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Original Research

Perioperative Outcomes of Immersive Virtual Reality as Adjunct Anesthesia in Primary Total Hip and Knee Arthroplasty

Kelly S. Barry, MD [a], Sindhuja R. Nimma, MD [b], Aaron C. Spaulding, PhD [c], Benjamin K. Wilke, MD [a], Klaus D. Torp, MD [b], Cameron K. Ledford, MD [a,*]

[a] Department of Orthopedic Surgery, Mayo Clinic, Jacksonville, FL
[b] Department of Anesthesiology and Perioperative Medicine, Mayo Clinic, Jacksonville, FL
[c] Division of Health Care Policy and Research, Mayo Clinic, Jacksonville, FL

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ABSTRACT

Background: Immersive virtual reality (IVR) is utilized as an adjunct to anesthesia to distract patients from their intraoperative environment, thereby potentially reducing sedative and narcotic medication usage. This study evaluated intraoperative and acute postoperative results of patients undergoing primary total hip (THA) and total knee arthroplasty (TKA) with and without IVR.

Methods: Utilizing IVR as an adjunct to spinal anesthesia, 18 primary THAs (n = 8) and TKAs (n = 10) were performed. These cases were 1:2 matched based on procedure type, age, sex, and body mass index to those performed without IVR. Intraoperative and postanesthesia care unit sedative/narcotic usage, vital signs, and pain scores were compared. Acute perioperative outcomes, including 24-hour oral morphine equivalent (OME), first ambulation distance, length of stay, and 30-day complications, were also analyzed. Pearson Chi-square and Wilcoxon-Mann-Whitney tests evaluated categorical and continuous variables, respectively.

Results: When compared to non-IVR primary THAs and TKAs, those performed with IVR utilized significantly less intraoperative sedation (48 mg vs 708 mg of propofol; $P < .001$) and trended toward less narcotic usage (13 mcg vs 39 mcg of fentanyl; $P = .07$). In the postanesthesia care unit, IVR and non-IVR patients showed no significant differences ($P > .3$) in vital signs, pain scores, or OME received. Additionally, similar ($P > .3$) postoperative outcomes were noted in both cohorts' 24-hour OME use, distance at first ambulation, length of stay, and 30-day complications.

Conclusions: The use of spinal anesthesia with the IVR adjunct to perform primary THAs and TKAs appears to be well-tolerated and associated with less intraoperative sedative medication usage than spinal anesthesia alone.

Introduction

Immersive virtual reality (IVR) is the creation of an artificial environment with a 3-dimension-enabled head-mounted device and noise-canceling headphones [1]. Most IVR devices aim to provide soothing experiences by using natural environments such as forests, beaches, snowy canyons, space, or botanical gardens to replicate calming surroundings [2–4]. Recently, IVR has been applied as a form of distraction in medical patient care to attenuate anxiety and general discomfort during interventions such as wound care, physical therapy, dental procedures, and perioperative processes of peripheral nerve blocks and anesthesia induction [1,5–10]. IVR utilization has further expanded intraoperatively as an adjunct to surgeries performed under regional or neuraxial anesthesia [11–14].

For orthopedic surgeries, early studies have provided favorable results on IVR's application, safety, and efficacy in reducing patients' anxiety and sedation requirements although utilization has been primarily for outpatient procedures [11,12]. This success has led to growing interest in IVR usage as an adjunct to spinal anesthesia during total hip arthroplasty (THA) and total knee arthroplasty (TKA) [13,14]. Despite the known advantages and pain-

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* Corresponding author. Department of Orthopedic Surgery, Mayo Clinic, 4500 San Pablo Road, Jacksonville, FL 32224, USA. Tel.: +1 904 953 2000.
E-mail address: ledford.cameron@mayo.edu

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reduction seen with spinal anesthesia compared to general anesthesia, sedative and narcotic medications are often still required to attenuate noxious stimuli associated with these procedures [15]. The addition of IVR as an adjunct would appear to be complementary to spinal anesthesia and perhaps decrease the need for these medications during THA and TKA.

The goal of this study was to compare the intraoperative, immediate postoperative, and 30-day acute postoperative results of patients undergoing primary THA or TKA with IVR as an adjunct to spinal anesthesia to those of procedures performed with spinal anesthesia alone. We hypothesized that IVR patients would require less intraoperative sedation and narcotics, maintain similar perioperative pain scores, and utilize fewer postoperative narcotics.

Material and methods

After the institutional review board approval was obtained, a single institutional retrospective review identified 18 patients from January 1, 2021 to July 1, 2021 who underwent primary THA (n = 8) or TKA (n = 10) with spinal anesthesia and IVR as an adjunct. Patients were excluded if aged ≤18 years, they had indications other than osteoarthritis, or were unable to tolerate the IVR experience fully during the surgery. IVR patients were matched 1:2 to controls that did not use IVR based on procedure type (THA or TKA), age (±3 years), sex (exact), and body mass index (±5 kg/m^2).

During the routine preoperative evaluation, elective total joint arthroplasty patients met with both surgeon and anesthesia providers to review the risks and benefits of the procedure and the choice of anesthetic options. Patients were provided information related to anesthesia options of general, spinal, or spinal with IVR and eventually self-selected into a surgery performed with or without IVR. Spinal anesthesia remains our current institutional recommendation and preference for THA and TKA and was solely utilized in both cohorts. For those patients interested in the adjunct, the IVR hardware (PICO G2 4K Enterprise [PICO, San Francisco, CA] goggles and Bose Quiet Comfort QC 35 noise-canceling headsets [Bose, Framingham, MA]), choice of the 4 different visual content environments created by HypnoVR (Strasbourg, France; https://hypnovr.io/en/solutions/softwares/), and voice-guided relaxation techniques/sounds were demonstrated (Fig. 1). On the day of surgery, both the anesthesiologist and surgeons confirmed the informed consent, including the patient's anesthetic plan and preference. If patients elected to receive an ultrasound-guided, single-shot nerve block, fascia iliaca for THA or saphenous (adductor canal) for TKA was performed. In the operating room, patients received a 10- to 30-mg dose of propofol prior to spinal anesthesia with 1.5% mepivacaine. Further sedation or narcotic dosing was titrated based on a subjective evaluation of patients' requirement as indicated by comfort level, pulse oximetry, and noninvasive arterial pressure monitoring. Specifically, both IVR and non-IVR patients initially received no sedation unless they felt uncomfortable or anxious about being fully awake per their request or abnormal vital signs/monitoring. In this case, propofol infusion was given to a level of minimal to moderate sedation as assessed by purposeful response to verbal or tactile stimuli, airway protection, and hemodynamic stability. Those patients selecting IVR were fitted for the IVR headset and headphones and informed of expected sounds, vibrations, or smells associated with the surgery. High-volume arthroplasty surgeons performed the THAs and TKAs at a single institution via the same approach (direct anterior for THA and medial parapatellar for TKA), contemporary techniques/implants, and standardized acute postoperative recovery protocols.

Perioperative results were separated and compared according to preoperative, intraoperative, immediate postoperative, and acute postoperative outcomes. Patient demographics, American Society of Anesthesiologists score, Charlson Comorbidity Index, anesthesia type (ie, spinal alone vs spinal and peripheral nerve block), and quantity of sedation (both preoperative and intraoperative) were recorded. There were no patients in either the IVR or non-IVR matched cohort that required intraoperative conversion to general anesthesia. Intraoperative outcomes included maximum heart rate, maximum systolic blood pressure, anesthesia time, intraoperative oral morphine equivalents (OMEs), and complications. Immediate postoperative outcomes included postanesthesia care unit (PACU) sedative/narcotic usage, vital signs, pain scores (Numerical Pain Rating Scale from 0 to 10), and recovery duration. Acute outcomes analyzed 24-hour OMEs, first ambulation distance with physical therapy, length of stay, and 30-day complications (readmissions or reoperations).

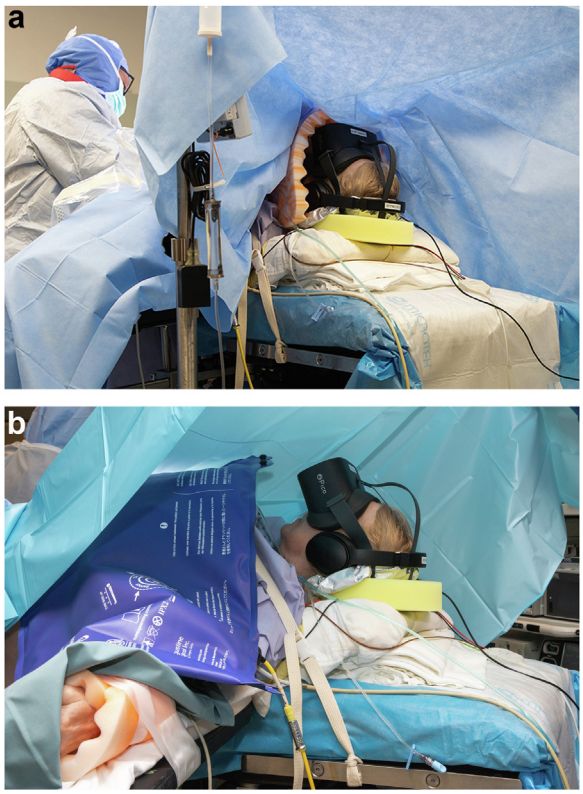

Figure 1. A patient undergoing primary total hip arthroplasty under spinal anesthesia with immersive virtual reality goggles and noise-canceling headphones including a view from anesthesia (a) and side profile (b).

For patients undergoing THA and TKA with IVR-adjunct anesthesia, the mean age was 74 years (range, 54-93 years), 67% were female, and the mean body mass index was 28 kg/m^2 (range, 20.0-34.5 kg/m^2). No significant difference existed between cohorts except for the IVR patient cohort having significantly ($P = .007$) more patients who were American Society of Anesthesiologists score 3 (Table 1). Additionally, there were no significant differences in preoperative hemoglobin levels, heart rate, systolic blood pressure, or OMEs provided before the surgery.

Statistical analysis

Matched cohorts were evaluated on differences in preoperative, intraoperative, immediate postoperative, and acute postoperative outcomes. Study demographics and outcomes were described as frequency and percentages or means and standard deviations. Pearson Chi-square tests were used for categorical variables while Wilcoxon-Mann-Whitney tests were used for continuous variables.

Table 1
A comparison of baseline characteristics between patients undergoing total joint arthroplasty with and without IVR-adjunct anesthesia.

Characteristics	IVR	No IVR	*P* value
Age (mean, range)	74 (57-93) y	73 (54-89) y	.601
Sex			
Female	12	24	.999
Male	6	12	
Body mass index (mean, range)	28 (20-35) kg/m^2	28 (22-34) kg/m^2	.659
ASA score			
2	8	29	.007
3	10	7	
Anesthesia type			
Spinal	5	6	.203
Spinal with block	13	30	
Procedure			
Total hip arthroplasty	8	16	.999
Total knee arthroplasty	7	14	
Robotic-assisted total knee arthroplasty	3	6	
Preoperative heart rate (mean, SD)	81 (±14) beats/min	84 (±15) beats/min	.588
Preoperative systolic blood pressure (mean, SD)	125 (±24) mm/Hg	114 (±20) mm/Hg	.106
Preoperative hemoglobin (mean, SD)	13.8 (±1.4) g/dL	13.5 (±1.2) g/dL	.653
Preoperative OME given (mean, range)	24 (0-55) OMEs	28 (1-58) OMEs	.178

ASA, American Society of Anesthesiology score; SD, standard deviation.

Stata/MP 17.0 (StataCorp, College Station, TX) was used to conduct the analysis, and *P* values of less than 0.05 were considered statistically significant.

Results

Intraoperative outcomes

Primary THA and TKA performed with IVR utilized significantly less intraoperative sedation (48 mg vs 708 mg of propofol; $P < .001$) than those without IVR. Although not significant with the numbers available, there was a trend toward less narcotic usage (13 mcg vs 39 mcg of fentanyl; $P = .07$) for the IVR patients. The operating room time was not different between cohorts ($P = .4$), and no IVR cases were intraoperatively abandoned. No significant differences were noted in maximum heart rate ($P = .1$) or systolic blood pressure ($P = .3$), and there were no intraoperative complications in either cohort (Table 2).

Immediate postoperative outcomes

The overall recovery duration in the PACU was 1.7 hours for IVR patients and 2.3 hours for controls ($P = .4$) (Table 3). There remained no significant difference between cohorts' maximum heart rate ($P = .4$), systolic blood pressure ($P = .4$), utilization of OMEs ($P = .7$), or antiemetics ($P = .7$). Additionally, pain scores upon patient arrival to the PACU and final pain scores were not significantly different ($P \geq .2$).

Acute postoperative outcomes

During the first 24 hours of acute hospital stay, no significant difference in OME ($P = .3$) or antiemetic utilization ($P = .9$) was seen between IVR and non-IVR patients (Table 4). Similarly, ambulation distance with physical therapy during the first attempt ($P = .5$), hospital length of stay ($P = .9$), and discharge home ($P = .2$) were not significantly different. Two complications (1 patient with postoperative anemia requiring a gluteal artery embolization and 1 patient with a postoperative hematoma requiring aspiration at 6 weeks) and 1 readmission/reoperation for a periprosthetic hip fracture at 2.5 weeks after the surgery occurred in the non-IVR cohort; none occurred in the IVR patients.

Discussion

The use of IVR-adjunct anesthesia represents a novel technology with the potential to reduce the use of sedative and narcotic medication during a major elective lower-extremity joint replacement. Less is known about the possible subsequent physiologic, psychologic, and pain-reduction benefits of a distraction therapy in this setting. According to our results, patients undergoing THA and TKA with IVR adjunct to spinal anesthesia required significantly less sedation and showed a trend toward less narcotics during the procedure compared to non-IVR controls. Otherwise, postoperative pharmacologic requirements, pain scores, and 30-day outcomes were similar between the groups.

The application of the IVR adjunct appeared to be well-tolerated by THA and TKA patients with intraoperative outcomes such as operative time, vital signs, and anesthetic complications that were not different from those of matched non-IVR surgeries. Perhaps the most encouraging finding was that IVR patients' maximum heart rate and systolic blood pressure remained well-controlled throughout the surgeries, which we believe confirms a calming, anxiolytic effect of the IVR experience despite significantly less sedation being utilized. Chan and Scharf found similar decreased sedation requirements in their pilot study of patients undergoing

Table 2
Intraoperative outcomes of patients undergoing total joint arthroplasty with and without IVR-adjunct anesthesia.

Intraoperative outcomes	IVR	No IVR	*P* value
Intraoperative maximum HR (mean, SD)	80 (±13) beats/min	86 (±12) beats/min	.079
Intraoperative maximum SBP (mean, SD)	134 (±12) mm/Hg	134 (±22) mm/Hg	.315
Operating room time (mean, SD)	128 (±22) min	131 (±17) min	.373
Intraoperative OME (mean, SD)	1.7 (±3.8) OMEs	2.1 (±5.5) OMEs	.93
Intraoperative propofol sedation (mean, SD)	48 (±27) mg	708 (±293) mg	<.001

HR, heart rate; SBP, systolic blood pressure.

Table 3
Immediate postoperative outcomes in the PACU of patients undergoing total joint arthroplasty with and without IVR-adjunct anesthesia.

Immediate postoperative outcomes	IVR	No IVR	*P* value
PACU duration (mean, SD)	1.8 (±1.3) h	2.3 (±1.8) h	.404
Initial pain score (mean, SD)	0.6 (±1.7)	1.2 (±2.4)	.329
Final pain score (mean, SD)	1.2 (±1.5)	2.1 (±2.1)	.159
Maximum heart rate (mean, SD)	81 (±14) beats/min	85 (±15) beats/min	.368
Maximum systolic blood pressure (mean, SD)	150 (±17) mm/Hg	145 (±23) mm/Hg	.378
Antiemetics (mean, SD)	6.1 (±2.5) mg	5.5 (±3) mg	.738
OMEs (mean, SD)	61 (±44) OMEs	64 (±42) OMEs	.645

various hip, knee, and foot procedures [11]. However, the results were not significant, likely due to inadequate power [11]. In contrast, a randomized controlled trial by Huang et al. showed no significant decrease in sedation medication between IVR and non-IVR THA and TKA cohorts [13]. It is important to note that in this study, intraoperative sedation needs were self-administered by the patient, and the treating anesthesiologist provided adjunct analgesia. As seen in our results with IVR patients, the benefits of reducing sedation requirements may only be evident if the anesthesia provider solely controls sedation during the case.

Although it did not reach significance, there was also a trend toward less narcotic requirements during THA and TKA performed with an IVR adjunct. Similar pain-mitigating effects of IVR have been seen in burn victims undergoing physical therapy sessions, which are crucial for minimizing long-term disability and preventing contractures. Burn patients performing physical therapy with virtual reality for distraction reported significantly lower visual analog scores than those without virtual reality. The magnitude of pain reduction did not diminish with repeated use of IVR in subsequent therapy sessions [5]. A randomized controlled trial of patients with hand injuries undergoing dressing changes also demonstrated significantly lower visual analog scores with the use of virtual reality [16]. Preliminary pain and narcotic use reduction during surgeries performed with IVR is encouraging; however, such a difference appears to be limited intraoperatively as pain scores and OMEs in the PACU and during hospitalization were not different between groups. The study is likely underpowered to determine such difference; thus, further research will be required to fully realize if the utilization of IVR during any potential painful episodes (ie, physical therapy, dressing change, sleeping etc.) could impact postoperative pain and narcotic requirements.

The immediate postoperative PACU experience of the IVR patients, including factors like overall time, vital signs, pain medication/antiemetic usage, and serial pain scores, is noninferior to that of the non-IVR group indicating at least an equal experience. Despite less sedation being utilized in the IVR group, we believe the nondifferent immediate postoperative outcomes may be due to the relatively quick half-life of the propofol sedation itself (estimated to be 40 minutes) [17]. A similar amount of time often elapses as the surgery is completed, dressings are placed, patients are transferred from the OR bed to a stretcher and transported to the PACU, and PACU arrival intake is completed by nursing. Given this duration, the propofol sedation is likely to be worn off in both groups. Any potential differences in vital signs, pain scores, or medication usage between the IVR and non-IVR patients may have been less evident.

IVR may also have a role in enhanced recovery programs after THA and TKA which are known to provide cost-efficient and high-quality patient care. Patient expectations and motivation are key components to ensuring their success [18–20]. Additionally, the in-hospital and 30-day postoperative outcomes between the 2 groups were also equivocal, with no significant differences in discharge location or complications, readmissions, or reoperations. Given our findings of decreased sedation and noninferior acute outcomes, IVR appears to be a safe, novel adjuvant for the rapid recovery protocol and/or same-day discharge for outpatient total joint replacements.

The major limitation of our study includes the relatively small sample size, which can result in inadequate power for insignificant findings. Patient selection bias is inherent as patients were offered and eventually self-selected the IVR experience for their surgery. Despite standardized care pathways, multiple anesthesia providers and surgeons were involved in the patients' surgical care episode, and subjective differences in anesthesia practice and procedural techniques exist. Furthermore, no blinding can be performed given the application of the IVR device, and such ongoing interactions may have also led to differences in the amount of sedation given by the treating anesthesia providers. It is important to note that no universally accepted or superior scale of assessing the depth of sedation and subsequent dosing currently exists [21]. Nevertheless, our anesthesia practitioners routinely perform anesthesia for a high volume of THAs and TKAs, and the practice standard is to minimize sedation based on the response to verbal and tactile stimulation similar to previously published sedation-assessment methods [22–24]. Baseline and postoperative mental status or health assessments were not obtained and could further elucidate the benefits of decreased pharmaceutical requirements between the groups. A well-powered randomized controlled trials will be needed to further delineate the potential benefits of IVR in total joint arthroplasty.

Conclusions

In summary, the use of spinal anesthesia with an IVR adjunct to perform primary THAs and TKAs appears to be well-tolerated and

Table 4
Postoperative outcomes of patients undergoing total joint arthroplasty with and without IVR-adjunct anesthesia.

Acute postoperative outcomes	IVR	No IVR	*P* value
Antiemetics (mean, SD)[a]	5.1 (±2.5) mg	5.9 (±5.4) mg	.871
Oral morphine equivalents (mean, SD)[a]	55 (±24) OMEs	64 (±30) OMEs	.306
Postoperative day 1 hemoglobin (mean, SD)	10.9 (±1.3) g/dL	10.7 (±1.6) g/dL	.427
Ambulation distance on first attempt (mean, SD)	84 (±67) feet	71 (±67) feet	.520
Length of stay (mean, SD)	30 (±9) h	35 (±27) h	.898
30-D complications	0	2	.547
30-D readmissions	0	1	.999
30-D reoperations	0	1	.999

[a] Antiemetic medication and OMEs administered during the first 24 h of hospital admission.

associated with less intraoperative sedative medication usage than spinal anesthesia alone. Additionally, with the numbers available, the surgical experience with IVR does not lead to worse immediate and acute postoperative outcomes for interested patients undergoing an elective arthroplasty. The utilization of the IVR adjunct may be considered a novel, safe anesthetic approach to total joint arthroplasty, and further investigation is warranted, particularly on the utility in outpatient total joint programs.

Conflicts of interest

Dr. C. K. Ledford is a committee member of American Academy of Orthopaedic Surgeons, American Association of Hip and Knee Surgeons, and American Board of Orthopaedic Surgery. All other authors declare no potential conflicts of interest.

For full disclosure statements refer to https://doi.org/10.1016/j.artd.2022.09.015.

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