai-PCA performance and perioperative pain management are analyzed, highlighting priorities for further clinical translation. As a core clinical specialty reflecting comprehensive hospital service capacity, anesthesiology benefits greatly from artificial intelligence. Integrating AI into pain medicine ushers in an era of big-data-driven preventive analgesia, which can improve patient comfort and satisfaction, enhance enhanced recovery after surgery (ERAS), and guide clinicians toward standardized, rational pain therapy.

Keywords

Patient-controlled Analgesia, AI-assisted Patient-controlled Analgesia, Postoperative Pain, Perioperative Pain Management, Standardization

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1. Historical Background of the Consensus

The evolution from patient-controlled analgesia (PCA) to artificial intelligence patient-controlled analgesia (Ai-PCA) has become a core component of perioperative pain management within enhanced recovery after surgery (ERAS), directly affecting the quality of postoperative recovery and patient satisfaction. PCA was proposed by Sechzer in 1976 as an on-demand analgesic medication principle for postoperative pain, and the first PCA pump soon followed [1-3]. In 1988, Professor Lisheng Zhang called for strengthened research on postoperative analgesia at the First National Academic Conference on Pain in China [4]. The PCA concept was introduced into China in 1993, and electronic PCA pumps were introduced into clinical practice in 1994. In 1997, the first Chinese clinical research article on PCA was published in the Chinese Journal of Anesthesiology [5]. Subsequently, more than ten serial papers on PCA were published in the Chinese Journal of Anesthesiology, reporting the analgesic efficacy of epidural PCA and PCA combination regimens. From 2013 to 2017, with the rapid development of computer, network, and intelligent technologies in clinical medicine, Chinese anesthesiology colleagues jointly developed a new type of Ai-PCA pump for analgesia. In 2018, the Expert Consensus on Intelligent Patient-controlled Analgesia Management was formulated [6]. By 2022, the Ai-PCA system had markedly improved the precision, reliability, and safety of pain treatment [7]. In 2023, the monograph Intelligent Patient-controlled Analgesia was published by People's Medical Publishing House, innovatively guiding the development of Ai-PCA [8]. Based on the characteristics of PCA development in China, four stages of PCA development and their landmark achievements have been proposed [9]. However, because pain varies greatly among individuals, influencing factors are complex, anesthesiology staffing is relatively insufficient, and PCA development remains uneven, a domestic survey in 2023 still showed a 48.7% incidence of moderate to severe postoperative pain [10]. To improve PCA efficiency and analgesia quality, and to identify an optimal plan suitable for standardized clinical application of postoperative PCA in China, the Chinese Journal of Pain Medicine invited the Guangzhou Anesthesia Medical Quality Control Center to lead and organize the drafting process. Forty-six experts in anesthesiology and pain medicine from 39 institutions nationwide used evidence-based medicine, combined with years of clinical experience, to discuss and revise the document over multiple rounds and vote on different clinical analgesia schemes one by one. The present Consensus was formulated to provide guidance for clinical application.

2. Formulation Basis of the Consensus

What is the core technology of anesthesiology? At present, there remains no definitive answer from developed Western countries. Chinese experts have held in-depth discussions and proposed that the core technologies of anesthesiology are the "4R" technologies: relief of pain, regulation of life, resuscitation, and restoration of organ function. Among these, relief of pain is the most important. The 4R core technologies of anesthesiology correspond closely to the 4R technologies of surgery: resection, repair, replacement, and regeneration. In patients undergoing surgery and experiencing surgical trauma, treatment through the 4R technologies of anesthesiology helps restore internal homeostasis and organ function, thereby supporting ERAS. Therefore, relief of pain is the key element of anesthesiology's core technology.

The formulation of the Consensus is based on the principle of "analgesia on demand." Its purpose is to address analgesic needs in different patients, at different time points, and under different pain intensities; this is an effective approach to reducing individual variability in pain and improving patient satisfaction [19]. The Consensus was prepared on the basis of the numerical rating scale (NRS) [11], the visual analogue scale (VAS) [12], and the Grading of Recommendations Assessment, Development and Evaluation (GRADE) evidence-grading standard [13], together with existing domestic and international diagnostic and treatment guidelines and consensuses. The quality of evidence in the Expert Consensus on the Standardized Clinical Application of Patient-controlled Analgesia is classified into four levels: high (A), moderate (B), low (C), and very low (D). Recommendation grades are divided into strong and weak recommendations. The expert committee used Tencent QR-code questionnaires for voting to determine the strength of consensus for each recommendation. A support rate of 100% indicated a "very strong" consensus; a support rate of 80% or above indicated a "strong" consensus; a support rate of 60% or below indicated that consensus was "not reached"; support rates between these levels indicated a "weak" consensus; and a support rate of 0% indicated "recommendation rejected." Detailed configuration schemes, system standards (including system composition and reference standards), clinical implementation details (workflows), and recommendation grades are provided in the Consensus.

3. Implementation Details of the Consensus

Pain is an unpleasant sensory and emotional experience associated with, or resembling that associated with, actual or potential tissue damage. Almost all types of surgical procedures cause tissue and nerve injury as well as inflammatory responses, thereby activating nociceptors and producing varying degrees of pain. Postoperative pain treatment includes three aspects: analgesic medications, routes of administration, and

configuration modes. PCA analgesic medications include opioids, non-steroidal anti-inflammatory drugs, local anesthetics, and PCA adjuvant analgesics, such as dexmedetomidine and esketamine. Common clinical routes for PCA include intravenous PCA (PCIA), epidural PCA (PCEA), peripheral nerve blocks, and other multimodal Ai-PCA approaches. PCIA can be used for moderate to severe postoperative pain, especially in patients who cannot tolerate oral medication. It is applicable for analgesia at all surgical sites in adults, for ASA physical status I-III patients, and for pediatric patients aged 0.6 years or older who have no preoperative cough or sputum and no severe cardiopulmonary, hepatic, or renal dysfunction. It can also be used for maintenance treatment of severe cancer pain and refractory cancer pain, as well as effective control of breakthrough pain [14]. PCEA is indicated for thoracic and abdominal surgery, pain syndromes, and analgesia in trauma patients, such as those with rib fractures. Epidural analgesia can help relieve pain caused by respiratory movements and may therefore reduce the occurrence of atelectasis and pulmonary inflammation. Under ultrasound guidance, peripheral nerve block (PNB) can be performed; for example, single-injection brachial plexus block using long-acting liposomal bupivacaine solution (133-266 mg/10-20 ml) can provide analgesia for up to 72 hours. Continuous peripheral nerve block (CPNB) delivers local anesthetics by continuous infusion or by retaining a catheter for PCA. For example, 0.2% ropivacaine can be used for peripheral nerve PCA with a continuous dose of 2-6 ml per administration, a bolus dose of 4-8 ml, and a lockout interval of 20-40 minutes, thereby providing longer-lasting analgesia. Other commonly used peripheral nerve block techniques include brachial plexus, femoral nerve, saphenous nerve, sciatic nerve, obturator nerve, ilioinguinal nerve, pericapsular nerve group block for the hip joint, thoracic paravertebral nerve block, transversus abdominis plane block, transversus thoracic muscle plane block, fascia iliaca block, erector spinae plane block, serratus anterior plane block, and quadratus lumborum block. These techniques are applicable not only to pain treatment in upper- and lower-limb surgery, but also to perioperative analgesia for patients undergoing abdominal, plastic, urologic, gynecologic, thoracic, and trauma surgery [15]. Multimodal analgesia combining PCIA with peripheral nerve block can be implemented by performing PNB with a long-acting local anesthetic before or at the end of surgery and then using a PNB + PCIA mode. This can significantly reduce analgesic medication consumption. Ultrasound-guided PNB using liposomal bupivacaine provides more complete and durable analgesia for postoperative PCIA, enabling early ambulation, early functional exercise, and early recovery [16].

4. Quality Management of the Consensus

The Ai-PCA system is an analgesic device that integrates the Internet of Things and artificial intelligence (AI). Its principle is to embed AI big-data models into the device to enable intelligent wireless transmission and control. The quality and efficiency of analgesia are therefore critically important. In accordance with the Notice of the General Office of the National Health Commission on Strengthening the Management of Narcotic Drugs and Class I Psychotropic Drugs in Medical Institutions (Guo Wei Yi Fa (2020) No. 13), as well as the Law of the People's Republic of China on Physicians, which came into effect on March 1, 2022, anesthesiologists should establish a digital-intelligent medical order system. Physicians issue electronic orders, nurses prepare analgesic medications and execute order parameters, and anesthesiologists do not handle medications independently. The intelligent order system automatically sets the formulation parameters for the PCA infusion pump, improving the efficiency of digital-intelligent analgesic care while strictly supervising narcotic and psychotropic drugs throughout the entire process. By using intelligent analgesia devices and multimodal analgesia schemes, institutions can organize and implement a virtual pain unit (VPU) management model [17]. Physicians from the acute pain service (APS) team should carefully manage and serve patients. Surgeons should perform their own duties, support the digital-intelligent analgesia work of APS physicians within the VPU team, accept recommendations on pain assessment and digital-intelligent treatment, strengthen analgesia quality control, and promote patient recovery. APS nurses in the VPU team participate in PCA rounds, psychological care, and removal of catheters and pumps when analgesia is completed. After pump removal, the intelligent analgesia pump is placed into an intelligent residual-volume verification and write-off robot, which performs intelligent registration, disposal, and write-off of the residual volume. By following the expert consensus on standardized analgesia management and combining it with different analgesic methods such as ultrasound-guided peripheral nerve block, the operation of analgesia pumps and analgesic effects can be tracked in real time; tracking can be standardized, data collection normalized, information storage digitized, quality control made intelligent, and analgesic medication made precise. The analgesia quality index (AQI) for intelligent PCA can be applied to reduce the incidence of moderate to severe postoperative pain and improve the quality of standardized postoperative analgesia management [18].

5. Implementation Outlook for Ai-PCA

Future postoperative analgesia will rely on intelligent analgesia devices and multimodal analgesia schemes to organize and implement a virtual pain unit (VPU) management model [19]. A management approach combining physicians from the acute pain service (APS) with the VPU should be adopted to manage and serve patients carefully and promote early recovery. Refined postoperative analgesia will lead clinical pain treatment into a new stage. Postoperative analgesia is one of the important components of perioperative management [20]. Severe postoperative pain affects the respiratory, circulatory,

and immune systems, and may cause 33% of patients to develop chronic pain, thereby exerting long-term negative effects on postoperative recovery and quality of life [21]. In addition to reducing pain intensity, the most important goal of postoperative analgesia is to enable early ambulation, early functional exercise, and early ERAS. Looking back on the development of analgesia in China, one can clearly see the arduous challenges faced by anesthesiologists in patient analgesia. The future development path of Ai-PCA remains long [22].

In 2025, the emergence in China of the DeepSeek large model presented a new atmosphere leading the wave of the era, triggered intense discussion in the technology community and a reshaping of beliefs about computing power, and further strengthened confidence in building an open AI ecosystem. AI-derived robotics has enormous potential in the healthcare industry. In the future, during VPU-APS physician rounds and follow-up visits, an "intelligent record template" can be used: physicians can click directly within the template, and the relevant data will automatically be transferred into the "intelligent quality-control management platform." The management platform can intelligently generate line charts and bar charts based on various data points, objectively displaying the effectiveness of pain-intensity control, achieving paperless, information-based, and intelligent follow-up, and improving data comparability. The improved future processing model for Ai-PCA will demonstrate the 5V characteristics of AI big data: volume, velocity, variety, veracity, and value, thereby realizing an advanced level of intelligence. Strengthening clinical research and clinical big-data analysis is the most direct and effective way to solve unknown clinical problems. Research findings can guide clinical practice and are more practical and reliable than general clinical experience, giving them important clinical value. AI science and technology can build intelligent analgesia data-training models and knowledge bases to support hospitals in medical care, training, and scientific research. With breakthroughs in AI technology and novel drug-delivery systems, the combination of Ai-PCA with ultra-long-acting liposomal bupivacaine local anesthetic and ultrasound-guided nerve block provides an innovative solution for multimodal analgesia. This combination is not only a precise and individualized analgesic strategy that reduces opioid dependence, but can also prolong analgesia through long-acting nerve-block technology and significantly optimize the perioperative pain-management workflow. Clinicians should take full advantage of new analgesia technologies in the new era, provide more timely and effective analgesia for patients, improve patient satisfaction with analgesia, and promote the high-quality development of digital-intelligent medical innovative analgesia systems [23].

Abbreviations

APS	Acute Pain Service
Ai-PCA	Artificial Intelligence-Assisted Patient-controlled Analgesia
GRADE	Grading of Recommendations Assessment, Development and Evaluation
AQI	Analgesia Quality Index
CPNB	Continuous Peripheral Nerve Block
ERAS	Enhanced Recovery After Surgery
NRS	Numerical Rating Scale
PCA	Patient-controlled Analgesia
PNB	Peripheral Nerve Block
VPU	Virtual Pain Unit
VAS	Visual Analogue Scale

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Conflicts of Interest

All authors declare that there are no conflicts of interest.

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