A preliminary assessment of vital-signs-integrated patient-assisted intravenous opioid analgesia (VPIA) for postsurgical pain: a case series

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Abstract

Background We developed a Vital-signs-integrated Patient-assisted Intravenous opioid Analgesia (VPIA) analgesic infusion pump, a closed-loop vital signs monitoring and drug delivery system which embodies in a novel algorithm that takes into account patients' vital signs (oxygen saturation, heart rate). The system aims to allow responsive titration of personalized pain relief to optimise pain relief and reduce the risk of respiratory depression. Moreover, the system will be important to enable continuous monitoring of patients during delivery of opioid analgesia.Methods Nineteen patients who underwent elective gynecological surgery with postoperative patient controlled analgesia (PCA) with morphine were recruited. The subjects were followed up from their admission to the recovery room/ ward for up to 24 hours until assessment of patient satisfaction on the VPIA analgesic infusion pump.Results The primary outcome measure of incidence of oxygen desaturation showed all patients had at least one episode of oxygen desaturation (<95%) during the study period. Only 6 (31.6%) patients had oxygen desaturation that persisted for more than 5 minutes. The average percentage time during treatment that oxygen saturation fell below 95% was 4.6%. Fourteen (73.7%) out of 19 patients encountered safety pause, due to transient oxygen desaturation or bradycardia. The patients' median [IQR] pain scores at rest and at movement after post-op 24 hours were 0.0 [2.0] and 3.0 [2.0] respectively. The average ± SD morphine consumption in the first 24 hours was 12.5 ± 7.1mg. All patients were satisfied with their experience with the VPIA analgesic infusion pump.Conclusions We have demonstrated the potential of VPIA analgesic infusion pump to increase the safety and patient satisfaction by incorporating vital signs monitoring to intravenous opioid analgesia.

Background

More than 230 million major surgeries are performed annually in the world that could result in moderate to severe post-surgical pain (1). Patient-controlled analgesia (PCA) with an opioid pump is often the commonly used technique, as patients are able to individualize their own analgesic therapy, potentially leading to greater pain relief efficacy and improved satisfaction (2). PCA allows greater autonomy in managing pain and could reduce analgesic consumption (3, 4). However, 10% of patients who receive PCA may still experience severe pain (5). Inadequate postoperative pain management account for unwanted physiological and psychological effect such as increased postoperative morbidity, delayed recovery to normal daily living, and reduced patient satisfaction. Importantly, it may lead to persistent pain after surgery, which is often neglected. Overall, inadequate pain management increases the use of health care resources and health care costs (6).

Opioids adverse effects such as nausea, vomiting, sedation and respiratory depression may occur especially with high risk patients. Advanced age, respiratory disease and obstructive sleep apnoea may significantly increase the risk of respiratory depression with repeated opioid dosing (7, 8). Opioid respiratory depression may be associated with an increase length of stay and overall costs (9). Intermittent monitoring measures are highly labor intensive, but still may not reliably recognise opioid-induced respiratory depression in the postoperative period (5). According to Anaesthesia Patient Safety

Foundation, patients having vital signs charted every 4 hours are usually left unmonitored >90% of the time. Since these patients are commonly administered with supplemental oxygen, this may eventually complicate the monitoring by masking hypoventilation, causing the signs of respiratory depression to be recognized only in its later stage provided pulse oximetry monitoring is used (10).

Our overall aim is to develop a Vital-signs-integrated Patient-assisted Intravenous opioid Analgesia (VPIA) analgesic infusion pump with closed-loop vital signs monitoring and drug delivery system which embodies a novel algorithm that accounts for patients' vital signs (oxygen saturation, heart rate). In this preliminary study, our primary aim is to investigate the incidence of oxygen desaturation (defined as having oxygen saturation of <95% in a patient for more than 60 seconds) in patients using our VPIA analgesic infusion pump. We investigated the side effects of opioid administration (nausea and vomiting, sedation), patients' satisfaction and vital signs monitoring data.

Methods

This study was approved by the SingHealth Centralized Institutional Review Board, Singapore (SingHealth CIRB Ref: 2015/3062), and registered on Clinicaltrials.gov (NCT02804022). Written informed consent was obtained from every patient before any study procedure. The study period was between January 2017 and June 2017 and was conducted at KK Women's and Children's Hospital, Singapore

We recruited female patients aged 21 to 70 years old with American Society of Anesthesiologists (ASA) status I or II, undergoing elective surgery with the intent of using postoperative PCA with morphine for postoperative analgesia. The exclusion criteria were patients with allergies to morphine, history of significant respiratory disease or obstructive sleep apnea, unwilling to wear oxygen saturation monitoring devices throughout the study duration, pregnancy and unable to comprehend the use of PCA. Recruitment was performed either in the pre-operative assessment clinic or on the same day of surgery if they had not attended pre-operative assessment clinic. An information brochure describing the use of VPIA analgesic infusion pump for post-operative analgesia, including potential side effects and complications was provided to patients. Study personnel then took written informed consent from the patients.

Setting up of Infusion Pump

The algorithm and the VPIA analgesic infusion pump ("Intellifuse pump"; Model: Opiva) was designed by Innovfusion Pte Ltd, Singapore (Figure 1). Intravenous morphine used in the VPIA analgesic infusion pump was administered according to institutional guidelines: morphine diluted in normal saline to a concentration of 1 mg/ml, with bolus doses of 1 mg morphine delivered as per patient demand. In the VPIA analgesic infusion pump, vital signs monitoring (oxygen saturation, pulse rate) was programmed into the VPIA variable lockout algorithm allowing a temporary pause to the pump when vital signs safety threshold was breached and subsequent increase the lockout interval upon re-starting, thereby improving the safety of this device. When the vital signs were within normal range, the system was able to increase or decrease the lockout interval according to the analgesic needs of the patient. This lockout interval was a safety mechanism that limited the frequency of demands. By allowing an adequately long interval

between each dose, patients were given sufficient time to achieve the opioid's effects before the next dose. However, if the interval were prolonged, the effectiveness of patient controlled analgesia would be reduced.

The detailed VPIA variable lockout algorithm is illustrated in Figure 2. The bolus lockout interval was empirically set at 7 minutes, and was adjusted automatically according to patient successful demands and patient safety in the event of abnormal vital signs monitoring. The monitoring data was performed by taking average epochs of 15 seconds to summarize the vital signs. Missing vital signs were dropped from the analysis. However, if there was no available vital sign for the whole duration of each epoch, a safety pause would be raised. The VPIA variable lockout algorithm reassessed for the recovery of patients' vital signs at the end of the safety lockout period. If patients' vital signs did not recover to safe levels, the pump automatically raised the on-board alarm. Conversely, if patients' vital signs recovered beyond the threshold limits by the end of the safety lockout period, the lockout interval would be prolonged to increase safety. If at any time, there were critically abnormal vital sign parameters, the system would trigger the "emergency safety stop" function to cease patient boluses. The system would be manually restarted by the clinician or nurse after reviewing the patient.

All study subjects had intravenous access established before surgery. The patients were instructed on the use of the VPIA analgesic infusion pump prior to the study and educated to press the demand button whenever they needed pain relief. While in the recovery room after surgery, the VPIA analgesic infusion pump secured with a 50ml syringe of 1mg/ml morphine was connected to the patient's intravenous line for analgesia. An integrated pulse oximeter for continuous monitoring of oxygen saturation, and heart rate was also connected to the patient. Intravenous morphine was administered via the intravenous line with an anti-reflux and anti-siphon valve.

Data Collection

We collected and analyzed three sets of data: (1) patient demographic, medical and nursing parameters, hospital medical records; (2) VPIA analgesic infusion pump data including opioid consumption, patient demands, successful demands, pattern of demands, oxygen saturation and heart rate; and (3) VPIA analgesic infusion pump user feedback survey that was conducted at the end of the study.

Following the initiation of VPIA analgesic infusion pump, attending nurses who were educated on the usage and side effects of morphine therapy would monitor the patient at regular intervals and document pain scores (0-10 numeric rating scale), blood pressure, heart rate, oxygen saturation and sedation score (0 for "awake, alert", 1 for "occasionally drowsy, easy to rouse, responds to calling", 2 for "occasionally drowsy, difficult to rouse, responds to shaking only"; 3 for "unresponsive and unarousable; defined as no response to voice or physical stimulation"; D for "distressed; defined as awake and in great pain"). Side effects such as nausea and vomiting were also recorded. An independent observer (acute pain service) would visit the patient on the following day to assess the patient's overall satisfaction (numerical score between 0-100%) with the postoperative analgesia provided.

The acute pain service would assess the patient based on the number of days she was placed on the VPIA analgesic infusion pump, during which the feedback on pain relief effectiveness and any side effect from the therapy was gathered. Once the indications for PCA opioid for pain management were deemed unnecessary by the patient's primary care team, the VPIA analgesic infusion pump was disconnected.

Sample size calculation and statistical analysis

The primary outcome measure of the study is the incidence of oxygen desaturation (defined as having oxygen saturation of < 95% in a patient for more than 60 seconds) in patients using the VPIA analgesic infusion pump, while the secondary outcome measures are bradycardia, sedation, nausea/vomiting, pain scores, total consumption of morphine, patient's satisfaction score. Patient's oxygen saturation and heart rate were measured every minute for 24 hours. Assuming that patients have < 3% oxygen desaturation, 0.005 width of interval and 95% confidence interval, we would require 18,000 oxygen saturation readings. Each patient would provide at least 1200 readings. Therefore, the study is adequately powered for 18 patients with 1200 readings (= 18 X 1200 ~ 21,600) for both the primary and secondary aims.

Patient demographics, surgical and anesthetic characteristics were summarized as frequency with corresponding proportion for categorical data and as mean ± standard deviation (SD) or median [interquartile range IQR)], whichever applicable. The incidence rate, and 95% confidence intervals (CI), of binary outcomes (such as desaturation, bradycardia) were estimated based on the exact method by Wilson (11), which have demonstrated to have good statistical properties even for small number of subjects and/or extreme probabilities (12, 13). Significance level was set at 0.05 and all tests were two-tailed. SAS version 9.3 software (SAS Institute; Cary, North Carolina, USA) was used for the analysis.

Results

Twenty patients were recruited for this study over a 6-month period (December 2016 to May 2017), however one was withdrawn as she had an exclusion criteria of ASA III. The baseline and demographic characteristics are shown in Table 1. The mean age of patients was 51.5 ± 8.8 years (ranged 36-66 years), with an average body mass index (BMI) of 24.7 ± 4.42 mean (SD) kg/m^2. All patients recruited went through scheduled open surgery, with the majority (n=15) under Total Abdominal Hysterectomy and Bilateral Salpingo-oophorectomy (TAHBSO). The rest were open myomectomy (n=2) and salpingo-oophorectomy (n=2). Intraoperative morphine and fentanyl was administered with a median [IQR] dosage of 8.0 [2.0] mg and 100 [0.0] mcg respectively.

The patients were offered pain relief via VPIA analgesic infusion pump once they were transferred to the Post-Anesthesia Care Unit (PACU; Table 2). The median [IQR] dosage of morphine consumption during the stay was 4.0 [5.0] mg, whereas the last pain score before sending to ward was 3.0 [2.0]. Minimal to moderate sedation was observed in 15 patients, whereas 4 other patients exhibited no sedation, having an overall median sedation scoring (n=19) of 1.0 [0.0]. Only one patient showed nausea or vomiting during this period.

The first 12 hours post-operative in 19 patients showed pain score at rest and movement of 2.0 [5.0] and 5.0 [3.0] respectively (Table 2). At 24 hours, patients had pain scores of 0.0 [2.0] and 3.0 [2.0] at rest and movement respectively. The average ± SD morphine consumption in the first 24 hours was 12.5 ± 7.1mg. Patients during the hospitalization had minimal nausea/vomiting and sedation.

The primary outcome measure of incidence of oxygen desaturation (Figure 3) showed that all patients had at least one episode of oxygen saturation (SpO_2) decreasing below 95% transiently during the study period. Only 13 (68.4%, 95%CI 46.0% - 84.6%) patients had oxygen desaturations that persisted for more than 60 seconds. However, only 8 (42.1%, 95%CI 23.1% - 63.7%) and 6 (31.6%, 95%CI 15.4% - 54.0%) patients had persisted oxygen desaturation for both 3 and 5 minutes respectively. The average time and percentage of time that SpO_2 fell below 95% was 10.1 ±14.9 minutes and 4.6% respectively. All patients had at least one episode of heart rate (HR) <60/min with 3 (15.8%, 95%CI 5.5% - 37.6%) patients experiencing a HR of <60/min for longer than 60 seconds duration (Figure 4). The average time and percentage of time on treatment that HR fell below 60/min was 43.9 (143.1) minutes and 8.8% respectively. Only 1 (5.3%, 95%CI 1.0% - 24.6%) patient had HR <60 for both 3 and 5 minutes. There was no clinically significant respiratory event of note.

Fourteen out of 19 (73.7%) patients encountered safety pause, whereas ten (52.6%) patients had experienced emergency safety stop during the study period. Median (range) number of safety pause was 5 (1 - 21). Reasons for safety pause either occurrence of oxygen desaturation or bradycardia. Eleven (57.9%) patients had safety pause due to SpO_2 < 95% but all had HR > 60 during the episode. Six (31.6%) patients had HR < 60 but all had SpO_2 > 95% during the episode. There were 2 (10.6%) patients experiencing oxygen desaturation <90% for more than one minute. Post-operative side effects included nausea / vomiting (6/19) and pruritus (1/19).

The median [IQR] number of demands of bolus was 21 [19] per patient. The patients' mean ± SD pain scores at rest and at movement after 24 hours surgery were 3.2 ± 3.3 and 6.11 ± 2.7 respectively. Feedback received on VPIA analgesic infusion pump showed that all patients agreed that the pump was safe and effective to use, although they remained neutral on the mobility of the pole when the pump was mounted onto it (Table 3).

Discussion

We presented a case series on a novel drug delivery system with a novel reactive clinical algorithm and integrated with continuous physiological monitoring, to provide appropriate response to breach in continuous vital signs monitoring. VPIA analgesic infusion pump comprises in-built vital signs monitors and an adaptive algorithm that takes advantage of the vital signs integration and patient initiation to modulate the consumption of analgesia by varying the lockout time of patient bolus (and therefore the dose). The results of the present study suggest that the use of VPIA analgesic infusion pump, when integrated with a VPIA variable lockout algorithm, is able to provide pain relief with good patient

satisfaction in post-operative acute pain management. No significant adverse event was observed in this study.

Chou et al. found that 80 patients that underwent total abdominal hysterectomy and later given acute postoperative morphine analgesia (1-mg bolus of morphine solution with lockout time of 5 min and a maximum dosage of 15 mg within a 4-hour period in the absence of background infusion) had an average pain score (visual analogue scale VAS; at rest) of 3.75 and 2.8 at 6 hour and 24 hour post-operatively, scorings of 0.9 and 0.5 in nausea and sedation respectively, and a further 15% (12/80) in vomiting (14). The same study also found an average morphine consumption of 40mg in 48 hours, which is higher than our present data. Another study on patients after total knee arthroplasty showed an approximate VAS pain score of 2 and 1.5 at 12 and 24 hours respectively as well as an average morphine consumption of 27mg in 48 hours, indicating the different opioid consumption and pain scores across various surgical procedures (15).

Respiratory depression is reported in up to 5% with the use of PCA opioids (5, 16). A retrospective study on Chinese patients receiving PCA intravenous morphine showed that the incidence of respiratory depression (as defined by oxygen desaturation <90% for longer than one minute) is 1.62% (20/1233). This study showed a higher incidence due to differences in definition of oxygen desaturation and there could also be under-diagnosis of oxygen desaturation during conventional intermittent routine monitoring (17).

We used a closed-loop system with safety pause to lock out patient demands with breaches in vital signs safety threshold. These vital signs safety thresholds can be adjusted by the healthcare provider for high risk populations (elderly, patients with respiratory disease or morbidly obese). While optimizing the size of bolus dose appears to provide good pain relief with minimal side effects, there are limited data available concerning the effects of various dose sizes. Owen et al. examined the effects of morphine dose with 0.5 mg, 1 mg or 2 mg demand morphine bolus. Most who were prescribed 0.5 mg demand dose were unable to achieve adequate analgesia, whereas a high incidence of respiratory depression was reported in those who received 2 mg. Hence, an optimal PCA bolus dose for morphine of 1 mg is proposed (18). This study concentrated on varying the duration of the lockout interval as a safety mechanism. This safety of margin allowed an interval to be long enough for patient to receive the drug effect from the bolus dose, before the next bolus was delivered. There is no recommended optimal lockout interval, hence this would need to be individualized to the patient's pain relief and safety requirements (19). We also gathered patient centric outcomes through patient feedback on device setup (patient handset, pole stand) and overall treatment experiences (interference with treatment, safety and effectiveness). The overall feedback was positive, but the reduced mobility of the pump due to vital signs monitor integration would be looked into in future developments. This may involve designing a more portable setup.

Hospital practice of intermittent vital signs monitoring with opioid delivery is a concern. More than 75% of patients with moderate to severe sleep apnea are undiagnosed, and conventional risk stratification for heightened post-op monitoring could potentially miss patients at increased risk of respiratory depression

(20). This could result in increased length of stay, risk of hospital-acquired infections and increased costs (21). Furthermore, the medical legal implications associated with respiratory depression are huge. Opioid related respiratory depression reportedly had payment to the plaintiff in 45% of claims, with a median payment of USD$216,750 (22).

The limitations of the study would be the small sample size as this study was conducted in gynecological surgeries. Patients with different gender and surgical procedures would need to be investigated in future larger trials that may require different predefined critical values. Future study plans will also include refining new vital signs sensors, incorporating respirator rate monitoring and better integration with the delivery system to ensure better data capture.

Conclusions

In conclusion, this VPIA analgesic infusion pump system is able to detect and automatically respond to oxygen desaturation and bradycardia by instituting safety pause. This pilot study pump has positive user feedback. Future research and development would be needed to assess holistically the cost-effective value of the system in providing safe and effective opioid delivery during postoperative pain management.

Abbreviations

ASA: American Society of Anesthesiologists; BMI: Body mass index; CI: Confidence intervals; IQR: Interquartile range; PACU: Post-Anesthesia Care Unit; PCA: Patient controlled analgesia; SD: Standard deviation; SpO2: Oxygen saturation; TAHBSO: Total Abdominal Hysterectomy and Bilateral Salpingo-oophorectomy; VAS: Visual analogue scale; VPIA: Vital-signs-integrated Patient-assisted Intravenous opioid Analgesia.

Declarations

Ethical approval and consent to participate

This study was approved by the SingHealth Centralized Institutional Review Board, Singapore (SingHealth CIRB Ref: 2015/3062), and registered on Clinicaltrials.gov (NCT02804022). The authors declare that all the recruited patients provided informed consent, and that this work was conducted in accordance with the Declaration of Helsinki.

Consent for publication

Not applicable.

Availability of data and materials

The datasets generated and analyzed in this work are available for anyone who wishes to access the data by contacting the corresponding author.

Competing interests

Ban Leong Sng is an associate editor of BMC Anesthesiology. Ban Leong Sng and Alex Sia Tiong Heng have filed a patent related to this work (SG 10201801161P, filed 12 Feb 2018, Singapore). Alex Sia Tiong Heng has intellectual property ownership and is the founding scientific director of Innovfusion Pte Ltd. All other authors reports no conflicts of interest in this work.

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Authors' contributions

All authors contributed to the study design, data analysis and discussion, drafting and/or revising the manuscript. All authors approved the final version of the manuscript, and agree to be accountable for all aspects of this work.

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References

1. Weiser TG, Regenbogen SE, Thompson KD, Haynes AB, Lipsitz SR, Berry WR, et al. An estimation of the global volume of surgery: a modelling strategy based on available data. The Lancet. 2008;372(9633):139-44.
2. Wrona S, Chisolm DJ, Powers M, Miler V. Improving processes of care in patient-controlled analgesia: the impact of computerized order sets and acute pain service patient management. Pediatric Anesthesia. 2007;17(11):1083-9.
3. Thomas V, Heath M, Rose D, Flory P. Psychological characteristics and the effectiveness of patient-controlled analgesia. British Journal of Anaesthesia. 1995;74(3):271-6.
4. Momeni M, Crucitti M, De Kock M. Patient-controlled analgesia in the management of postoperative pain. Drugs. 2006;66(18):2321-37.
5. Paul JE, Buckley N, McLean RF, Antoni K, Musson D, Kampf M, et al. Hamilton Acute Pain Service Safety StudyUsing Root Cause Analysis to Reduce the Incidence of Adverse Events. Anesthesiology:

The Journal of the American Society of Anesthesiologists. 2014;120(1):97-109.
6. Joshi GP, Ogunnaike BO. Consequences of inadequate postoperative pain relief and chronic persistent postoperative pain. Anesthesiology Clinics of North America. 2005;23(1):21-36.
7. Maddox RR, Williams CK, Oglesby H, Butler B, Colclasure B. Clinical experience with patient-controlled analgesia using continuous respiratory monitoring and a smart infusion system. American journal of health-system pharmacy. 2006;63(2):157-64.
8. Schein JR, Hicks RW, Nelson WW, Sikirica V, Doyle DJ. Patient-controlled analgesia-related medication errors in the postoperative period. Drug safety. 2009;32(7):549-59.
9. Etches RC. Respiratory depression associated with patient-controlled analgesia: a review of eight cases. Canadian journal of anaesthesia. 1994;41(2):125.
10. Weinger MB, Lee LA. No patient shall be harmed by opioid-induced respiratory depression. APsF Newsletter. 2011;26(2):21-8.
11. Wilson EB. Probable inference, the law of succession, and statistical inference. Journal of the American Statistical Association. 1927;22(158):209-12.
12. Newcombe RG. Interval estimation for the difference between independent proportions: comparison of eleven methods. Statistics in medicine. 1998;17(8):873-90.
13. Brown LD, Cai TT, DasGupta A. Interval estimation for a binomial proportion. Statistical science. 2001:101-17.
14. Chou W-Y, Wang C-H, Liu P-H, Liu C-C, Tseng C-C, Jawan B. Human opioid receptor A118G polymorphism affects intravenous patient-controlled analgesia morphine consumption after total abdominal hysterectomy. Anesthesiology: The Journal of the American Society of Anesthesiologists. 2006;105(2):334-7.
15. Chou WY, Yang LC, Lu HF, Ko JY, Wang CH, Lin SH, et al. Association of μ-opioid receptor gene polymorphism (A118G) with variations in morphine consumption for analgesia after total knee arthroplasty. Acta Anaesthesiologica Scandinavica. 2006;50(7):787-92.
16. Macintyre P, Loadsman J, Scott D. Opioids, ventilation and acute pain management. Anaesthesia and intensive care. 2011;39(4):545-58.
17. Tsui S, Tong W, Irwin M, Ng K, Lo J, Chan W. The efficacy, applicability and side-effects of postoperative intravenous patient-controlled morphine analgesia: an audit of 1233 Chinese patients. Anaesthesia and intensive care. 1996;24(6):658-64.
18. Owen H, Plummer J, Armstrong I, Mather L, Cousins M. Variables of patient-controlled analgesia 1. bolus size. Anaesthesia. 1989;44(1):7-10.
19. Ginsberg B, Gil KM, Muir M, Sullivan F, Williams DA, Glass PS. The influence of lockout intervals and drug selection on patient-controlled analgesia following gynecological surgery. Pain. 1995;62(1):95-100.
20. Ankichetty S, Chung F. Considerations for patients with obstructive sleep apnea undergoing ambulatory surgery. Current Opinion in Anesthesiology. 2011;24(6):605-11.

21. Cohen MJ, Schecter WP. Perioperative pain control: a strategy for management. Surgical Clinics. 2005;85(6):1243-57.
22. Lee LA, Caplan RA, Stephens LS, Posner KL, Terman GW, Voepel-Lewis T, et al. Postoperative Opioid-induced respiratory DepressionA closed claims analysis. The Journal of the American Society of Anesthesiologists. 2015;122(3):659-65.

Tables

Table 1 Baseline and demographic characteristics of recruited subjects

Parameters	No. of patients	Mean (SD)/ Median [IQR] /Percentage
Age; years	19	51.5 (8.8)
Race	19	
Chinese	13	68.4%
Indian	3	15.8%
Malay	2	10.5%
Others	1	5.3%
Weight; kg	19	62.0 (9.85)
BMI; kg/m^2	19	24.7 (4.42)
ASA Status	19	
I	5	26.3%
II	14	73.7%
Intraoperative morphine (mg)	19	8.0 [2.0]
Intraoperative fentanyl (mcg)	19	100 [0.0]

SD: Standard deviation. IQR: Interquartile range.

Table 2 Pain characteristics during Post Anesthesia Care Unit (PACU) and ward stay

Parameters	No. of patients	Mean (SD)/ Median [IQR] /Percentage
During PACU stay	19	
Morphine (mg)	19	4.0 [5.0]
Last pain score before discharge (0-10)	19	3.0 [2.0]
Last sedation score before discharge (0-3)	19	1.0 [0.0]
Nausea/vomiting before discharge (0-3)	19	0.0 [0.0]
During Ward stay		
12 hours Post-op	19	
Pain score (at rest) (0-10)	19	2.0 [5.0]
Pain score (movement) (0-10)	19	5.0 [3.0]
Sedation score (0-3)	19	0.0 [0.5]
Nausea/vomiting	18	0.0 [1.0]
24 hours Post-op	19	
Pain score (at rest) (0-10)	19	0.0 [2.0]
Pain score (movement) (0-10)	19	3.0 [2.0]
Sedation score (0-3)	19	0.0 [0.0]
Nausea/vomiting	19	0.0 [0.0]
Morphine consumption (24 hours; mg)	19	12.5±7.1
Side effect		
Nausea / vomiting	6	31.6%
Pruritus	1	5.3%

Table 3 Post-operative feedback (n=19) on the VPIA analgesic infusion pump

Parameters	Values
Feedback (1-5; 1: Strongly disagree; 5: strongly agree)	
Patient handset button	4.0 (1.0)
Mobility of pole with mounted pump	3.0 (0.0)
No interference of vital signs monitoring with treatment	4.0 (2.0)
Pump safety	4.0 (1.0)
Pump effectiveness	4.0 (1.0)

Figures

Figure 1

An illustration of Vital-signs-integrated Patient-assisted Intravenous opioid Analgesia (VPIA) analgesic infusion pump.

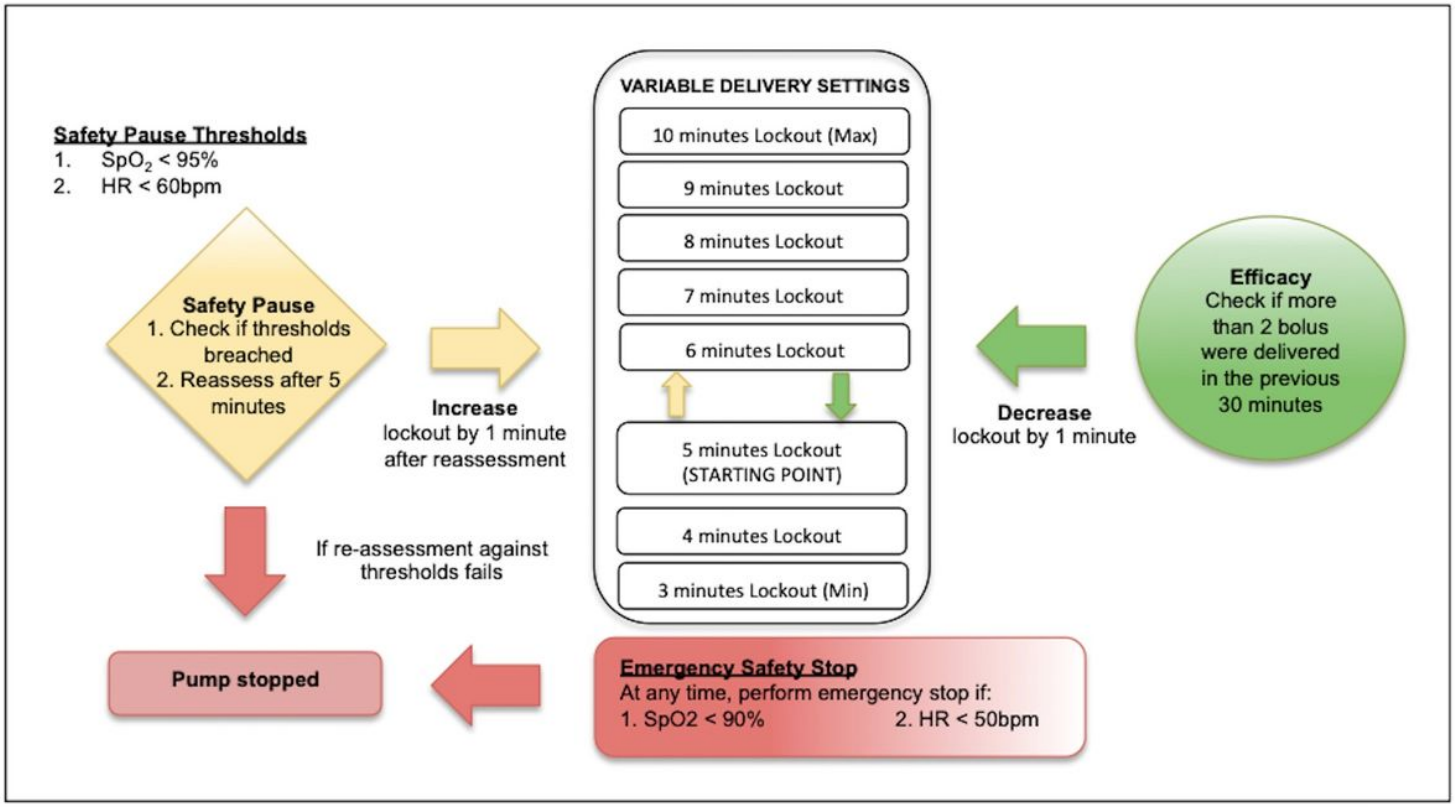

Figure 2

The proposed Vital-signs-integrated Patient-assisted Intravenous opioid Analgesia (VPIA) analgesic infusion pump and the variable lockout algorithm.

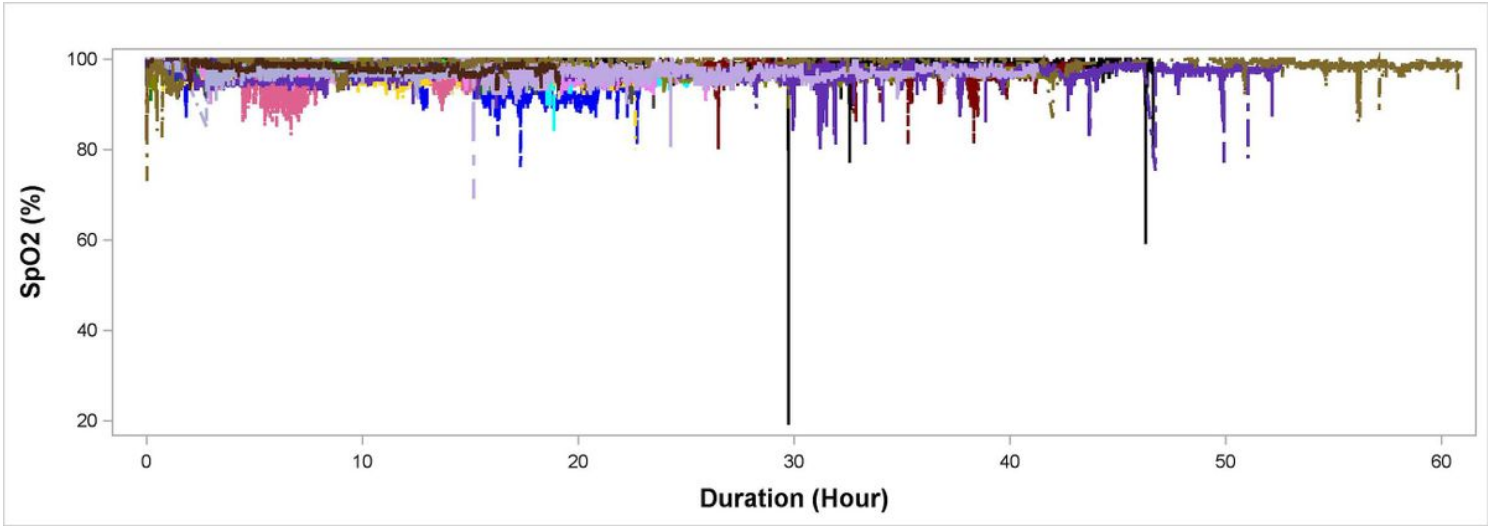

Figure 3

Level of oxygen saturation (SpO2) versus time (hour) in all 19 patients expressed in different colors.

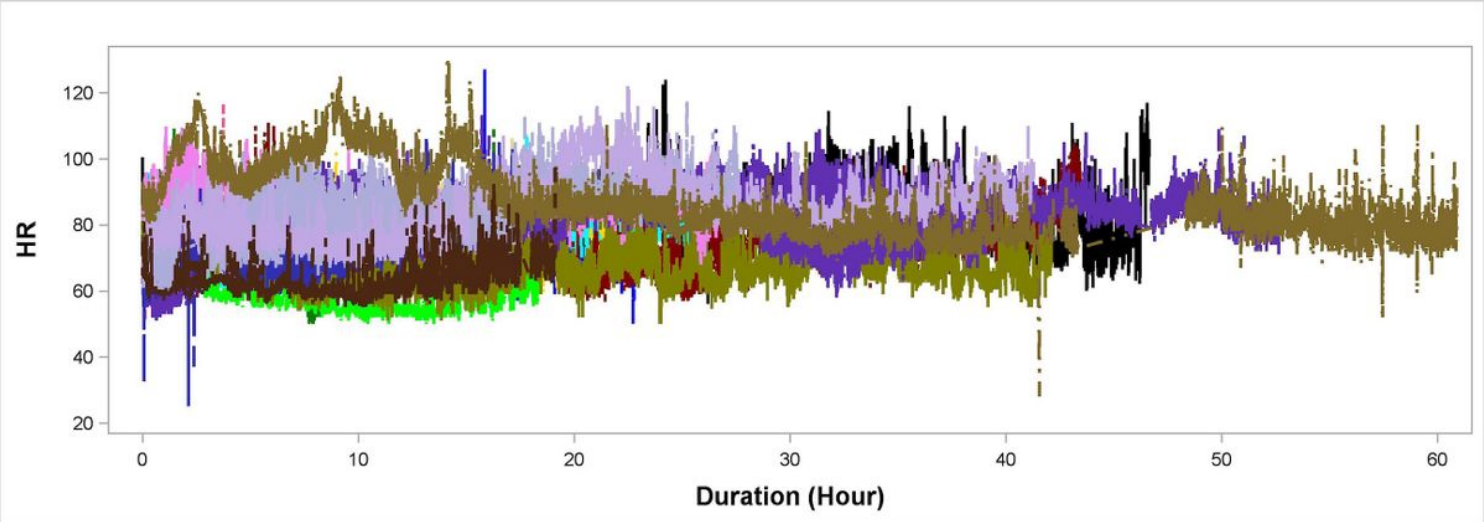

Figure 4

Heart rate (HR) versus time (hour) in all 19 patients expressed in different colors.