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Time of return of neurologic function after spinal anesthesia for total knee arthroplasty: mepivacaine vs bupivacaine in a randomized controlled trial

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ABSTRACT

Background: Mepivacaine as an intermediate-length spinal anesthetic for rapid recovery in total knee arthroplasty (TKA) has not been fully described. We compared spinal mepivacaine vs bupivacaine for postoperative neurologic function in patients undergoing primary TKA.
Methods: Thirty-two patients undergoing primary TKA were enrolled. Primary outcome measure was return of motor and sensory function. Secondary outcome measures included assessment of urinary function, pain via visual analog scale (VAS) scores, opioid usage, distance walked and pain with physical therapy, time to discharge readiness, and complications.
Results: Patients with mepivacaine spinal anesthetic had faster return of sensory function (164 ± 38.6 vs 212 ± 54.2 minutes, $P = .015$), return of motor function (153 ± 47.4 vs 200 ± 45.2 minutes, $P = .025$), and time to straight leg raise (148 ± 43.5 vs 194 ± 50.8 minutes, $P = .023$). The mepivacaine group experienced significantly fewer episodes of urinary retention and shorter time to urination (344 ± 154.4 vs 416 ± 96.3 minutes, $P = .039$). Patients exhibited slightly higher VAS pain scores in the postanesthesia care unit (1.0 ± 1.7 vs 2.7 ± 2.3, $P = .046$) with no difference in opioid consumption. There were no differences in VAS scores or opioid use on the inpatient ward. Patients achieved discharge readiness 71 minutes faster in the mepivacaine group. There was no need to convert to general anesthesia or transient nerve symptoms in either group.
Conclusions: Patients undergoing TKA with mepivacaine spinal anesthetic had a reliably more rapid neurologic recovery after TKA compared to bupivacaine.

Introduction

Interest in ambulatory total knee arthroplasty (TKA) has drastically risen and the incidence is expected to increase [1]. The driving forces behind this outpatient paradigm shift include varying degrees of patient and surgeon preference, payor-directed financial savings from both the initial surgical episode and subsequent care, and increasing data showing its safety and potential for lesser complications in certain populations [2]. This mandates a thorough re-evaluation of the entire process, in particular the organization and efficiency required in a busy ambulatory surgery setting. Advancements in surgical technique, perioperative pain regimens, and postoperative physical therapy protocols have already decreased surgery durations, time to ambulation, and lengths of stay [3-6]. As ambulatory and short stay protocols further develop for outpatient TKA, new perioperative protocols should be developed to meet the demands of the patient, physician, and institution. Traditionally cited barriers to same-day discharge include aberrations in patient motor function and proprioception,

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delayed ambulation, and issues with urinary retention and pain control [4-6].

Multiple anesthetic techniques have been used for ambulatory surgery and have allowed ambulatory arthroplasty surgery in many centers [7-9]. Spinal anesthesia is an attractive option due to its low cost, reliability, rapid onset, and potentially ideal duration of action for arthroplasty procedures. This procedure minimizes side effects such as nausea and vomiting, avoids airway manipulation, has rapid recovery from sensory and motor blockade, and has been shown to have less 30-day readmissions compared to general anesthesia [4,5,10,11]. Many anesthetics have been studied and current standards of care vary depending on the intended length of surgery, drug availability, and side effect profiles. Currently, there is a paucity of evidence as to which anesthetic is optimal in the setting of ambulatory TKA. Goals for the spinal anesthetic should be as follows: sufficient duration, rapid return of neurological (motor, sensory, and bladder) function, and ability for the patient to mobilize expeditiously while allowing the patient to be discharged safely with low risk of side effects, complications, and readmission.

The current standard of care for total joint arthroplasty has utilized bupivacaine spinal anesthesia at most centers given its recognized safety profile. The long duration of action of spinal bupivacaine, up to 3-9 hours [12], may hinder motor recovery and early discharge. Some have seen success using lower doses of bupivacaine in an attempt to shorten its duration. However, many studies question the reliability of a lower dose of a given spinal medication since it is the chemical nature of the drug—not the dose or volume—that is more important for length of action. One study did a systematic review to find an optimal dose of bupivacaine in an ambulatory surgery setting and found a very narrow reliability margin to yield the desired effect [13].

Lidocaine has recently gained popularity at ambulatory surgery centers given its short length of action (90-120 minutes) [14]. However, this duration of action may be too short for single-shot spinal anesthesia depending on various intraoperative variables, and many anesthesiologists have concerns about the frequency of transient neurological symptoms (TNSs). Previously known as “transient neurologic toxicity” when initially described with lidocaine in 1993, it has also gone by the name of “transient radicular irritation” and presents with pain that can be light to severe with onset that occurs within 24 hours of injection [15]. TNS is used to currently describe such pain, lasting no more than a few days, originating in the gluteal region radiating to both lower extremities after a single injection of any spinal anesthetic [16,17]. Mepivacaine is an intermediate-acting local anesthetic with a reported duration of action of 90-150 minutes, which may offer a favorable pharmacokinetic profile for ambulatory arthroplasty without the historic TNS drawback. Several modern studies regarding other procedures have shown that mepivacaine has a faster recovery from induction, decreased urinary retention, and increased patient and surgeon satisfaction [16-20]. Until recently, mepivacaine had only been described for knee arthroscopy and anterior cruciate ligament reconstruction [16,17]. Both of these randomized studies found benefit to a lower mepivacaine dose with differing amounts of added fentanyl to prolong and titrate its duration. Earlier last year, we published a retrospective cohort study of our institution’s experience with mepivacaine and bupivacaine in primary TKA and found that mepivacaine had adequate duration, rapid recovery with fewer urinary complications, and a shorter length of stay [21].

The purpose of our study is to compare spinal mepivacaine vs bupivacaine for timing of neurologic recovery and related metrics in patients undergoing TKA while furthering our institution’s comfort in working with this spinal anesthetic. We hypothesized that mepivacaine would provide a safe, comfortable, and expeditious postoperative course when compared to our standard bupivacaine.

Material and methods

The study was reviewed and approved by our institutional review board for the appropriately powered number of patients. We abided by the Consolidated Standards of Reporting Trials (CONSORT) statement [22] and registered the study at ClinicalTrials.gov (NCT02980926) before data analysis.

The primary univariate endpoint was time to full neurologic motor return of the lower extremity. Without prior published data on the return-of-function with mepivacaine and minimal clinically important difference as a practical standard, an a priori power analysis was conducted to detect a difference of 30 minutes between the 2 groups. Based on a prior study [23], the mean time of motor block for 40-60 mg of mepivacaine was 138 minutes with a standard deviation of 26. Power analysis using nQuery Advisor 7.0 (Statistical Solutions Ltd., Boston, MA) was performed prior to our study to assess the primary hypothesis that mepivacaine would provide at least a 30-minute faster return of full motor function compared to bupivacaine. A sample size of 13 in each group had an 80% power to detect that difference, assuming the common standard deviation of 26 minutes using a 2-group t-test with a 0.05 two-sided significance level. Our institutional review board only allowed an additional 20% more patients to be added to account for any incomplete collection data or patient dropout to yield a total of 32 study patients, 16 in each group. Secondary outcomes include a determination if the duration of anesthetic was long enough to comfortably complete all surgeries without complications, such as TNS, and if measures such as urinary function, pain, and early mobility show potential for further benefits with a shorter acting anesthetic.

Thirty-two consecutive patients undergoing unilateral primary TKA by a single fellowship-trained surgeon were assessed for study eligibility and written consent obtained from July 2016 through September 2016. As we had been using mepivacaine regularly for primary arthroplasty by late 2015, it had become our standard recommendation. For this reason, all subjects agreed to consent to the study. All surgeries were performed at a suburban academic center with involvement of a senior resident adhering to a consistent surgical technique. Patients were excluded from the study if they had contraindications to or refusal of spinal anesthesia, previous neurologic conditions, inability to participate in preoperative history and physical examination, chronic back pain or radiculopathy, known history of sensitivity to local anesthetics, history of urinary retention/incontinence, or history of postoperative nausea and vomiting.

Subjects were then randomized via sealed envelopes to receive either 10.5-12 mg of 0.75% hyperbaric bupivacaine or 60-68 mg of isobaric 2% mepivacaine based on height and weight per institution protocols (Table 1). The surgeon, patient, nurses, and therapists were blinded to the intervention, and anesthesiologists were aware only in time to draw up the medication and had no interaction with them after the spinal was introduced. All patients received spinal anesthetic placed by a senior staff anesthesiologist and received intravenous sedation by a certified nurse anesthetist using a standard protocol.

Table 1
Spinal anesthetic dosing.

Patient height[a]	Bupivacaine 0.75% dose		Mepivacaine 2% dose	
Between 4′10″ and 5′7″	1.4 mL	10.5 mg	3 mL	60 mg
Greater than 5′7″	1.6 mL	12 mg	3.4 mL	68 mg

No additives (fentanyl, epinephrine) were added to any spinal dose.
[a] Patients under 4′10″ were excluded from the study (none were encountered).

All patients were compliant with a standardized multimodal perioperative pain and nausea protocol. Patients were given sustained-release morphine 15 mg, meloxicam 15 mg, and gabapentin 300 mg. Dexamethasone 8 mg was given intravenously after anesthetic induction for nausea and pain control. Patients were asked to urinate prior to transfer to the operating room and Foley catheters were not utilized. Intraoperatively, a periarticular injection of 120 mL of diluted ropivacaine 300 mg with epinephrine 1 mg and ketorolac 30 mg was used for local administration. Intraoperative surgeon-delivered adductor canal blockade with 20 mL of the cocktail was added as previously described [24]. The postoperative pain regimen consisted of sustained-release morphine 15 mg every 8 hours for 24 hours, meloxicam 15 mg daily, gabapentin 300 mg twice daily, scheduled oral acetaminophen 975 mg every 8 hours, scheduled tramadol 50 mg every 6 hours, and oxycodone 5-10 mg as needed with morphine 1-2 mg intravenously for breakthrough pain. A repeat dose of dexamethasone 8 mg intravenously was also given the morning after surgery. All patients were mobilized immediately after surgery when physical therapy was available and neurologic function was sufficient.

The recovery room nurse assessed every primary outcome of neurologic recovery and urination at 20-minute intervals. The same physician assistant did the initial examination in conjunction with the recovery room nurse to ensure correct technique in an effort to ensure reproducibility. The nursing joint coordinator and floor nurse would continue the examinations on the ward if any patients had not hit resolution and urinated prior to leaving the postanesthesia care unit (PACU). Simple functional neurologic assessments were done (straight leg raise, great toe extension, ankle dorsiflexion, and sensation deficits) and recorded on a collection sheet attached to the cover of the chart. We defined full sensory recovery as the first of 2 consecutive normal readings (to eliminate interpretation variability) to the foot in a progressively distal manner. Full motor recovery was defined as "Yes" to all 3 functional measures. Secondary outcomes, such as urination and related difficulties, physical therapy mobilization, and pain/nausea were collected from the electronic medical record.

Postoperative metrics were recorded by blinded inpatient nursing and physical therapy staff and included pain control, episodes of urinary retention, and TNS complaints. Pain scores were assessed on a 10-point visual analog scale (VAS) at regular (<4 hour) intervals. TNS was defined as new onset back pain or dysesthesia with radiation to the buttocks, hips, thighs, or calves occurring within the first 24 hours of surgery and lasting for 2-3 days [25,26]. Standard protocol for urination was that patients were due to void 6 hours after surgery. If not, a bladder scan was performed and straight catheterization performed if more than 240 mL of urine was present based on institutional definition of urinary retention. Episodes of straight catheterization or Foley placement were used as the measurement for urinary complications, as we found documentation of incontinence to be variable. In our experience, we have found that most retention occurs in males while incontinence is more common in females.

Opioid consumption was converted to intravenous morphine equivalents for statistical analysis [27,28]. The initial phase of care, in the PACU, was defined as the time the patient arrived in the unit to the time that the patient arrived on the floor. Postoperative day 0 was defined as the time the patient was admitted to an inpatient bed, until 07:00 AM the following morning. Postoperative day 1 was defined as 07:00 AM the day after surgery until 07:00 AM the following day. Any additional postoperative days were similarly noted. During each phase, VAS scores were reported as averages. VAS scores were also recorded after each physical therapy session as an individual time point. Due to the variability of time each patient spent in a given phase of care, consumption of morphine equivalents was standardized to an hourly rate as validated in other studies [27,28].

Nausea and vomiting were assessed using the same phase of care definitions as described above. Per institutional protocol, any individual episode of nausea is recorded in the medical record. Nausea was recorded in a binary fashion and any request for antinausea medication (ie, ondansetron) was also included as a surrogate. Discharge criteria from the hospital were standardized among all patients; mainly walking >150 ft with a walker and negotiating stairs safely with no residual urinary or pain control concerns, and return of normal examination.

Statistical analysis

All continuous variables are described using means and standard deviations, while all categorical variables are described using counts and percentages. Univariate 2-group comparisons were performed using chi-squared or Fisher's exact tests for categorical variables, and using 2-group *t*-tests or Wilcoxon rank-sum tests for continuous variables. Fisher's exact test was used when expected cell counts were <5, and Wilcoxon rank-sum tests were used when group sizes were small or when normality assumptions were violated. Statistical significance was set at $P < .05$. All analyses were performed using SAS 9.4 (SAS Institute Inc., Cary, NC).

Results

A total of 32 patients were enrolled in the study. One patient was excluded from analysis due to protocol violations leaving 31 patients included for further analysis (Fig. 1). The average age was 65.2 years and the average body mass index was 34.6 kg/m^2 (Table 2). Fifteen patients were administered mepivacaine and 16 patients were administered bupivacaine. There were no differences in demographics between the 2 groups (Table 2).

Patients who administered mepivacaine experienced statistically faster return of sensory function (164 ± 38.6 vs 212 ± 54.2 minutes, $P = .015$), motor function (153 ± 47.4 vs 200 ± 45.2 minutes, $P = .025$), and straight leg raise (148 ± 43.5 vs 194 ± 50.8 minutes, $P = .023$) (Table 3). Overall return to baseline extremity function (motor and sensory) was faster with mepivacaine (168 ± 38.2 vs 223 ± 41.5 minutes, $P = .002$). To illustrate delays in recovery, Table 4 shows those patients who took beyond an arbitrary 200 minutes for neurologic recovery. There were significantly more patients in the mepivacaine group who recovered full motor and sensory function within 200 minutes (10/15 vs 4/16, $P = .032$).

Length of stay was not found to be different in the 2 cohorts. Three patients in the mepivacaine group sustained discharge delays related to medical comorbidities unrelated to anesthetic choice. In addition, social factors, time of surgery, physical therapy availability, and other reasons obscure the length of stay in this sample size. We therefore determined time to discharge readiness (in an idealized surgical process flow) to be when the patient was urinating independently, had a normal examination (motor/sensory), pain was controlled (VAS <5), and had no nausea or vomiting. Time to discharge readiness was significantly shorter in the mepivacaine group by 71 minutes (345 vs 416, $P = .038$).

Time until intentional urination was significantly shorter in the mepivacaine group (344 vs 416 minutes, $P = .039$). We chose the 6-hour point as the period at-risk for catheterization since hospital protocol mandated an operator-dependent bladder scan (Table 5). There were significantly more patients in the bupivacaine group with failure to void within 6 hours compared to mepivacaine (13/16 vs 6/15, $P = .029$). There were no differences in the number of combined straight catheterizations or Foley placements. There was 1 patient in the mepivacaine group who required straight

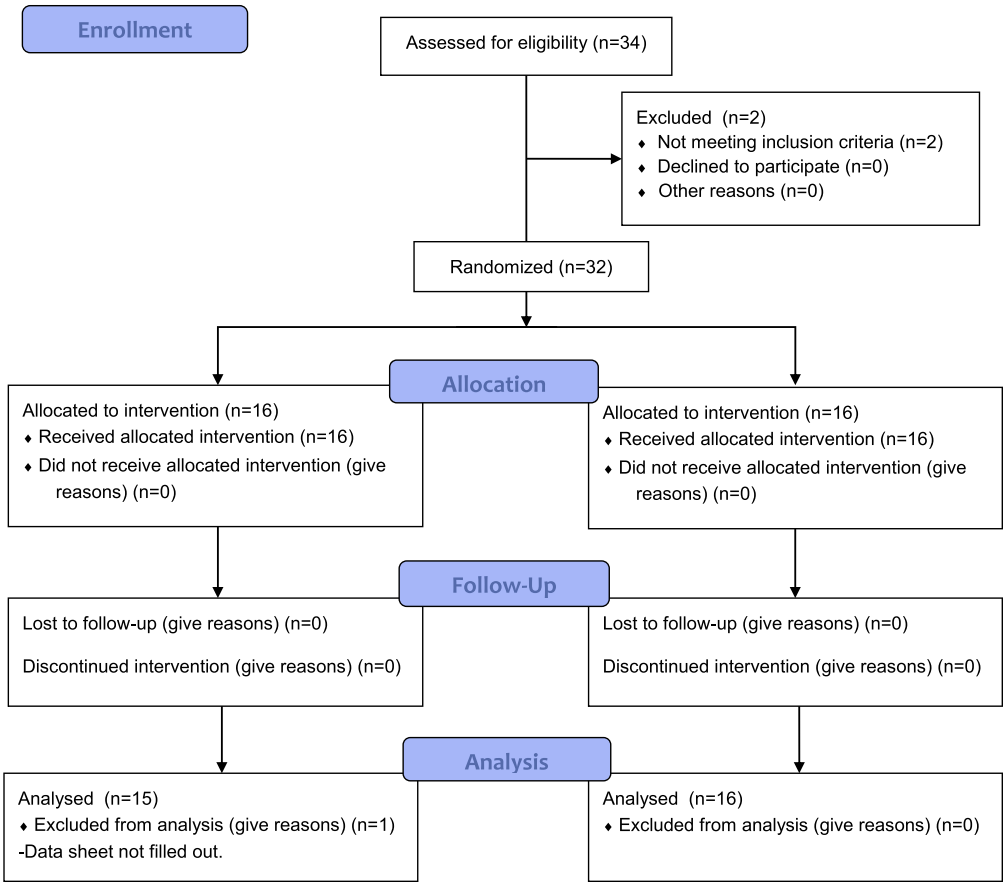

Figure 1. CONSORT flow diagram. CONSORT flow diagram outlining patient eligibility and randomization.

catheterization on postoperative day 1. There was 1 episode of urinary retention in the bupivacaine group requiring Foley placement on postoperative day 1; this was due to symptomatic retention secondary to benign prostatic hyperplasia. There was 1 episode of significant urinary incontinence in the bupivacaine group. No patient in either cohort received an extended indwelling catheter.

Pain was well controlled in the early postoperative period in both groups. Average VAS pain scores in the PACU were slightly greater in the mepivacaine group (VAS score 2.7 ± 2.3 vs 1.0 ± 1.7, $P = .046$). However, the 1.7 difference would be expected with earlier return of sensation, and while statistically significant, it is small enough to have negligible clinical significance given said benefits. There was no difference in pain control the night of surgery, postoperative day 1, or throughout the remainder of hospitalization (Table 6). There was no significant difference in the rate of morphine consumption per hour at any time point. Physical therapist-assessed pain scores during therapy sessions were similar between the 2 groups at all time points (Table 7).

There was no statistical difference in the day of the first physical therapy encounter or performance with physical therapy, as measured by distance walked, in patients given mepivacaine or bupivacaine (Table 7). There were no cases of TNS observed in either group. No patients in either cohort required a blood transfusion. There was no statistical difference in postoperative nausea or vomiting (Table 8).

Table 2
Demographic data of mepivacaine and bupivacaine groups.

	All patients	Mepivacaine	Bupivacaine	*P* value
Total	31	15	16	
Age (y) (mean ± SD)	65.2	66.6 ± 9.7	63.8 ± 9.0	.783
Sex, n				
Male	9	4	5	>.999
Female	22	11	11	
Side, n (%)				
Left	11	5 (33%)	6 (38%)	>.999
Right	20	10 (67%)	10 (63%)	
Mean height (m)	1.7	1.7	1.7	.492
Mean weight (kg)	96.9	102	92.3	.269
Body mass index (kg/m^2) (mean ± SD)	34.6 ± 6.6	36.3 ± 7.4	32.9 ± 5.5	.223
Spinal to arrival in PACU (min) (mean ± SD)	117 ± 15.2	114 ± 16.8	121 ± 13.1	.321

SD, standard deviation.

Table 3
Postoperative sensory and motor function.

Time to return (min)	All (mean ± SD)	Mepivacaine (mean ± SD)	Bupivacaine (Mean ± SD)	*P* value
Sensory function	189 ± 52.3	164 ± 38.6	212 ± 54.2	**.015**
Motor function	177 ± 51.4	153 ± 47.4	200 ± 45.2	**.025**
Straight leg raise	172 ± 52.1	148 ± 43.5	194 ± 50.8	**.023**
Both motor and sensory	196 ± 48.2	168 ± 38.2	223 ± 41.5	**.002**
Normal: motor, sensory, and urination	3382 ± 125.1	345 ± 144.4	416 ± 96.3	**.038**

SD, standard deviation.
Bold values are statistically significant.

Table 4
Prolonged return of sensory and motor functioning.

	All (N = 31)	Mepivacaine (N = 15)	Bupivacaine (N = 16)	*P* value
Time to normal sensation >200 min				
Yes	14	4	10	.073
No	17	11	6	
Time to normal motor >200 min				
Yes	12	4	8	.273
No	19	11	8	
Time to straight leg raise >200 min				
Yes	11	3	8	.135
No	20	12	8	
Time to normal sensation and motor >200 min				
Yes	17	5	12	**.032**
No	14	10	4	

Bold values are statistically significant.

Discussion

As the landscape for reimbursement continues to change, there is a greater focus on length of stay and complications. Value-based decisions and perioperative protocols to maximize quality, safety, and efficiency will become paramount. Although surgeons led the field through the technical aspects of the minimally invasive era, they traditionally have been less involved with the preoperative and postoperative care that can have equivalent ramifications on a modern day arthroplasty. One could argue that these untapped phases of improvement may be the most attainable now that technical advances have become more modest and incremental. Many providers are initially concerned with length of time a different spinal anesthetic may provide to be assured they complete the surgery safely. This study was designed to investigate such early postoperative neurologic recovery and to identify factors that potentially inhibit same-day discharge.

Our study found that patients undergoing TKA with mepivacaine spinal anesthetic had faster return of motor and sensory function, decreased time to urination, and achieved discharge readiness sooner than the bupivacaine group. There were fewer concerns regarding urinary retention and fewer patients placed on a urinary retention protocol with mepivacaine. This is likely due to mepivacaine's shorter duration of action, compounded with the fact that given institutional protocol, patients who urinated before 6 hours did not require frequent bladder scans which have a higher likelihood of requiring catheterization. Patients who did not void 6 hours after surgery had frequent bladder scans with a higher likelihood of catheterization. Pain was well controlled in both groups with only a small and transient increase in pain in the PACU and equivalent pain control afterward with use of mepivacaine. Of note, previous studies have showed that the minimal clinically important difference for VAS pain scores is 2.9 [29]. Our study showed a 1.7 difference between mepivacaine and bupivacaine in the PACU, which was below this clinically significant threshold, thus showing clinically equivalent pain control between the 2 groups at all time points. Duration of any spinal anesthetic can have large variations and is more dependent on the molecular structure of the given injectate and patient cerebrospinal fluid characteristics rather than demographics [30]. We found mepivacaine to have adequate duration to comfortably perform the surgery despite technical time variations that relate to various body habitus and deformity states, as well as surgeon teaching responsibilities. There were no episodes of TNS, which were of major concern to our anesthesia colleagues. We have now performed thousands of cases beyond this study without a single episode of such neurologic complications. Our study provides evidence that mepivacaine provides many advantages and few drawbacks compared to the gold standard bupivacaine as a spinal anesthetic in rapid recovery TKA.

Patient recovery of motor and sensory function is a challenge in the discharge pathway when implementing ambulatory surgery protocols [16]. Physical therapy is often delayed pending the return of normal neurologic function and the interplay with standard therapy staffing hours that may not accommodate patient mobilization until late in the afternoon or evening [31]. Our study showed that mepivacaine significantly accelerated the return to sensory function by approximately 48 minutes, return to motor function by 47 minutes, and time to straight leg raise by 46 minutes. Early mobilization has been shown to shorten inpatient hospital stay by 1.8 days with no increase in the risk of adverse events [32]. In the accelerated outpatient setting, a prolonged return of neurologic function and delayed mobilization can be the difference between same-day discharge and 23-hour short stay surgery. Early mobilization has long been recognized to help with improved pain control, bowel function, and prevention of thromboembolism as secondary benefits. Although a nearly 1-hour difference in return-to-function may not have large implications on an individual patient basis, in the context of a high-volume outpatient surgery

Table 5
Postoperative urinary retention.

	All (N = 31)	Mepivacaine (N = 15)	Bupivacaine (N = 16)	*P* value
Urinary issues, n				
Yes	2	1	1	>.999
No	29	14	15	
Time to urination >6 h, n				
Yes	19	6	13	**.029**
No	12	9	3	
Time to first intentional urination (min) (mean ± SD)	381 ± 125.8	344 ± 145.4	416 ± 96.3	**.039**

SD, standard deviation.
Bold values are statistically significant.

Table 6
Postoperative pain assessments and length of stay.

	All (N = 31)	Mepivacaine (N = 15)	Bupivacaine (N = 16)	*P* value
Total length of stay (h)	31.9 ± 14.0	31.5 ± 11.5	32.3 ± 16.4	.829
Pain (VAS)				
PACU	1.8 ± 2.2	2.7 ± 2.3	1.0 ± 1.7	**.046**
POD 0	3.4 ± 1.9	3.5 ± 1.8	3.3 ± 2.0	.953
POD 1	3.2 ± 2.0	3.2 ± 1.7	3.1 ± 2.4	.805
POD 2	4.8 ± 1.9	3.4 ± 0.8	6.2 ± 1.6	.067
POD 3	5.6 ± 1.7	6.6 ± 1.2	4.1 ± 0.8	.222
Morphine usage (equivalents/h)				
PACU	3.0 ± 3.9	3.9 ± 3.9	2.2 ± 3.8	.147
POD 0	1.1 ± 0.5	1.1 ± 0.6	1.0 ± 0.5	.739
POD 1	1.7 ± 2.2	1.7 ± 1.9	1.7 ± 2.6	.902
POD 2				

POD, postoperative day; SD, standard deviation; VAS, average visual analog scale score over 24-h period.
Data are expressed as mean ± SD.
Bold values are statistically significant.

Table 7
Physical therapy performance and pain.

	All (N = 31)	Mepivacaine (N = 15)	Bupivacaine (N = 16)	*P* value
Day of first PT encounter, n				
POD 0	20	9	11	>.999
POD 1	10	5	5	
Distance with PT (ft) (mean ± SD)				
POD 0	83.8 ± 94.6	63.9 ± 54.5	100 ± 118.2	>.999
POD 1	170 ± 91.3	177 ± 111.1	163.3 ± 71.5	.721
POD 2	98.6 ± 60.9	118.0 ± 75.9	83.8 ± 53.8	.615
Pain with PT (VAS; mean ± SD)				
POD 0	4.2 ± 2.8	4.6 ± 3.5	4.0 ± 2.2	.650
POD 1	3.3 ± 2.4	3.7 ± 2.6	3.0 ± 2.2	.557
POD 2	5.1 ± 2.9	5.0 ± 1.7	5.3 ± 3.8	.863

POD, postoperative day; PT, physical therapy; SD, standard deviation.

center, this 1-hour difference can have implications on workflow and could equate to less nursing burden and PACU bed usage.

It has been shown in multiple studies that use of longer acting anesthetics increases the incidence of postoperative urinary retention since the detrusor muscle, responsible for the ability to urinate, is one of the last muscles to return after spinal anesthesia [20,33]. The opposite is also seen regarding the time to void after shorter acting anesthetics such as mepivacaine [19]. The result of faster regression of sensory and motor block leads to a more rapid recovery of bladder function [19,34,35]. This was certainly found to be the advantage we witnessed in this study, as patients who administered mepivacaine anesthetic had a decreased time to initial urination. Urinary retention may have far-reaching implications, as urinary retention has been shown to correlate with higher rates of bacteriuria [36,37]. Prevention of postoperative urinary retention is imperative, as the literature has shown a 3-6 times increase in deep infection if postoperative bacteriuria occurs secondary to catheterization [38-42]. Patients who fail to void after 6 hours require closer monitoring, traditionally requiring bladder scans, which place them at risk for catheterization given historic urologic recommendations. Recently, we have become more comfortable observing patients temporarily fill their bladder up to 800 mL if asymptomatic before manipulating [43], giving them a chance to avoid the catheter trauma if it is related to a resolving spinal anesthetic. Even if concerns of bladder dystonia at such volumes are not relevant today, any delay in urination could certainly delay discharge in the ambulatory setting.

Mepivacaine has been in use since 1956, but the popularity of lidocaine supplanted its use early on [44]. Early author experience with 20,000+ mepivacaine spinals wrote that this local anesthetic "could be considered one of the best for spinal anesthetic blocks" [45]. However, TNS became more common with both of these shorter acting anesthetics, which discouraged intrathecal usage, as the historic rate of TNS has been reported as high as 40% with some lidocaine preparations [18,46]. However, recent literature has not found TNS to be a problem with mepivacaine [16,17,19,26,47]. It has been conjectured that the reason TNS symptoms were high in the 1990s were due to higher, nonstandardized concentrations, older preservatives, and antiquated purification methods [26]. Several studies have shown that contemporary formulations of mepivacaine have TNS rates as low as 0%-7.4%, which is similar to the rate of TNS in the standard bupivacaine preparation, and a lower incidence than the reported rates with lidocaine [44]. Our study found no incidence of TNS in either the mepivacaine or bupivacaine group, consistent with these more contemporary studies.

Pain control, mobilization, and physical therapy performance are common impediments to discharge in ambulatory TKA, especially when using anesthetics with a shorter duration of action such as mepivacaine. Our data show that patients who administered mepivacaine transiently had worse pain control in the PACU, but there were no differences in VAS scores or morphine equivalents during the remainder of the hospital course. The fact that patients used equivalent amounts of pain medications is further reflected by the fact that there was minimal difference in postoperative nausea or vomiting, which is often attributed to opioid medications. Furthermore, there was no difference in physical therapy performance with a traditional mobilization program. In a more progressive ambulatory protocol, however, the

Table 8
Postoperative nausea and vomiting.

	All (N = 31)	Mepivacaine (N = 15)	Bupivacaine (N = 16)	*P* value
Nausea, n				
POD 0				
Yes	4	3	1	.333
No	27	12	15	
POD 1				
Yes	0	0	0	N/A
No	31	15	16	
Vomiting, n				
POD 0				
Yes	3	2	1	.600
No	28	13	15	
POD 1				
Yes	0	0	0	N/A
No	31	15	16	
Ondansetron requested, n				
Yes	3	3	0	.101
No	28	12	16	

N/A, not applicable; POD, postoperative day.

71 minutes of faster discharge readiness may have significant implications in getting patients mobilized and home along with inherent PACU workflow improvements. It has been shown that multimodal pain control is one of the most important factors in ensuring early discharge, and when implementing a multimodal pain control protocol as was done in our study, patients experience mild pain levels regardless of the anesthetic choice [48].

This study comprised consecutive patients indicated for primary TKA with a wide variety of body habitus, deformity, and activity level. This broad generalizability represents a typical arthroplasty surgeon's practice in either an individual or academic setting while giving a novice an estimated duration of action for mepivacaine to plan accordingly.

Limitations

Although the primary outcome we were looking at was standardized, the study would have been stronger had it been the same nurse examining all of the patients to minimize interpretation variability. We did keep the examination simple and consistently taught the nurse our routine upon arrival to the PACU. Secondary measures may have had even more variables. Sedation during the procedure did vary depending on the anesthetist's preference, which might influence nausea and pain control afterward. All were standardized to a general protocol of the short-acting agents midazolam, fentanyl, or propofol. This same issue can relate to PACU nurses' discretion within the protocol to use intravenous hydromorphone as needed, which may have influenced nausea rates. Physical therapy would work with patients in the afternoon before the conclusion of their shift at 5 PM. Some patients may have been seen closer to surgery or later on, which would have allowed more recovery time. Since the study was conducted on all TKAs that day with either group, the variability in time before formal ambulation should have been evenly distributed, though our sample size is extremely small for this metric. Our therapists, like many, can get into a routine where a patient walks the expected maximum distance and is not pushed beyond that level for a false sense of maximum ability. We were not pushing for same-day discharges at that time, so the length of stay is not a true reflection of their capabilities. Urinary dysfunction was weighted more toward our male population given retention. Our female population, while evenly distributed, may have had some variable occurrence of undocumented incontinence, as has been our experience with longer acting anesthetics. It is important to note that this study was not powered to investigate such secondary outcomes. Our institution's recently published retrospective cohort study found that mepivacaine allowed for a more rapid recovery after TKA with less urinary complications than bupivacaine (3.8% vs 16.5%) which enabled a shorter length of stay [21]. Further research with larger numbers from differing institutions will be needed to confirm the appeal of mepivacaine as a spinal option for rapid recovery following total joint arthroplasty.

Conclusions

Our study found that patients undergoing TKA with mepivacaine spinal anesthetic had a more rapid neurologic recovery after TKA compared to bupivacaine as seen by return of sensory and motor function and improved time to urination. There were no anesthetic conversions, complications, or TNS events. This intermediate-acting anesthetic has an ideal duration of action to allow for surgical flexibility and shows promise as an everyday option for rapid recovery after arthroplasty.

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