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Original Article

Current status and application of patient-controlled analgesia: a literature review

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Abstract: Postoperative pain control is an important aspect of postoperative patient management. Although postoperative pain management and its effects have received significant attention in recent decades, it remains a major challenge that can easily be ignored. There are many postoperative analgesic methods, the most common of which is patient-controlled analgesia (PCA). PCA can be divided into mechanical analgesia pumps and electronic analgesia pumps. With the rapid development of Internet technology, wireless remote monitoring and management integrated wireless analgesia system has emerged. It is an Internet-based electronic analgesia pump. This article reviews the advantages and disadvantages of mechanical and electronic analgesia pumps, and the advantages of wireless analgesia systems. Related clinical application indicates that PCA is an effective analgesic method. PCA can not only relieve the pain of patients, but also reduce the workload of the nursing staff. Analgesics can be taken according to the needs of the patient. PCA is an analgesic method suitable for individualized treatment of different patients.

Keywords: Postoperative pain, self-controlled analgesia pump, electronic, mechanical, wireless analgesia system

Introduction

Pain is the most common symptom in patients after surgery, because different procedures cause different degrees of pain, each patient has different tolerance to pain, and preventive analgesia can get twice the result with half the effort. Patient controlled analgesia (PCA) is an advanced analgesic method in the world. Clinical application of this technology has been expanded year by year. Insufficient pain relief can have certain consequences, which may delay the recovery and hospitalization time, increase the number of re-admissions, reduce patient satisfaction, and increase overall health care costs [1]. Postoperative pain will have a significant impact on patients. The improved postoperative analgesia can help alleviate pain in patients, enable them to move early, reduce the incidence of complications, and improve their quality of life. However, postoperative analgesia can bring some adverse reactions, so careful clinical observation, reasonable prevention and timely treatment are particularly important. The current patient-controlled analgesia (PCA) is mainly classified into mechanical analgesia pump and electronic analgesia pump. The wireless analgesia system is a PCA information management system based on Internet combined with electronic analgesia pump and wireless data transmission. This article gives a brief review of the current classification and progress of PCA, and summarizes the advantages and disadvantages of each PCA and related clinical application.

Introduction to PCA

The history of PCA development

Early pain has not been treated in the hospital settings. According to statistics, more than 70 million patients receive surgery every year in the United States, and among them, 80% experience acute postoperative pain and 20% experience severe pain [2, 3]. According to Grass, at least 50% of the patients received traditional

intramuscular injection of opioid and their pain relief was insufficient [4]. Patient controlled analgesia (PCA) was proposed by Sechzer in 1965 as a "feedback loop" for analgesia. Based on this principle, a PCA system was designed [5]. It was not until the mid 1970s that PCA with microprocessors came out to replace the mechanical clock PCA. Since then, PCA has been in use for nearly a decade; the emergence of the first commercial PCA pump in 1976 promoted the development of patient-controlled analgesia (PCA) technology [4]. Until 1984, the first international PCA symposium was held in the UK. During the conference, several commonly used PCA pumps were displayed, which can be used in various hospitals, marking that PCA has really entered the stage of clinical application. With the development of microelectronic technology in the early 1990s, PCA became smaller and more intelligent, and the era of PCA really came [6]. At present, the majorities of medical staff are familiar with and use PCA technology, and have received good results [7].

Classification of the PCA

Traditionally, postoperative analgesia is done by giving opioid analgesics; opioids are commonly used in pumps and can provide better postoperative results because of their effectiveness and availability [8]. However, excessive doses of opioids may have multiple side effects, including exhaust depression, lethargy, nausea and vomiting, pruritus, intestinal obstruction, urinary retention and constipation. The prescription for the multimodal analgesia regimen does not include opioid analgesics (such as local anesthetics). Currently, anesthesiologists can use a variety of new drugs, analgesic techniques and devices, and preventive methods to select analgesia, including patient-controlled analgesia (PCA), multimodal analgesia and preemptive analgesia [9].

PCA technology is one of the most common and effective methods of postoperative analgesia. It is suitable for patients with moderate or severe acute pain, as well as cancer patients [8]. The method of administration is set by the anesthesiologist according to the needs of the patient and cannot be changed at will. In terms of administration routes, PCA can be divided into intravenous PCA (PCIA), epidural PCA (PCEA), regional nerve block PCA (PCNA), subcutaneous PCA (PCSA), etc. However, intravenous PCA and epidural PCA are most commonly used clinically [6]. PCA can be divided into epidural pumps and intravenous pumps according to different injection methods and internal drugs. Epidural pumps often use local anesthetics, morphine, etc., while intravenous pumps often use fentanyl. The use of the two should be strictly distinguished, the epidural pump cannot be connected to the intravenous infusion end, and the venous pump cannot be connected to the epidural junction, otherwise there will be a general anesthetic effect or serious complications of local anesthesia [10]. The analgesia pumps can be divided into a mechanical analgesia pumps and an electronic analgesia pumps according to the driving methods. According to whether it can be reused, it can be divided into disposable and reusable analgesic pumps. According to whether it is controllable, it can be divided into controllable and non-controllable [11].

Although significant advances have been made in anesthetic techniques for pain management, intravenous (IV) patient-controlled analgesia (PCA) using opioids is the most commonly used form of postoperative analgesia. Studies have shown that a method for PCA to be given by way other than IV has been developed and has shown a certain prospect in clinical trials [12]. A new approach is being developed for systemic PCA that is less invasive and has a simple dosing regimen than IV PCA. These include intranasal (IN), inhalation, oral, sublingual, and percutaneous PCA systems. 1. Intranasal (IN) PCA: A solution prepared by using the dry powder preparation in water or saline using the opioid by the IN route. Rapid absorption and distribution of drugs in the nasal mucosa, studies have shown that morphine is shown to be effective in the second-stage study for relief of moderate to severe orthopedic pain [13]. It is currently in phase III development. Other opioids can be delivered via the IN route using a nasal spray device; but similar to IN morphine, these studies lack devices that contain typical PCA safety features. However, the IN method causes nasal congestion, upper respiratory tract infection, rhinitis, pharyngitis or nosebleed after long-term use [14]. 2. Inhalation of PCA: The inhaled morphine system (AERx Pain Management System; Aradigm Corporation, Hay-

ward, CA, USA) shares many typical safety features with PCA (such as lock-up period and liquid dose), Studies have shown that the use of morphine in phase II trials has the same efficacy and safety as standard IV PCA [15]. In a phase II study of pain in patients after orthopedic surgery, inhalation of fentanyl (Aerophys; YM Biosciences, Mississauga, ON, Canada) using a respiratory activated nebulizer was also effective [16, 17]. 3. Oral PCA: On-Demand Oral PCA device (Avancen, Mount Pleasant, SC, USA) is a device that locks onto the IV pole within reach of the patient. The RFID (radio frequency identification) wristband is programmed into the device and placed on the patient's wrist. At the end of the locking interval, the green indicator lights to alert the patient to the next dose. After the patient records the pain level on the device's pain scale (0-10) and slides the wristband in front of the device, the tray can be transferred to the open position and the patient can take the pill for medication. An evaluation of patients using the device showed that 95% of patients found that they provided better pain control than oral medications. In addition, more than 90% of nurses reported that it saved time, and more than 80% of nurses found it reliable and easy to program and access dispensing data for drugs [18]. Although this oral PCA device is a good choice for delivery and care of oral tablet drugs, its utility in the treatment of moderate to severe postoperative pain will be limited [12]. 4. Sublingual PCA device: Sufentanil NanoTab PCA system (AcelRx Pharmaceuticals, Redwood City, CA, USA) is designed for Sufentanil. The system uses a NanoTab (a 3 mm diameter oral transmucosal dosage form designed to minimize saliva response) in a preprogrammed handheld device with locking and RFID that allows for single user identification. The results showed that sufentanil characteristics were very suitable for use as a postoperative titratable drug; sublingual PCA was safer and more gentle than IV administration [15, 19]. The sufentanil NanoTab PCA system has been shown to provide effective postoperative analgesia with low side effects. 5. Skin penetration PCA: fentanyl ion penetration system (IONSYS) (Ortho-mcneil, Raritan, NJ, USA) is a non-invasive PCA method of pre-programming [20-23]. The system is attached to the patient's chest or upper arm by an adhesive. When the patient presses the button, fentanyl is transferred through the skin by iontophoresis. The system has a 10-minute lock-up interval and allows the patient to have a transdermal dose of 10 minutes each time it is activated. The dose of fentanyl will change over time [12]. The five new routes of administration described above may improve the pharmacokinetic profile of certain opioids that are not delivered by a classic IV drug such as sufentanil, and may have the advantage of a dedicated delivery device that does not require programming. Since IV PCA errors pose a risk to patient safety and cost increases, these alternative PCA methods should be further developed to minimize errors while providing an effective method and management for postoperative analgesia.

Mechanical and electronic analgesia pumps

The mechanical analgesia pump injects the liquid medicine by its internal pressure, and the pumping liquid does not flow at a uniform speed. At first, it is faster, and the middle gradually becomes stable. When a little liquid flows away, the pumping speed obviously increases [24]. It is composed of a reservoir, an automatic switch and a manual switch. The elastic retracting force of the silicone reservoir is used to drive the liquid, and the epidural catheter enters the spinal canal or the intravenous infusion tube to enter the vein to achieve analgesia. However, the electronically controlled analgesia pump is injected into the liquid by the motor, and the injection of the liquid is more stable. It consists of an electronic infusion control system and a liquid storage infusion system. The liquid storage bag is a one-time use. It uses high-performance single-chip microcomputer and control circuit to effectively control the infusion flow rate. The basic flow rate, PCA amount and locking time can be set according to the patient's specific conditions [25]. Studies have pointed out that mechanical analgesia pumps may affect the analgesic pump due to loss of elasticity, or the inability of the drug solution to enter due to blockage of the connected infusion catheter [26]. The electronic analgesia pump is pumped into the liquid by the motor, and the injection of the liquid is more uniform. If the connected catheter is blocked and the liquid cannot be pumped, the electronic analgesia pump will issue an alarm and correct it in time to provide better service for the patient. For anesthesiologists and paramedics, especially patients, electronic analgesic pumps are preferred [27].

PCA has the potential to address many of the issues associated with routine intramuscular injection when performing moderate to severe analgesia after surgery, and many studies have compared PCA with conventional analgesic methods, such as intramuscular injection. The literature review systematically summarizes the results of randomized controlled trials associated with postoperative PCA [28, 29]. Studies have shown that patients who receive PCA or intramuscular injections are on opioids when they are regularly given manual injections. There is little difference between consumption and pain scores, and the main difference between the two techniques is the patient's preference. Many authors have commented that PCA enables patients to resist postoperative side effects by titrating analgesics, which not only improves inadequate pain relief provided by nurses, but also enables patients to control analgesia themselves [30, 31]. However, other scholars believe that control is not important to patients, what is important is the feasibility of PCA to provide analgesia [32]. There are many disposable and electronic patient-controlled analgesia (PCA) devices that can be administered by epidural, intravenous or other routes [33]. In general, electronic analgesia pumps are safe and effective for patient-controlled epidural analgesia (PCEA) for childbirth and postoperative pain management [34]. A clinical study evaluated two electronic analgesic pumps GemStar pumps (Hospira Inc, Illinois and USA) and AmbIT Dynamic Infusion Therapy Pumps (Sorenson Medical Products, Utah, USA) for many years [35]. The GemStar pump has multiple power supplies; despite they are large in size and weight, the GemStar pump is also highly rated for not limiting mobility. And the ambit pump is a lightweight, battery-powered device that's smaller, lighter and more portable than the GemStar pump, designed to achieve optimal portability. Both PCA are portable compact devices, and PCA pumps provide continuous or intermittent analgesic solution delivery through an easy-to-program interface, as well as multiple programming and alarm functions. The patient and related care personnel were evaluated for user satisfaction and functionality of the two pumps. One group was used for childbirth and the other group was used for postoperative management. The results showed that both pumps were highly evaluated by patients and caregivers. There are no significant differences in degrees, but there are subtle differences in their strengths and weaknesses. The ambit pump is more advantageous in terms of storage in the delivery room than the GemStar pump and is more popular with patients, probably because it has a larger display. But for those who have not used the ambit pump before, the GemStar pump is easier to master.

Although many new analgesic drugs and PCA technologies have been developed in recent years, up to now, 50% to 70% of patients are not able to effectively control postoperative pain, and there are insufficiency of postoperative analgesia, and the accident rate is as high as 1.2% [36-38]. Studies have shown that the factors causing insufficient pain or even accidents in patients are multi-faceted [39, 40]. The reasons are: patients return to the ward after surgery, scattered in various wards, resulting in poor communication between patients and doctors. The doctor did not adjust the dosage of the drug; the analgesic pump alarm could not be timely responded; the patients could not receive postoperative analgesia because of the shortage of anesthesiologists and the distance between the anesthesiology department and the ward; the anesthesiologist's management of postoperative analgesia is not rigorous and standard. In summary, the main reason is the lack of advanced analgesic equipment, personalized analgesic programs and effective analgesia management [41].

With the improvement of economic and technological level, it has become possible to use advanced methods for effective postoperative analgesia. Internet-based PCA treatment is an inevitable trend in the development of pain treatment. As an active pain management system, the wireless analgesia system is a postoperative pain solution that integrates wireless remote monitoring, information management and high-precision electronic PCA pump. The wireless analgesia system consists of an analgesic terminal and a wireless analgesic management system. The analgesic terminal consists of an infusion device and a disposable special reservoir, and the wireless analgesia management system consists of a base station and management software [42]. The wireless analgesia system is a combination of electronic analgesia pump and wireless data trans-

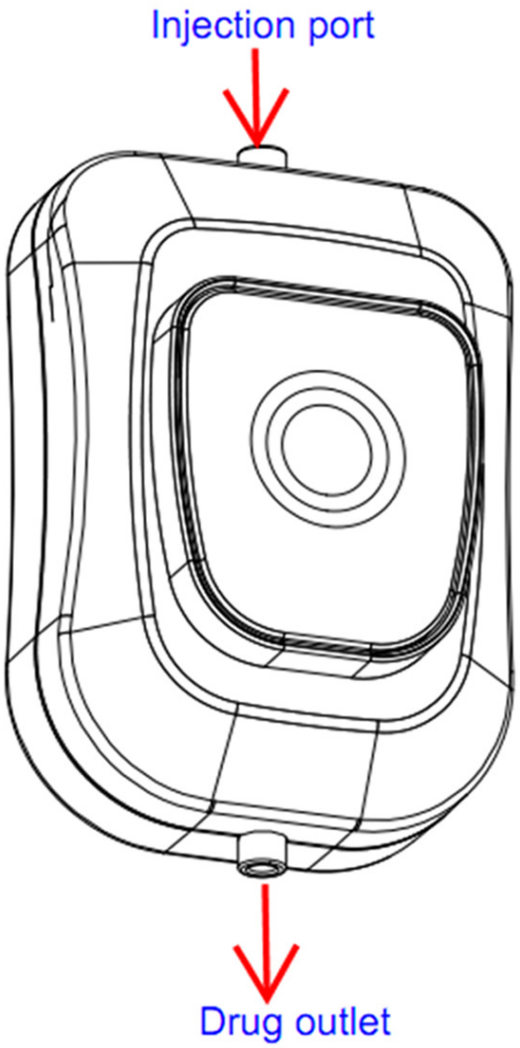

Figure 1. Sustainability adjustment PCA analgesic pump.

mission. It can transmit the information of the running wireless analgesia pump to the monitoring station for analysis and process by radio transmission. The hardware and electronic analgesia pump of the system ensures effective analgesia for patients. Software devices with statistical and analytical multi-function databases can realize real-time monitoring of PCA.

It helps the medical staff to monitor the analgesic pump in use in a centralized and real-time manner, to understand the operation of the analgesic pump in time, and to have an alarm function for the patient's analgesic and clogging of the infusion line, and finally form an electronic record of patient-controlled analgesia. The wireless analgesia pump can also adjust the parameters of the analgesic pump according to the patient's pain level, and meet the individualized needs of the patient's treatment. Through supervision of the wireless analgesia pump system, the effective number of times the patient presses the self-controlled analgesia key is observed in real time, first time to judge the quality of the patient's analgesia, timely treatment of pain. The alarm function of the wireless analgesia system eliminates the impact of bedside alarms on the patient, even in cases where the patient does not know, such as "end of infusion"; the anesthesiologist has received information that can be processed in advance according to the patient's condition. Studies have shown that compared with electronic analgesia pumps, wireless analgesia monitoring system has obvious advantages in postoperative intravenous analgesia, shortening effective treatment time, and significantly improving the patient's self-controlled intravenous analgesia 48 h after treatment [43]. The overall satisfaction, which is conducive to the informationization and standardized management of patient-controlled analgesia. Wireless analgesic system is an integral part of the Internet application and hospital information construction; the system can be used in microelectronics medical equipment and medical equipment information management system, is a safe, convenient and professional pain management automation equipment; wireless analgesic system can promote the development of professional direction toward informationization and standardization.

Discussion

Patient controlled analgesia (PCA) pump is an appropriate tool to control pain and it is a safe and reliable analgesic method. In recent years, PCA has been widely used in clinical practice and plays an important role in the treatment of postoperative acute pain. It has a wide range of applications in the treatment of analgesia such as childbirth, orthopedics, and cancer treatment. The patient-controlled analgesia pump is not only favored by patients, but also highly praised by medical staff. At present, most hospitals use disposable mechanical pumps and electronic analgesic pumps. The mechanical analgesia pump has the characteristics of small size, simple operation, easy porta-

Figure 2. PCA analgesic pump actual figure.

bility, low price, no power, no programming error. It greatly simplifies the PCA system, but the special material of the flow valve and infusion tube will affect the operation of PCA; safety may be reduced without warning function. In addition, the management of the mechanical analgesic pump also requires the anesthesiologist to perform repeated examination and observation of the patient every day. Due to the busy nursing work of medical staff, it is impossible to accurately observe the effective number of patients pressing the automatic analgesic pump. If the infusion line is blocked, it cannot be found and processed in time. However, the injection of electronic analgesia pump is accurate and equipped with alarm device, which can detect and process faults in time. In addition, the electronic analgesia pump is more flexible. It not only makes the patient more comfortable, reduces the pain of the patient and the adverse reactions, but also reduces the workload of the medical staff. However, the operation of the electronic PCA is complicated and programming errors may occur. The buttons are easy to be accidentally activated and lead to drug overdose, button failure, power interruption, battery shortage and other shortcomings. At present, there are more disposable mechanical analgesic pumps on the market, such as sustainable adjustment analgesia pumps, and patient-controlled analgesia pumps (PCA). The continuous analgesic pump on the market can choose 2 ml/h, 4 ml/h, 6 ml/h and 8 ml/h multi-flow sustainable infusion. Due to the related production process and material problems, the infusion pump cannot be uniformly injected, which affects the analgesic effect. In order to solve the problems of mechanical pumps, we propose a concept that combines the two on the basis of a sustainable analgesia pump and a patient-controlled (PCA) analgesia pump. The effect is shown in **Figure 1** and the real object in **Figure 2**. The disposable mechanical pump combines the sustainable adjustment with the PCA in the same drug delivery box. It not only facilitates patient-controlled analgesia, but also is convenient for the medical staff to regulate the flow rate. Based on the original flow rate, we also added a flow rate of 0 ml/h to achieve a multi-flow rate adjustment of 0-6 ml/h. The sachets and pipes of the analgesic pump are imported originals. It solves the problem that the mechanical pump on the market cannot uniformly inject the liquid, but compared with the electronic analgesic pump, the price is relatively low. The economic burden of the patient is not increased.

For mechanical and electronic analgesia pumps, some scholars have used two pumps for orthopedic surgery and found that mechanical analgesia pumps have fewer failures and higher patient satisfaction [44, 45]. Other studies have pointed out that the electronic pump is suitable for a larger population because it can be regulated according to the different needs of different patients [46]. **Table 1** summarizes the advantages and disadvantages of mechanical analgesia pumps, electronic analgesia pumps and wireless analgesia systems. In practical application, the choice of analgesia pump depends on the patient's specific conditions, the environment, the familiarity of the medical staff and the patient's ability to use a self-controlled analgesia pump. PCA pump can not only alleviate severe postoperative pain, but also reduce the occurrence of postoperative complications and promote postopera-

Table 1. Comparison of PCA

Species	Characteristics	Advantages	Disadvantages
Mechanical analgesia pump	Injecting liquid medicine by elastic retractive force of silicone reservoir	Small size, no power, simple operation, easy to carry, low price, no programming errors	Fluid injection is not stable, no alarm function
Electronic analgesia pump	Injection of liquid medicine by electric motor	Uniform and accurate injection, alarm device	Operation is cumbersome, prone to programming errors, button failure, insufficient battery
Wireless analgesia system	Based on Internet wireless remote monitoring, information management and high precision PCA pump	Safe, convenient, real-time monitoring, automatic generation of patient-controlled analgesia records	--

tive rehabilitation. PCA technology can use the Internet to set the parameters of the analgesic pump in accordance with the actual situation of the patient, in a safe and effective range, to achieve patient control and management. Patients only need to press the button of analgesic pump, and the liquid will be gradually injected into the body with small input and constant speed, so as to maintain a stable plasma concentration when patients are in pain, and the best effect can be obtained with the lowest dose and side effects, avoiding large fluctuations in plasma concentration and side effects caused by traditional methods [47, 48]. Studies have shown that PCA technology is feasible and safe for most patients with severe tumor pain who have poor response to oral analgesics, and PCA is used in family care after surgery for patients with advanced and advanced diseases [49].

In the past few decades, many experiments have evaluated safety and effectiveness of PCA. PCA can inject drugs at a constant rate and maintain stable plasma drug concentration, which has a good analgesic effect. It can minimize toxicity and side effects of analgesics and avoid serious physical and psychological changes caused by severe pain, which can help patients shorten postoperative pain time. Another advantage of PCA is that patients can control the dosage and time of medication according to their own needs, and can effectively overcome individual differences in pharmacokinetics. PCA is a method that truly meets the needs of different patients for individualized analgesic treatment. Although PCA technology has many benefits, there are still some risks in use. Studies have shown that from 1998 to 2003, when PCA analgesic pumps were involved in treatment, the risk of injury was increased by more than 3.5 times [50]. For electronic analgesic pumps, there are two main types of errors that may occur with PCA treatment: human error and equipment error. Human factors were identified as the main cause of PCA-related errors, and most errors occurred during the dosing phase [51].

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Disclosure of conflict of interest

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