

Role of ketamine for analgesia in adults and children

Nalini Vadivelu, Erika Schermer¹, Vijay Kodumudi², Kumar Belani³, Richard D Urman⁴, Alan David Kaye⁵

Department of Anesthesiology, School of Medicine, Yale University, New Haven, CT 06520, ¹Program of Applied Translational Research, Yale University, New Haven, CT 06510, ²University of Connecticut, College of Liberal Arts and Sciences, Storrs, CT, ³Department of Anesthesiology, University of Minnesota Children's Hospital, Minneapolis, MN 55454, ⁴Department of Anesthesiology, Harvard Medical School, Brigham and Women's Hospital, Boston, MA, ⁵Department of Anesthesiology and Pharmacology, Louisiana State University Health Sciences Center, New Orleans, LA, USA

Abstract

Ketamine an N-methyl-D-aspartate (NMDA) receptor blocking agent and a dissociative anesthetic with neurostimulatory side effects. In recent years, multiple research trials as well as systematic reviews and meta-analyses suggest the usefulness of ketamine as a strong analgesic used in subanesthetic intravenous doses, and also as a sedative. In addition, ketamine was noted to possess properties of anti-tolerance, anti-hyperalgesia and anti-allodynia most likely secondary to inhibition of the NMDA receptors. Tolerance, hyperalgesia and allodynia phenomena are the main components of opioid resistance, and pathological pain is often seen in the clinical conditions involving neuropathic pain, opioid-induced hyperalgesia, and central sensitization with allodynia or hyperalgesia. All these conditions are challenging to treat. In low doses, ketamine does not have major adverse dysphoric effects and also has the favorable effects of reduced incidence of opioid-induced nausea and vomiting. Therefore, ketamine can be a useful adjunct for pain control after surgery. Additional studies are required to determine the role of ketamine in the immediate postoperative period after surgical interventions known to produce severe pain and in the prevention and treatment of chronic pain.

Key words: Analgesia, ketamine, N-methyl-D-aspartate receptor, perioperative, side effects

Introduction

There are approximately 25 million inpatient surgical procedures performed every year in the United States. A primary concern and challenge for patients and physicians is adequate perioperative pain care. Despite advances in technology including continuous peripheral nerve catheters and ultrasound guided nerve blocks, > 80% of patients report inadequate pain control resulting in persistent postoperative pain, extended hospital stay, and impaired rehabilitation.^[1] Overtreatment may result in

adverse events associated with excessive analgesic usage including increased morbidity and mortality, a higher risk of cardiac, pulmonary, gastrointestinal, and immune complications, and a higher rate of thromboembolic events. Other side-effects include central nervous system (CNS) mediated sedation and pulmonary complications including aspiration and atelectasis.^[2]

Pharmacological Properties

Ketamine has been found to be an ideal anesthetic due to its dose-dependent nature of producing analgesia, amnesia, unconsciousness, and akinesia.^[2] The dosage is well-established single bolus and consistent across patients.^[3] It has been suggested in animals that in addition to low-grade analgesia and high dose anesthesia ketamine could work in synergy with opioids at a dose termed the third dose range of ketamine where ketamine would be devoid of analgesic effects.^[4] Clinical studies are required to confirm the third dose effect of ketamine in humans.

Ketamine is a noncompetitive antagonist at NMDA receptor with analgesic and anti-hyperalgesic properties. Its chiral center on the C₂ atom of the ketamine cyclohexane

Address for correspondence: Dr. Richard D. Urman, Brigham and Women's Hospital/Harvard Medical School, 75 Francis St., Boston, MA 02115, USA.
E-mail: urmanr@gmail.com

Access this article online	
Quick Response Code:	Website: www.joacp.org
	DOI: 10.4103/0970-9185.168149

ring gives rise to two enantiomers of ketamine (S(+)- and R(-)-).^[5,6] It binds to the phencyclidinic site on postsynaptic channels and reduces the frequency and opening time of ion channels.^[7] This blockade by ketamine at the NMDA receptors is dose-dependent in that the rate of onset and the recovery from blockade are increased by applying NMDA agonists.^[8] The blockade at NMDA occurs by two different mechanisms. Firstly, by blocking the open channel, it subsequently reduces the mean open time of the channel. Secondly, upon binding to the closed receptor, it decreases the frequency of channel opening by an allosteric mechanism. Ketamine at lower concentrations predominantly causes blockade of the closed channel, whereas at higher concentrations it results in the blockade of both open and closed channels. These differences in the mechanism of receptor blockade based on ketamine concentrations have clinical implications. At low concentrations, analgesic properties are evident, whereas at higher concentrations anesthetic properties become apparent.^[8] Its noncompetitive nature allows glutamate to continue binding to these sites. In chronic pain states, upregulation of the NMDA receptor results in increased central sensitization and hyperalgesia. As a result, antagonists such as ketamine have been seen to stop afferent nociceptive transmission to the brain.^[6,9] Ketamine also maintains blood pressure and preserves spontaneous breathing and laryngeal reflexes.^[10] The S(+) isomer increases anesthetic potency two-fold over the racemic mixture while decreasing the psychotomimetic side effects.^[11] The second enantiomer, S(-) ketamine, has been suggested to have anti-hyperalgesic properties.^[12]

Various *in vitro* studies have demonstrated that ketamine blocks the high-affinity state of the dopamine D2 receptor. This might explain the psychomimetic effects occurring during emergence, as well as explain the catalepsy seen during peak anesthetic effects.^[13] Other *in vitro* studies have also demonstrated that ketamine has anti-inflammatory effects as it reduces tumor necrosis factor alpha, interleukin-6 (IL-6) and IL-8 levels, and also suppresses NF-KB expression which has a supposedly pivotal role in pro-inflammatory response. However, the exact mechanism by which it exerts the anti-inflammatory effect remains unclear.^[14]

Routes and Doses for Ketamine

Ketamine can be given via different routes: oral (PO), subcutaneous (SC), continuous SC infusion, per rectum, intramuscular (IM), intravenous (IV) and transdermal. Intranasal solutions and powders have also been used. The most common route used postoperatively is the IV route.

Doses Vary Upon the Route of Administration

The usual PO starting dose is 10-25 mg q8h, and intervals of q4-12 dosing have been reported. The dose can be increased up to 0.5-1 mg/kg q8h. Maximum reported dose is 200 mg q 6 h. For transdermal administration use 5-15% in Pluronic Lecithin Organogel; it is often combined with ketoprofen 10% and lidocaine 5%. Table 1 contains some useful instructions for patients in need of ketamine therapy to ensure patient safety. The SC dose is 10-25 mg (0.2-0.5 mg/kg) administered intermittently as needed. For example, it is commonly used for wound dressing changes and wound debridements. Single analgesic doses of ketamine can range from 0.2 to 0.5 mg/kg IV and 0.5-1.0 mg/kg IM given over 1-2 min. Larger doses can cause respiratory depression.^[7] Continuous IV infusions are usually started at 0.1-0.2 mg/kg/h. Small doses of an antisialogogue may be necessary to prevent excessive salivation.^[15] At higher doses, dissociative states can be induced by disconnection of the thalamocortical and limbic systems.^[16]

Ketamine for the Treatment of Chronic and Acute Pain

Ketamine has been used for the treatment of chronic and acute pain. An evidence-based study on the use of ketamine in chronic pain was done by Correll *et al.*^[17] who conducted a retrospective review of 33 patients with the chronic regional pain syndrome (CRPS) on treatment with subanesthetic ketamine infusion therapy. The study demonstrated some evidence that low dose ketamine infusion may provide safe and effective treatment to selected patients with intolerable CRPS. The concerns in this study were hepatic dysfunction and CNS side effects.

A large retrospective study done on the efficacy and tolerability of ketamine for perioperative control of acute pain in adults was conducted by Bell *et al.*^[18] Assessment of 37 trials revealed that 27 of 37 trials reduced pain intensity or rescue pain medication requirement or both perioperatively. Quantitative analysis showed that ketamine in the first 24 h after surgery reduced morphine requirements and decreased the incidence of postoperative nausea and vomiting. The authors did state that since the review was heterogeneous, interpretation of the data should be done with caution especially while suggesting a regimen for the use of ketamine.

For example, as shown in Table 2, the following ketamine flow sheet is used by the pain service at a tertiary care academic

institution. It is a conservative ketamine flow sheet with suggested ketamine infusion rates based on patient weight for starting a ketamine continuous infusion. The recommended ketamine dosage for initiation of therapy ranges from 60 to 120 µg/kg/h (0.06-0.12 mg/kg/h). It can be titrated to effect and increased appropriately with observation.

Norketamine is produced after IV injection. While little research has been performed on the analgesic characteristics of norketamine, a recent human study conducted to evaluate the effects of norketamine on acute ketamine analgesia suggests no correlation of norketamine to acute pain relief.^[9]

Ketamine is a highly lipophilic compound, and it distributes rapidly from that the systemic circulation. It has been noted

in humans up to that 47% of ketamine is bound to plasma proteins, and the free fraction is responsible for determining the rate of diffusion to the site of action.^[19] Ketamine is metabolized by in the liver by the enzymes CYP3A4, CYP2B6, CYP2C9 via N-demethylation and oxidation to norketamine (its primary active metabolite) and dehydroxynorketamine (a minor inactive metabolite) respectively. Norketamine is one-third to one-fifth as potent as ketamine, but it may provide prolonged anesthesia.^[20] It is subsequently metabolized by CYP2A6 and CYP2B6 to 4-,5-, and 6-hydroxynorketamine. After the glucuronidation of norketamines and hydroxyl norketamines in the liver, both are eliminated through the kidneys and bile.

Recent research has highlighted ketamine mediated analgesic properties and neuroprotection by its antagonism at the

Table 1: Patient education handout

Ketamine

Brand name(s): Ketalar®

There may be other brand names for this medicine

When this medicine should not be used

You should not receive this medicine if you have had an allergic reaction to ketamine

How to use this medicine

Injectable

A nurse or other trained health professional will give you this medicine

This medicine is given as a shot into one of your muscles. It can also be given through a needle placed in one of your veins

Drugs and foods to avoid

Ask your doctor or pharmacist before using any other medicine, including over-the-counter medicines, vitamins, and herbal products

Make sure your doctor knows if you are using any kind of narcotic pain medicine such as codeine, hydrocodone, oxycodone, OxyContin®, Percocet®, Tylenol® 3, or Vicodin®. Tell your doctor if you use a barbiturate such as phenobarbital

Make sure your doctor knows if you drink alcohol on a daily or regular basis

Warnings while using this medicine

Make sure your doctor knows if you are pregnant or breast feeding. Tell your doctor if you have blood circulation problems or untreated high blood pressure

This medicine may make you dizzy, drowsy, or confused for several hours. If you have had outpatient surgery, you will need someone to drive you home

This medicine may make you have unusual thoughts or behaviors after the surgery. You might feel confused or excited, or you might see or hear things that are not really there. You might feel as if you are dreaming while you are awake. Call your doctor if these thoughts or behaviors are severe or last longer than 24 h

Wait at least 24 h after you receive this medicine before you drive, use machines, or do anything else that could be dangerous if you are not alert

Possible side effects while using this medicine

Call your doctor right away if you notice any of these side effects

Allergic reaction: Itching or hives, swelling in your face or hands, swelling or tingling in your mouth or throat, chest tightness, trouble breathing

Fast, slow, or uneven heartbeat

Lightheadedness or fainting

Redness, pain, or blistering where the shot was given

If you notice these less serious side effects, talk with your doctor

Cough

Eye twitching, or double vision

Muscle stiffness

Nausea, vomiting, or loss of appetite

Skin redness or mild rash

If you notice other side effects that you think are caused by this medicine, tell your doctor

Reference: UCLA Micromedex-Ketamine, with permission

Table 2: Suggested ketamine infusion rates based on patient's weight

Recommended Dosage: 60-120 mcg/kg/hr or 0.06-0.12 mg/kg/hr
Concentration: 2 mg/mL

Weight (kg)	Infusion dose (mg/kg/hr)						
	0.06	0.07	0.08	0.09	0.1	0.11	0.12
	Infusion rate (ml/hr)						
50	1.5	1.75	2	2.25	2.5	2.75	3
55	1.65	1.925	2.2	2.475	2.75	3.025	3.3
60	1.8	2.1	2.4	2.7	3	3.3	3.6
65	1.95	2.275	2.6	2.925	3.25	3.575	3.9
70	2.1	2.45	2.8	3.15	3.5	3.85	4.2
75	2.25	2.625	3	3.375	3.75	4.125	4.5
80	2.4	2.8	3.2	3.6	4	4.4	4.8
85	2.55	2.975	3.4	3.825	4.25	4.675	5.1
90	2.7	3.15	3.6	4.05	4.5	4.95	5.4
95	2.85	3.325	3.8	4.275	4.75	5.225	5.7
100	3	3.5	4	4.5	5	5.5	6

Mechanism = NMDA antagonist, Used as an analgesic in patients with severe opioid resistant pain, neuropathic pain, phantom limb pain, or chronic pain. Also used as an adjunct in opioid detoxification. Adverse events = Hypertension, tachycardia, increased cardiac output, paradoxical myocardial depression, increased pulmonary artery pressure, hallucinations, tonic-clonic movements. Ketamine infusion flow sheet.

Source: Modified with permission, from UCLA, Department of Anesthesiology

NMDA receptor. The amnesia and sedation produced by ketamine are associated with few cardiopulmonary adverse reactions, making it useful in procedural sedation, in particular with spontaneous ventilation commonly seen in the emergency room setting.^[21] The large therapeutic window and low cost of ketamine make it an attractive choice in environments where monitoring and resources are sparse.^[22]

Ketamine has morphine-sparing effects in subanesthetic doses, thereby increasing respiratory and hemodynamic stability. In addition, low doses of ketamine did not elicit the typical responses of increased heart rate and high blood pressure usually associated with ketamine administration.^[23] The combined treatment can thus reduce the side effects of opioids, and protocols have evolved for low dose ketamine administration [Tables 3 and 4]. The psychomimetic effects of ketamine leading to dissociative anesthesia, emergence agitation and nausea and vomiting have led to negative comments on its clinical role.

Newer Uses of Ketamine

The use of ketamine, a phencyclidine derivative as a potential analgesic was first identified in the early 1960s.^[2] It was one of the 200 derivatives investigated for clinical use. However, concerns about ketamine-induced psychotomimetic effects decreased its popularity. Initial efficacy was focused primarily on the anesthetic properties of ketamine and as an induction agent; its analgesic properties were largely ignored until it came

to market in 1970, following Food and Drug Administration approval.^[2] Evolving research has suggested a positive role for ketamine for postoperative analgesia, applied either alone or in combination with other analgesics to adequately alleviate pain while maintaining hemodynamic stability. Ketamine is a highly lipid soluble dose-dependent anesthetic and analgesic that can be administered orally, rectally, intranasally, IV, IM, or intrathecally.^[3] It has been successfully applied for nociceptive and neuropathic pain.^[3] Although ketamine is known to increase intracranial pressure, it has been tolerated during neurosurgical procedures and patients have not sustained neurological damage following cardiopulmonary surgery.^[4] Nociceptive stimuli are known to trigger the release of catecholamines. This causes disturbances in respiratory and immune function. Such complications can increase hospitalization time, raise costs, and create the potential for chronic pain state.^[23] Ketamine offers better sedation and analgesia with fewer respiratory effects when compared to midazolam or fentanyl. In addition, it provides anxiolysis while maintaining cardiovascular stability.^[7] Thus, recent studies suggest its benefits in treating chronic pain,^[4] depression,^[24] as an analgesic during burn care^[2] and other complex and challenging subpopulations. Ketamine blocks nitric oxide, m-opioid and NMDA receptors.^[2] These properties support its role for chronic pain management.

Ketamine as an Analgesic

Typical analgesics improve pain scores and decrease analgesic complications while allowing a quicker rehabilitation and mobilization period. Despite early reports of ketamine's undesired dissociative side effects, more recent research has overwhelmingly documented that the drug provides many advantages for use during surgical procedures. Addition of ketamine as an adjuvant to opioids in treating postoperative pain results in effective postoperative analgesia^[25] as well as attenuation of acute analgesic tolerance to opioids, and prevents rebound pain that occurs following opioid usage. Therefore, a ketamine/opioid combination can result in decreased opioid consumption and extended analgesia.^[26] In order to assess the efficacy of IV ketamine in minimizing postoperative analgesia, a randomized double-blind clinical trial was conducted in 40 patients undergoing elective laparoscopic cholecystectomy.^[25] Patients > 18 years of age, American Society of Anesthesiologists (ASA) I and II have were included in the study. Those with body mass index of <18 or >35 kg/m², history of chronic substance/alcohol abuse, contradiction to opioids, ketamine and nonsteroidal anti-inflammatory drugs were excluded. Two groups were identified, a propofol group (administered propofol and alfentanil with saline) and a ketamine group

Table 3: Low dose ketamine infusion protocol

Low dose ketamine infusion

For use by acute, chronic and palliative care patients. This policy is not indicated for use in end of life pain and symptom control

Purpose

To provide effective, consistent, safe pain management for patients who have unrelieved pain even with the use of high dose of opioid or who have tolerance to opioid therapy. This policy provides for an interdisciplinary approach to pain management

Policy

General

Initiation of ketamine infusion must be started in ICU or PACU. After 4 h of assessment and vital signs monitoring, the patient may return to their home unit if stable

The pain management or palliative care services are to serve as a consultant for all patients (except those in picu) receiving ketamine infusions and will follow patients for 12 h after the infusion has been discontinued

The infusion of ketamine in the icu/pacu or general floors is to be used only as adjunctive analgesia for patients with intractable pain that is not controlled with conventional analgesic regimen as determined by pain management or palliative care service

A registered nurse must complete the ketamine education and competency prior to administering the ketamine infusion

All ketamine doses will be determined exclusively by the pain service or palliative care service

Ketamine must be infused using the continuous basal rate mode and must be used with a locked patient-control compartment (PCA pump is appropriate)

The patient is to be placed on a cardiac monitor with continuous pulse oximetry and with vital signs monitoring until the ketamine infusion is discontinued

Ketamine infusion will be prepared with NS in a syringe as 100 mg/50 ml with a concentration of 2 mg/ml or 500 mg/50 ml with a concentration of 10 mg/ml

Ketamine boluses may only be administered in the icu or pacu by the pain management or palliative care service

No additional iv, im, po narcotics, sedatives or cns depressants are to be given except as ordered by pain management or palliative care service

No blood draws are to be obtained from the port or IV line where the continuous ketamine is infusing

Procedures

Physician's responsibilities

The pain management or palliative care service, with the exception of patients in picu, shall solely determine which patients are eligible, and prescribe low dose (0.06-0.12 Mg/kg/h) of ketamine infusions. When necessary, the pain management or palliative care service may recommend a higher dose

The PCA pump programming orders are to include: Medication, concentration of the medication, mode, basal rate in mg/h

The pain management or palliative care service is to order the vital sign frequency and parameters, and notify nursing staff of any additional requirements as needed

Order initial ketamine using the low ketamine infusion order set (Form # xxxxx). change in ketamine infusion must be written on the pre-printed Low dose ketamine infusion order sheet

Nursing staff responsibilities

Institute falls precautions and instruct the patient and the family regarding the need to ask for assistance when ambulating to reduce the risk of falling

At the change of the shift or during any "hand off", the RN will verify the medication, dose, and settings with a second RN

Assess IV site for patency per unit standard and PRN

Do not "Y" connect any other IV medications into the Ketamine infusion with the exception of IV comparable opioid, i.e., morphine

A minimal fluid infusion rate may be used to keep the vein open

Assessment and monitoring parameters

In ICU's/PACU

Upon initiation of ketamine infusion, the patient must be monitored in pacu or icu with vital signs every 15 min × 4, then every 30 min × 2, then at a minimum of q 2 h

On the floor

Vital signs are to be assessed at least every 4 h or as ordered by the pain management or palliative care service throughout administration. If a dose is increased by the ordering service, vital sign × 1 is to be obtained in 30 min

Assess for signs of adverse psychological manifestations, pain management or palliative care service should be notified if patient experiences iii-vi

Pleasant, dream-like states

Vivid imagery

Hallucinations

Delirium

Nystagmus-early sign that the dose is too high (mild nystagmus is an expected outcome)

Confusion and nightmares-late sign that dose is too high

Continued

Table 3: (Continued)

The following are to be assessed

- Medication, concentration, dose, mode, and basal rate
- Vital signs with oxygen saturation per unit standard and PRN
- Pain scores with vital signs per unit standard and PRN
- Sedation score with vital signs per unit standard and PRN

Agitated, restless

- Cooperative, oriented
- Asleep, easily arousable
- Asleep, arouses to voice
- No response to verbal stimuli
- No response to pain

Documentation

- Pain assessment and reassessment will be documented based on using the appropriate age related pain scales
- The following assessment is required to be documented in the medical record when a patient is on a ketamine infusion
- Pain score at least every 4 h and PRN
- Sedation level at least every 4 h and PRN
- RR at least every 4 h and PRN
- Oxygen saturation at least every 4 h and PRN
- Total dose in mg infused every 4 h
- Plan of care review every shift
- Provide patient education handout [refer to Table 1]

Notify the pain management or palliative Care Service if

The following signs of adverse reaction occur

- RR 30% <baseline
- HR 20% >baseline
- Systolic BP 20% >baseline
- Diastolic BP 20% >baseline
- Enhanced muscle stiffness

ICU = Intensive care unit, PICU = Pediatric Intensive care unit, PACU = Postanesthesia care unit, PCA = Patient-controlled analgesic, NS= Normal saline, IV = Intravenous, IM = Intramuscular, PO = Plus oral, CNS = Central nervous system, RR = Respiratory rate, HR = Heart rate, BP = Blood pressure.
Source: Modified with permission, from UCLA, Department of Anesthesiology

(administered propofol and alfentanil with ketamine). The number of additional doses of alfentanil and the total amount given intraoperatively were recorded. Assessment of pain and cumulative analgesic consumption were recorded at postanesthesia care unit (PACU) admission, PACU discharge, and postoperatively for 24 h. The study showed that patients in the ketamine group had better analgesia both intra- and post-operatively. Additionally, analgesic consumption in the ketamine group was reduced when compared to the propofol group. After this, its use as a drug for postoperative pain using patient-controlled analgesic became recognized.^[27]

Epidural Ketamine

There has been increased interest in recent times of the use of ketamine via the epidural route for postoperative analgesia as part of a multimodal regimen. A study on 100 patients by Sethi *et al.* studied the role of ketamine via the epidural route for postoperative analgesia when combined with bupivacaine and morphine undergoing major upper abdominal surgery.^[28] However, there are

concerns for neurotoxicity in animals^[29] and the report of spinal myelopathy after intrathecal injection of large doses of ketamine.^[30] Preservative-free ketamine in a concentration of 0.2 mg/ml was used in their study to avoid possible neurotoxicity due to epidural ketamine.

Subramaniam *et al.* studied the use of ketamine via the epidural route in 46 ASA physical status I and II patients who underwent major upper abdominal surgery.^[31] They found that in patients undergoing major abdominal surgery there was improved analgesia without the increase of side effects during administration of dilute epidural ketamine at a dose of 1 mg/kg with morphine 50 µg/kg. More clinical studies are warranted to evaluate the use of routine epidural ketamine administration.

Drawbacks of Ketamine

Nonmedical use of ketamine began to spread once its anesthetic and psychostimulatory properties were recognized. The use of ketamine as a “club drug” rose in popularity during the 1990s and has seen another wave of consumption in

Table 4: Orders for ketamine infusion

Physician Name: _____ Acute Pain Service Palliative Care Service
 Orders to be written only by acute pain or Palliative Care Service
 Recommended dosage: Ketamine infusion 60-120 mcg/kg/h (=0.06-0.12 mg/kg/h)
 Medication (drug and concentration)
 Patient weight: _____ kg
 Baseline RR ____; HR ____; BP ____mmHg
 Ketamine 100 mg in 50 ml NS syringe (2 mg/ml)
 Ketamine 500 mg in 50 ml NS syringe (10 mg/ml)
 Pump program parameters (delivered via locked patient-control compartment, i.e., PCA pump)
 Mode: Continuous basal mode only
 Units: mg
 Ketamine syringe concentration: 2 mg/ml 10 mg/ml
 Dose: mcg/kg/h=_____mg/kg/h=_____mg/h
 Must be completed by MD
 Recommended: 60-120 mcg/kg/h = 0.06-0.12 mg/kg/h
 Treatment of side effects
 Ondansetron 4 mg IV every 6 h PRN severe nausea
 Lorazepam 1 mg IV every 4 h PRN unpleasant dreams, mild hallucinations, or agitation
 Assessment and monitoring parameters
 Document vital signs, including BP, HR, RR, sedation level, and signs of adverse psychological manifestations
 In ICU's/PACU: Upon initiation of ketamine drip, the patient must be monitored in the PACU or ICU with vital signs q15 min ×4, then every 30 min ×2, then a minimum of every 2 h
 Floor (non-ICU) patients: Vital signs assessed upon transfer and at least every 4 h or as ordered by the Pain Management or Palliative Care Service throughout the administration of Ketamine infusion. After a dose increase, vital signs should be assessed in 30 min ×1, then q4 h and PRN thereafter
 Assess for signs of adverse psychological manifestations, and notify the Pain Management or Palliative Care Service if patient experiences iii — vi
 Pleasant, dream-like states
 Vivid imagery
 Hallucinations
 Delirium
 Nystagmus-early sign that the dose is too high (mild nystagmus is an expected outcome)
 Confusion and nightmares-late sign that dose is too high
 The following are to be assessed
 Drug, concentration, dose, mode, basal rate
 Vital signs with oxygen saturation
 Pain scores with vital signs and PRN
 Sedation score with vital signs and PRN
 Notify Pain Management/Palliative Service for the following
 RR 30% < baseline, stop infusion then call Pain Service or Palliative Care physician
 HR 20% > baseline
 Systolic or diastolic BP 20% > baseline
 Sedation scale: If patient is unresponsive to verbal stimuli or pain
 Inadequate analgesia, after checking integrity of IV site, tubing, and pump
 Any severe adverse psychological manifestations listed above
 Muscle stiffness
 Other: _____
 No additional narcotics, sedatives or CNS depressants are to be given except as ordered by the Acute Pain Service or Palliative Care Service
 MD Signature: _____ Pager _____ Date: _____ Time: _____
 RN Signature: _____ Date: _____ Time: _____

BP = Blood pressure, RR = Respiratory rate, HR = Heart rate, NS = Normal saline, PCA = Patient-controlled analgesic, IV = Intravenous, ICU = Intensive Care Unit, PACU = Postanesthesia Care Unit.

Source: Modified with permission, from UCLA, Department of Anesthesiology

contemporary times. Ketamine is also known under the street names of “special K,” “vitamin K,” and “LA coke,” and is used recreationally by traditionally younger generations

to produce altered states of consciousness, delirium, and slowed perception of time.^[32] The drug is inexpensive and easily accessible and can be either ingested nasally in powder

form, smoked when added to cigarettes or administered IV or SC.^[7] However, ketamine is also highly addicting, and multiple studies have demonstrated profound short-and long-term effects on the human body. Even occasional use of ketamine impairs working, episodic, and semantic memory.^[33] Magnetic resonance imaging detectable changes in the brain were studied in 21 ketamine addicts to note the various regions in the human brain that are susceptible to chronic ketamine injury. The ages of the included subjects ranged between 19 and 48 years and those with a previous history of brain tumor or neurological disease were excluded from the study. The subjects had been using ketamine in doses of 0.2-3 g/day over duration of 0.5-12 years. Atrophy was evident in frontal, parietal, occipital cortices, prefrontal lobes, brain stem and corpus striatum of addicts with the severity of lesions depending on the duration of addiction.^[34] This is especially concerning as users and abusers of ketamine tend to be adolescents or young adults. In this regard, ketamine can cross the placenta into fetal circulation, leading to atrophy of the fetal brain.^[10] Another drawback of ketamine is its damaging effects on the bladder and renal system, leading to bleeding and incontinence.^[32]

While ketamine alone or in combination with other drugs has proved successful in many realms, its usefulness is limited. Ketamine has been found to worsen the behaviors of individuals with obsessive-compulsive disorder, creating delayed-onset suicidal ideation.^[35] Individuals with Kisbourne syndrome, also known as opsoclonus-myoclonus ataxia, appear to develop increased myoclonus and opsoclonia when administered ketamine and atropine.^[36] Due to the potential for hallucinations, patients with psychiatric ailments or those abusing alcohol or amphetamines should not receive ketamine, as it may worsen preexisting conditions.^[3]

Conclusion

In summary, ketamine is a strong analgesic employable in subanesthetic without major neuropsychiatric adverse effects. Ketamine decreases pain intensity in the postoperative period, and it has been shown clinically to decrease opioid consumption, decrease the side effects of opioids and increase the time for rescue analgesics—all these are attractive properties that suggest a role for ketamine as a useful adjuvant in the treatment of postoperative pain. In addition to further exploring the role of ketamine as an adjuvant for perioperative pain control, continued research is needed to determine if perioperative ketamine is useful for the treatment of pain after surgery known to result in severe pain and in the prevention and treatment of chronic pain.

Acknowledgments

The authors would like to thank the UCLA Pain Committee chaired by Dr. Siamak Rahman, MD who developed the ketamine order sets and patient educational handout, Tables 1 and 2.

References

1. Apfelbaum JL, Chen C, Mehta SS, Gan TJ. Postoperative pain experience: Results from a national survey suggest postoperative pain continues to be undermanaged. *Anesth Analg* 2003;97:534-40.
2. Grathwohl KW. Does ketamine improve postoperative analgesia? More questions than answers. *Pain Med* 2011;12:1135-6.
3. Guldner GT, Petinaux B, Clemens P, Foster S, Antoine S. Ketamine for procedural sedation and analgesia by nonanesthesiologists in the field: A review for military health care providers. *Mil Med* 2006;171:484-90.
4. Persson J. Ketamine in pain management. *CNS Neurosci Ther* 2013;19:396-402.
5. Domino EF. Taming the ketamine tiger 1965. *Anesthesiology* 2010;113:678-84.
6. Noppers I, Niesters M, Aarts L, Smith T, Sarton E, Dahan A. Ketamine for the treatment of chronic non-cancer pain. *Expert Opin Pharmacother* 2010;11:2417-29.
7. Cromhout A. Ketamine: Its use in the emergency department. *Emerg Med (Fremantle)* 2003;15:155-9.
8. Orser BA, Pennefather PS, MacDonald JF. Multiple mechanisms of ketamine blockade of N-methyl-D-aspartate receptors. *Anesthesiology* 1997;86:903-17.
9. Niesters M, Martini C, Dahan A. Ketamine for chronic pain: Risks and benefits. *Br J Clin Pharmacol* 2014;77:357-67.
10. Dong C, Anand KJ. Developmental neurotoxicity of ketamine in pediatric clinical use. *Toxicol Lett* 2013;220:53-60.
11. Leal PC, Sakata RK, Salomão R, Sadatsune EJ, Issy AM. Assessment of the effect of ketamine in combination with remifentanyl on postoperative pain. *Braz J Anesthesiol* 2013;63:178-82.
12. Lee SK. The use of ketamine for perioperative pain management. *Korean J Anesthesiol* 2012;63:1-2.
13. Seeman P, Ko F, Tallerico T. Dopamine receptor contribution to the action of PCP, LSD and ketamine psychotomimetics. *Mol Psychiatry* 2005;10:877-83.
14. Bhutta AT. Ketamine: A controversial drug for neonates. *Semin Perinatol* 2007;31:303-8.
15. Salas S, Frasca M, Planchet-Barraud B, Burucoa B, Pascal M, Lapiana JM, et al. Ketamine analgesic effect by continuous intravenous infusion in refractory cancer pain: Considerations about the clinical research in palliative care. *J Palliat Med* 2012;15:287-93.
16. Svenson JE, Abernathy MK. Ketamine for prehospital use: New look at an old drug. *Am J Emerg Med* 2007;25:977-80.
17. Correll GE, Maleki J, Gracely EJ, Muir JJ, Harbut RE. Subanesthetic ketamine infusion therapy: A retrospective analysis of a novel therapeutic approach to complex regional pain syndrome. *Pain Med* 2004;5:263-75.
18. Bell RF, Dahl JB, Moore RA, Kalso E. Peri-operative ketamine for acute post-operative pain: A quantitative and qualitative systematic review (Cochrane review). *Acta Anaesthesiol Scand* 2005;49:1405-28.
19. Dayton PG, Stiller RL, Cook DR, Perel JM. The binding of ketamine to plasma proteins: emphasis on human plasma. *Eur J Clin Pharmacol* 1983;24:825-31.

20. Kohrs R, Durieux ME. Ketamine: Teaching an old drug new tricks. *Anesth Analg* 1998;87:1186-93.
21. White PF, Way WL, Trevor AJ. Ketamine — Its pharmacology and therapeutic uses. *Anesthesiology* 1982;56:119-36.
22. Green SM, Clark R, Hostetler MA, Cohen M, Carlson D, Rothrock SG. Inadvertent ketamine overdose in children: Clinical manifestations and outcome. *Ann Emerg Med* 1999;34:492-7.
23. Neshar N, Serovian I, Marouani N, Chazan S, Weinbroum AA. Ketamine spares morphine consumption after transthoracic lung and heart surgery without adverse hemodynamic effects. *Pharmacol Res* 2008;58:38-44.
24. Aan Het Rot M, Zarate CA Jr, Charney DS, Mathew SJ. Ketamine for depression: Where do we go from here? *Biol Psychiatry* 2012;72:537-47.
25. Karcioğlu M, Davarci I, Tuzcu K, Bozdoğan YB, Turhanoglu S, Aydoğan A, et al. Addition of ketamine to propofol-alfentanil anesthesia may reduce postoperative pain in laparoscopic cholecystectomy. *Surg Laparosc Endosc Percutan Tech* 2013;23:197-202.
26. Guignard B, Coste C, Costes H, Sessler DI, Lebrault C, Morris W, et al. Supplementing desflurane-remifentanyl anesthesia with small-dose ketamine reduces perioperative opioid analgesic requirements. *Anesth Analg* 2002;95:103-8.
27. Barreveld AM, Correll DJ, Liu X, Max B, McGowan JA, Shovel L, et al. Ketamine decreases postoperative pain scores in patients taking opioids for chronic pain: Results of a prospective, randomized, double-blind study. *Pain Med* 2013;14:925-34.
28. Sethi M, Sethi N, Jain P, Sood J. Role of epidural ketamine for postoperative analgesia after upper abdominal surgery. *Indian J Anaesth* 2011;55:141-5.
29. Borgbjerg FM, Svensson BA, Frigast C, Gordh T Jr. Histopathology after repeated intrathecal injections of preservative-free ketamine in the rabbit: A light and electron microscopic examination. *Anesth Analg* 1994;79:105-11.
30. Karpinski N, Dunn J, Hansen L, Masliah E. Subpial vacuolar myelopathy after intrathecal ketamine: Report of a case. *Pain* 1997;73:103-5.
31. Subramaniam K, Subramaniam B, Pawar DK, Kumar L. Evaluation of the safety and efficacy of epidural ketamine combined with morphine for postoperative analgesia after major upper abdominal surgery. *J Clin Anesth* 2001;13:339-44.
32. Hills CE, Jin T, Siamantouras E, Liu IK, Jefferson KP, Squires PE. 'Special k' and a loss of cell-to-cell adhesion in proximal tubule-derived epithelial cells: Modulation of the adherens junction complex by ketamine. *PLoS One* 2013;8:e71819.
33. Visser E, Schug SA. The role of ketamine in pain management. *Biomed Pharmacother* 2006;60:341-8.
34. Wang C, Zheng D, Xu J, Lam W, Yew DT. Brain damages in ketamine addicts as revealed by magnetic resonance imaging. *Front Neuroanat* 2013;7:23.
35. Niciu MJ, Grunschel BD, Corlett PR, Pittenger C, Bloch MH. Two cases of delayed-onset suicidal ideation, dysphoria and anxiety after ketamine infusion in patients with obsessive-compulsive disorder and a history of major depressive disorder. *J Psychopharmacol* 2013;27:651-4.
36. Maranhão MV, de Holanda AC, Tavares FL. Kinsbourne syndrome: Case report. *Braz J Anesthesiol* 2013;63:287-9.

How to cite this article: Vadivelu N, Schermer E, Kodumudi V, Belani K, Urman RD, Kaye AD. Role of ketamine for analgesia in adults and children. *J Anaesthesiol Clin Pharmacol* 2016;32:298-306.

Source of Support: Internal Department funding, Brigham and Women's Hospital/Harvard Medical School, Boston MA, USA, **Conflicts of Interest:** None declared.

Author Help: Reference checking facility

The manuscript system (www.journalonweb.com) allows the authors to check and verify the accuracy and style of references. The tool checks the references with PubMed as per a predefined style. Authors are encouraged to use this facility, before submitting articles to the journal.

- The style as well as bibliographic elements should be 100% accurate, to help get the references verified from the system. Even a single spelling error or addition of issue number/month of publication will lead to an error when verifying the reference.
- Example of a correct style
Sheahan P, O'leary G, Lee G, Fitzgibbon J. Cystic cervical metastases: Incidence and diagnosis using fine needle aspiration biopsy. *Otolaryngol Head Neck Surg* 2002;127:294-8.
- Only the references from journals indexed in PubMed will be checked.
- Enter each reference in new line, without a serial number.
- Add up to a maximum of 15 references at a time.
- If the reference is correct for its bibliographic elements and punctuations, it will be shown as CORRECT and a link to the correct article in PubMed will be given.
- If any of the bibliographic elements are missing, incorrect or extra (such as issue number), it will be shown as INCORRECT and link to possible articles in PubMed will be given.