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Liposomal Bupivacaine Plus Bupivacaine Versus Ropivacaine Plus Dexamethasone Brachial Plexus Blockade for Arthroscopic Rotator Cuff Repair

An Unblinded Randomized Controlled Trial

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Background: Brachial plexus blockade is utilized for pain control during arthroscopic rotator cuff repair. The purpose of the present study was to evaluate brachial plexus blockade with liposomal bupivacaine plus bupivacaine (LB+B) as compared with ropivacaine plus dexamethasone (R+D) for arthroscopic rotator cuff repair. Our hypothesis was that the use of LB+B would result in lower pain scores and opioid consumption as compared with R+D.

Methods: We performed a randomized controlled trial of 45 patients receiving ultrasound-guided brachial plexus blockade with LB+B and 44 patients receiving R+D prior to arthroscopic rotator cuff repair. The "worst pain" score in a 24-hour period, oral morphine equivalent dose (OMED), and overall benefit of analgesia score (OBAS) were recorded for 8 days following surgery.

Results: Patient-reported "worst pain" was significantly lower in the LB+B group as compared with the R+D group on postoperative day 0 through day 5. OMED was significantly less for all 8 days studied, with an average cumulative 8-day OMED of 48.5 milligram equivalents in the LB+B group as compared with 190.1 milligram equivalents in the R+D group ($p < 0.001$). The OBAS score was significantly lower in the LB+B group as compared with R+D group on all postoperative days. The use of LB+B for brachial plexus blockade resulted in a 4% complication rate in a population of patients predominantly with American Society of Anesthesiologists (ASA) scores of 1 and 2.

Conclusions: The use of LB+B for brachial plexus blockade during arthroscopic rotator cuff repair was associated with a significant and sustained decrease in the "worst pain" score, opioid consumption, and OBAS compared with R+D. LB+B for brachial plexus blockade also exhibited a strong safety profile.

Level of Evidence: Therapeutic Level I. See Instructions for Authors for a complete description of levels of evidence.

Although arthroscopic rotator cuff repair can be painful, it is a routine ambulatory surgical procedure, largely because of advances in perioperative pain management, including brachial plexus blockade[1]. A recent meta-analysis questioned the overall efficacy of brachial plexus blockade[2] due to rebound pain in the first 16 to 24 hours[3,4].

Previous studies have confirmed the benefits of combining additives with local anesthetics[5-9] for brachial plexus blockade to enhance duration of action. Dexamethasone, when added to ropivacaine or bupivacaine, prolongs analgesia from interscalene blocks[1,5,8-11]. Liposomal bupivacaine (LB) (Exparel; Pacira BioSciences) is the only sustained-release local anesthetic that is approved by the U.S. Food and Drug Administration (FDA) for brachial plexus blockade[12]. It provides sustained local anesthetic release, with plasma levels reported >72 to 120 hours following brachial plexus blockade[12], which is purported to extend analgesia and decrease rebound pain[9].

Disclosure: The **Disclosure of Potential Conflicts of Interest** forms are provided with the online version of the article (http://links.lww.com/JBJSOA/A367).

A **data-sharing statement** is provided with the online version of the article (http://links.lww.com/JBJSOA/A369).

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We hypothesized that the use of ultrasound-guided LB plus bupivacaine (LB+B) for brachial plexus blockade during arthroscopic rotator cuff repair would result in lower postoperative pain scores over an 8-day period compared with ropivacaine plus dexamethasone (R+D). Secondary outcomes included opioid consumption and the overall benefit of analgesia score (OBAS).

Materials and Methods

This study was approved by the institutional review board at the facility where all procedures were performed. It was registered at www.clinicaltrials.gov (NCT04737980) and adhered to CONSORT (Consolidated Standards of Reporting Trials) guidelines (Fig. 1). The inclusion and exclusion criteria are detailed in Table I.

Baseline Data

Sex, body mass index (BMI), and American Society of Anesthesiologists (ASA) score[13] were recorded within 1 week before surgery. Within 1 week before surgery, patients were queried electronically to determine the Patient-Reported Outcomes Measurement Information System (PROMIS) Global-10 score[14,15], brief resilience scale (BRS)[16], PEG (Pain, Enjoyment of Life and General Activity) score[17], and "worst" preoperative pain on a daily basis using an 11-point numeric rating scale (possible range, 0 to 10 points) (see Appendix).

Interventions and Procedures

Patients were randomized by means of block randomization, with use of GraphPad QuickCalcs (https://www.graphpad.com/quickcalcs/randomize1/), to receive brachial plexus blockade with 10 mL of LB 1.3% (133 mg) plus 10 mL of 0.5% bupivacaine HCl[18] (Group LB+B) or 30 mL of 0.5% ropivacaine plus 8 mg (2 mL) of preservative-free dexamethasone (Group R+D). The data collector who allocated subjects, the anesthesiologists performing the blocks, and the subjects were not blinded to the study arm. Ultrasound was used preoperatively to perform a refined variation of the interscalene block: the superior trunk block[19]. The targeted level was immediately before the branching-off point of the suprascapular nerve. The admixture was injected in small aliquots with needle repositioning to observe spread above and below the superior trunk of the brachial plexus. All patients were managed intraoperatively with general anesthesia and a laryngeal mask airway. No nonsteroidal anti-inflammatory drugs (NSAIDs), opioids, or antiemetics were routinely administered.

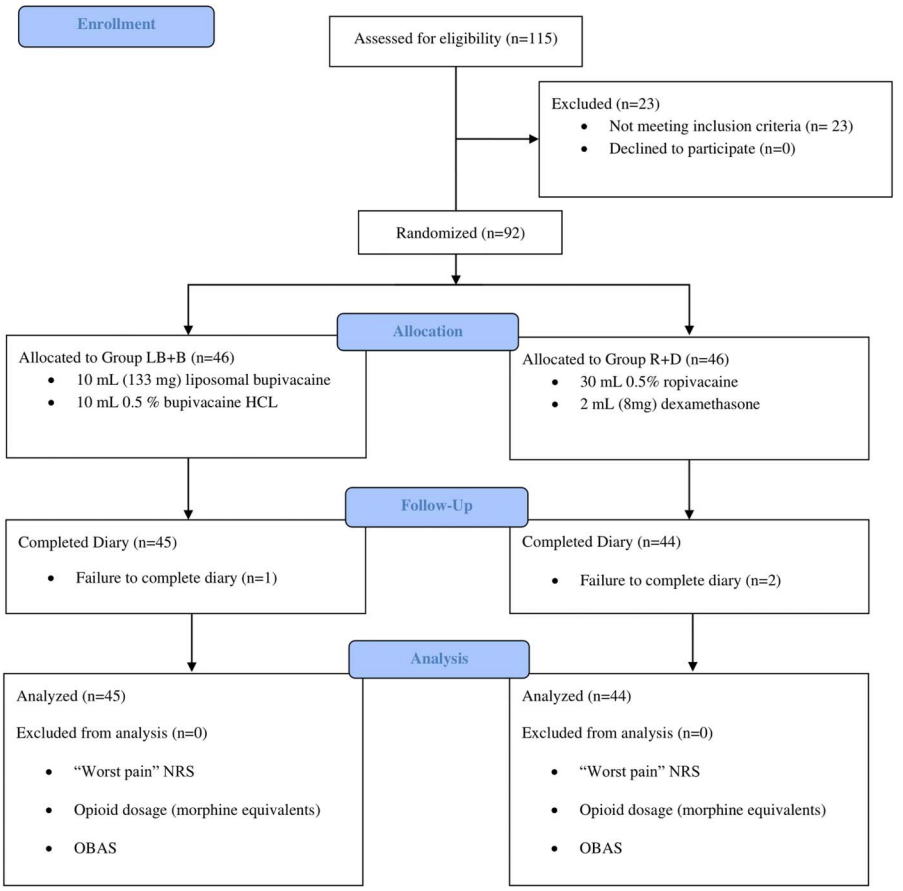

Fig. 1

CONSORT flow diagram. NRS = numeric rating scale.

TABLE I Study Inclusion and Exclusion Criteria Applied to Trial Enrollment

Inclusion Criteria	Exclusion Criteria*
• Supraspinatus tendon tear • Infraspinatus tendon tear • Combined supraspinatus and infraspinatus tendon tear	• Age, <18 yr • Revision surgery • Subscapularis tear • Chronic opioid use (for >3 months prior to surgery) • Allergy to local anesthetics or opioids • Chronic pain (fibromyalgia, RSD, CRPS) • Pulmonary disease (reactive airway disease, COPD) • NSAID intolerance, chronic kidney disease, history of gastritis • Workers' Compensation or medicolegal claim • Neurologic deficit of involved upper extremity

*RSD = reflex sympathetic dystrophy, CRPS = complex regional pain syndrome, COPD = chronic obstructive pulmonary disease.

All arthroscopic rotator cuff repair procedures were performed by a single shoulder surgeon (R.W.S.) in an ambulatory surgery center. The arthroscopic portals (3 main and 2 accessory) were infiltrated with 2 mL of 0.25% bupivacaine. All arthroscopic rotator cuff repairs were performed with a transosseous-equivalent suture bridge repair technique in which 5.5-mm anchors were utilized medially and the sutures were tied in mattress configuration. The suture limbs were then draped laterally and compressed with knotless 4.75-mm anchors. When necessary, a biceps tenodesis (with use of the open subpectoral onlay technique) and/or an acromioplasty was performed. Tear size was assessed intraoperatively with use of the Cofield classification system[20]. Fatty infiltration of the supraspinatus and infraspinatus muscles was assessed with magnetic resonance imaging (MRI) according to the technique described by Fuchs et al.[21]. Operative time was assessed.

Postoperatively, each patient was prescribed scheduled ketorolac (10 mg orally every 6 hours for 5 days) and was instructed to take acetaminophen as needed, not to exceed a total cumulative dose of 3,600 mg in combination with opioid/acetaminophen consumption. Each patient was prescribed oxycodone/acetaminophen (5 mg/325 mg) or hydrocodone/acetaminophen (5 mg/325 mg) with instructions to take 1 to 2 doses of opioid ("minimum effective dose") for moderate (5 to 7 points on the numeric rating scale) or severe pain (≥8 to 10 points on the numeric rating scale), respectively, as needed, at a frequency of every 4 to 6 hours.

Study Outcomes

The primary end point was the "worst pain" (on the numeric rating scale) on each postoperative day (POD). Secondary outcomes included opioid consumption; the OBAS score[22], which assesses analgesic effect and avoidance of side effects (see Appendix); responder rate; and percent opioid-free each POD. Patients were provided diaries in which to record multiple data points on the day of surgery and each of the successive 7 days. Patients were instructed to record "worst pain" and the OBAS score[22] at the beginning of each POD for the preceding 24 hours by recall. Opioid usage was recorded in real time. The duration of 8 days coincided with the routine follow-up schedule after surgery, and it exceeded the reported duration of interscalene block analgesia with LB (48 to 72 hours)[23] as well as R+D (22 hours)[10], hence ensuring that their comparative cumulative effect on postoperative pain would not be underestimated. Opioid consumption was recorded as the number of tablets consumed daily and was converted into the oral morphine equivalent dose (OMED)[24].

The cumulative "responder" rate and opioid-free percentage were derived from the postoperative pain score according to the numeric rating system and opioid consumption. "Responder" was defined as achieving >50% pain reduction from baseline "worst pain." A patient was classified as a "responder" on a discrete POD when pain reduction exceeded 50% of baseline. However, the same patient was not considered to be a "responder" once their pain reduction dropped below 50% on the subsequent POD. A patient was classified as "opioid-free" on a discrete POD if their cumulative opioid consumption since POD 0 was zero.

Statistical Analysis

Statistical analysis was performed with use of R software (v4.0.3; R Foundation for Statistical Computing). Preoperative patient characteristics were evaluated with use of the t test (continuous data) and the chi-square test (categorical data). Raw "worst pain" scores were first evaluated with use of the 1-sided Wilcoxon rank-sum test at each time point. Treatment effect was estimated for "worst pain" change from baseline, OMED, and OBAS with use of mixed-effects modeling to account for repeated measures. A mixed-effects model with natural splines was fitted to "worst pain" change from baseline including the fixed effects of treatment group, POD, treatment-by-POD interaction, and baseline pain score with random intercept of subject and random slope of POD; a conditional F-test with Kenward-Roger approximation for

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the degrees of freedom[25] was used to compute p values. The overall treatment effect on "worst pain" change from baseline was estimated with use of the least-squares mean from the constructed mixed-effects model. Differences between the 2 cohorts on the "worst pain" change from baseline were also evaluated relative to the reported minimum clinically important difference (MCID) of acute postoperative pain (1 point on the numeric rating scale)[26]. A Poisson mixed-effects model with natural splines was applied to longitudinal OMED and OBAS scores, with a Wald z-test to compute significance as degrees of freedom are not applicable for generalized models. Overall treatment effect on the OMED was estimated with use of the least-squares mean from the constructed Poisson mixed-effects model. A 1-sided chi-square test with continuity correction was performed to examine the treatment effect on the postoperative "responder rate" and opioid-free percentage over time.

For each end point above, we also performed daily pairwise comparison of Group LB+B and Group R+D from POD 0

TABLE II Preoperative Patient Demographic and Baseline Characteristics of Group LB+B and Group R+D*

Characteristics	Group LB+B (N = 45)	Group R+D (N = 44)	P Value
Age *(yr)*			
Mean (SD)	59.4 (5.6)	60 (6.2)	0.672
Median [Min, Max]	59.0 [45.0, 74.0]	59.5 [48.0, 74.0]	
Sex *(no. of patients)*			
Female	13 (28.9%)	21 (47.7%)	0.107
Male	32 (71.1%)	23 (52.3%)	
BMI *(kg/m^2)*			
Mean (SD)	27.2 (3.4)	26.9 (4.0)	0.733
Median [Min, Max]	27.0 [21.0, 41.0]	27.0 [18.0, 37.0]	
ASA *(no. of patients)*			
1	14 (31.1%)	10 (22.7%)	0.591
2	26 (57.8%)	30 (68.2%)	
3	5 (11.1%)	4 (9.1%)	
Preop. "worst pain"			
Mean (SD)	5.5 (1.8)	6.0 (1.8)	0.229
Median [Min, Max]	5.0 [2.0, 10.0]	6.0 [2.0, 10.0]	
Preop. least pain			
Mean (SD)	2.8 (1.5)	3.0 (1.8)	0.563
Median [Min, Max]	3.0 [0, 6.0]	3.0 [1.0, 10.0]	
Preop. average pain			
Mean (SD)	4.2 (1.5)	4.5 (1.5)	0.295
Median [Min, Max]	4.0 [2.0, 8.0]	4.5 [2.0, 10.0]	
BRS score			
Mean (SD)	4.1 (0.7)	3.9 (0.6)	0.176
Median [Min, Max]	4.2 [2.3, 5.0]	3.8 [2.8, 5.0]	
PEG score			
Mean (SD)	5.3 (1.4)	5.0 (1.7)	0.365
Median [Min, Max]	5 [2.3, 8.3]	4.7 [1.7, 9.7]	
PROMIS-10 Physical			
Mean (SD)	65.3 (13.0)	68.0 (9.4)	0.278
Median [Min, Max]	65.0 [40.0, 95.0]	70.0 [45.0, 85.0]	
PROMIS-10 Mental			
Mean (SD)	72.1 (13.8)	73.4 (11.2)	0.626
Median [Min, Max]	75.0 [30.0, 100]	75.0 [45.0, 95.0]	

*No significant differences were determined between Groups LB+B and R+D. SD = standard deviation, Min = minimum value, Max = maximum value, ASA = American Society of Anesthesiologists classification system, BRS = Brief Resilience Scale, PEG = Pain, Enjoyment of Life and General Activity, PROMIS = Patient-Reported Outcomes Measurement Information System.

to POD 7, using least-squares means from the respective analysis model, and adjusted for multiplicity with use of the Bonferroni method because of its strict control of the overall false-positivity rate. The least-squares mean differences along with 95% confidence intervals (CIs) and adjusted p values were reported. In all instances, the level of significance was set at $p < 0.05$.

Prior to the study, a power analysis was done to determine the sample size. Based on the assumption that a 40% decrease in "worst pain" from baseline to 24 hours postoperatively on an 11-point numeric rating scale would be clinically relevant, and with power set at 80% and alpha set at 0.05, it was estimated that the number of patients required in each cohort was 30. Therefore, we enrolled 92 patients, allowing for an attrition rate of 35%. This calculation was based on a previous study that utilized a similar volume of ropivacaine for brachial plexus blockade for shoulder surgery[27].

Source of Funding

There was no funding for this research study or manuscript preparation.

Results

Baseline Characteristics Before Intervention

Between July 2019 and February 2020, 92 patients were enrolled. Eighty-nine patients completed the study, with 3 patients (1 from Group LB+B and 2 from Group R+D) being excluded for not completing their home diary. Thus, the analysis included 45 patients in Group LB+B and 44 patients in Group R+D (Fig. 1). There were no significant differences between groups in terms of baseline, intraoperative, or immediate postoperative characteristics (Tables II, III, and IV).

Primary Outcome

Unadjusted "worst pain" scores were significantly lower in the LB+B group as compared with the R+D group on POD 0 through POD 5, despite similar "worst pain" scores at baseline (mean, 5.5 [standard error (SE), 0.3] versus 6.0 [SE, 0.3]; $p = 0.085$) (Table V). In Group LB+B, the "worst pain" was maintained at or under 1.5 points from POD 0 through POD 7. On average, the "worst pain" level was 68% lower in Group LB+B compared with Group R+D from POD 0 through POD 5 ($p \leq 0.002$).

The change in patient-reported postoperative "worst pain" from baseline was evaluated with use of mixed-effects modeling because of repeated measures. On average, the reduction in pain from baseline "worst pain" was 2.4 (SE, 0.3; 95% CI, 1.9 to 3.0; $p < 0.001$) greater for Group LB+B as compared with Group R+D (Table VI, Fig. 2). Moreover, the reduction in pain from baseline was significantly greater in Group LB+B compared with Group R+D from POD 0 through POD 5.

The change from baseline "worst pain" for both cohorts was also tested against the MCID threshold of 1 point[26],

TABLE III Intraoperative and Immediate Postoperative Patient Characteristics*

Characteristics	Group LB+B (N = 45)	Group R+D (N = 44)	P Value
No. of liters of arthroscopy fluid			
Mean (SD)	11.1 (4.6)	11.6 (4.2)	0.586
Median [Min, Max]	10.5 [3.0, 24.0]	12.0 [6.0, 24.0]	
No. of anchors			
Mean (SD)	2.9 (1.0)	3.2 (0.8)	0.175
Median [Min, Max]	3.0 [2.0, 7.0]	3.0 [2.0, 5.0]	
Subacromial decompression *(no. of patients)*	22 (49%)	20 (45%)	0.740
Distal clavicle excision *(no. of patients)*	15 (33%)	12 (27%)	0.761
Biceps tenodesis *(no. of patients)*	12 (27%)	18 (41%)	0.152
Operative time *(min)*			
Mean (SD)	51.4 (11.1)	50.0 (11.2)	0.549
Median [Min, Max]	53.0 [23.0, 74.0]	47.5 [32.0, 81.0]	
PACU time *(min)*			
Mean (SD)	81.2 (18.5)	87.2 (14.4)	0.095
Median [Min, Max]	84 [8, 119]	86 [54, 121]	
Pain at PACU discharge			
Mean (SD)	0.5 (1.2)	0.5 (1.5)	0.846
Median [Min, Max]	0 [0, 6]	0 [0, 8]	

*Comparison of volume of arthroscopy fluid utilized, number of bone anchors used to repair rotator cuff tendon(s), operative time, concomitant operative procedures, recovery time in post-anesthesia care unit (PACU), and level of pain on the 11-point numeric rating system at the time of discharge from PACU. No significant differences were observed between Groups LB+B and R+D. SD = standard deviation, Min = minimum value, Max = maximum value.

TABLE IV Rotator Cuff Tear Size and Muscle Degeneration Characteristics*

Characteristics	Group LB+B (N = 45)	Group R+D (N = 44)	P Value
Rotator cuff tear size[20] *(no. of patients)*			0.964
Small	9 (20%)	7 (16%)	
Medium	10 (22%)	9 (20%)	
Large	23 (51%)	25 (57%)	
Massive	3 (7%)	3 (7%)	
Goutallier grade[21] *(no. of patients)*			
Supraspinatus			0.431
Grade 0	16 (36%)	14 (32%)	
Grade 1	17 (38%)	14 (32%)	
Grade 2	12 (27%)	16 (36%)	
Grade 3	0 (0%)	0 (0%)	
Grade 4	0 (0%)	0 (0%)	
Infraspinatus			0.903
Grade 0	15 (33%)	16 (36%)	
Grade 1	22 (49%)	17 (39%)	
Grade 2	8 (18%)	11 (25%)	
Grade 3	0 (0%)	0 (0%)	
Grade 4	0 (0%)	0 (0%)	

*Rotator cuff tear size was assessed according to Cofield classification system as small (<1 cm), medium (1-3 cm), large (3-5 cm), or massive (>5 cm)[20]. Fatty degeneration of the supraspinatus and infraspinatus muscles was classified according to the Goutallier grading system as Grade 0 (no fatty infiltration), Grade 1 (muscle contains some fatty streaks), Grade 2 (<50% fatty muscle atrophy), Grade 3 (equal fat and muscle), or Grade 4 (>50% fatty muscle atrophy)[21].

demonstrating a significant daily treatment effect on POD 0 ($p = 0.001$), POD 1 ($p < 0.001$), POD 2 ($p < 0.001$), POD 3 ($p < 0.001$) and POD 4 ($p = 0.007$). Although rebound pain occurred in Group R+D between surgery and POD 1, no rebound pain was noted in Group LB+B (Fig. 2).

TABLE V Patient-Reported "Worst Pain" Level*

	Group LB+B	Group R+D	P Value
Baseline	5.5 (0.3) [5.0, 6.1]	6.0 (0.3) [5.5, 6.5]	0.085
POD 0	0.7 (0.2) [0.3, 1.1]	2.9 (0.4) [2.1, 3.8]	<0.001
POD 1	1.2 (0.2) [0.8, 1.7]	5.2 (0.4) [4.4, 6.0]	<0.001
POD 2	1.4 (0.2) [0.9, 1.9]	4.5 (0.3) [3.8, 5.2]	<0.001
POD 3	1.5 (0.2) [0.9, 2.0]	3.9 (0.4) [3.1, 4.6]	<0.001
POD 4	1.3 (0.2) [0.8, 1.8]	3.7 (0.3) [3.0, 4.4]	<0.001
POD 5	1.1 (0.2) [0.7, 1.5]	2.2 (0.3) [1.6, 2.7]	0.002
POD 6	1.0 (0.2) [0.7, 1.4]	1.5 (0.3) [0.9, 2.2]	0.338
POD 7	0.7 (0.2) [0.3, 1.0]	1.5 (0.3) [0.9, 2.1]	0.013

*Summary of patient-reported "worst pain" level at each postoperative day (POD) on the 11-point numeric rating scale for a given 24-hour period in Groups LB+B and R+D. The values are reported as the mean, with the standard error of the mean in parentheses and the 95% CI in brackets. Unadjusted p values are shown for daily pairwise comparisons.

Secondary Outcomes

Opioid Utilization

There was a 6.9-fold (SE, 1.3; 95% CI, 4.0 to 12.0; $p < 0.0021$) lower average daily OMED for Group LB+B as compared with Group R+D. With each day examined independently, POD 0 through POD 7 demonstrated a significant reduction in OMED for Group LB+B as compared with Group R+D (Table VII). Figure 3 demonstrates a rebound effect on POD 1 for OMED in Group R+D, which was not seen in Group LB+B. OMED was nearly 89% lower for Group LB+B as compared with Group R+D on POD 1 ($p = 0.002$).

The cumulative 8-day OMED for Group R+D was 3.9 (SE, 1.0; 95% CI, 3.7 to 4.1; $p < 0.001$) times that for Group LB+B, indicating a significantly lower OMED for Group LB+B as compared with Group R+D.

Correlation Between Numeric Rating Scale Pain and Opioid Utilization

Correlation coefficients were determined each day for "worst pain" and OMED. The average correlation coefficient from POD 0 through POD 7 was 0.64 (95% CI, 0.59 to 0.68; $p < 0.001$). The correlation was highest for POD 1 through POD 4.

Rate of Responders and Opioid-Free Percentage

On POD 0, 91% of patients in Group LB+B were "responders," compared with only 48% of those in Group R+D ($p < 0.001$).

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TABLE VI Change in "Worst Pain" from Baseline*

	Group LB+B	Group R+D	P Value
Average daily	−4.7 (0.2) [−4.7, −4.0]	−1.9 (0.2) [−2.3, −1.6]	<0.001
POD 0	−5.0 (0.3) [−5.6, −4.4]	−2.5 (0.3) [−3.1, −1.9]	<0.001
POD 1	−4.6 (0.2) [−5.1, −4.2]	−1.4 (0.2) [−1.8, −0.9]	<0.001
POD 2	−4.4 (0.2) [−4.8, −3.9]	−1.0 (0.2) [−1.3, −0.5]	<0.001
POD 3	−4.3 (0.2) [−4.7, −3.9]	−1.4 (0.2) [−1.8, −1.0]	<0.001
POD 4	−4.4 (0.2) [−4.8, −4.0]	−2.5 (0.2) [−2.9, −2.1]	<0.001
POD 5	−4.6 (0.2) [−5.0, −4.1]	−3.6 (0.2) [−4.0, −3.1]	0.005
POD 6	−4.8 (0.2) [−5.3, −4.4]	−4.1 (0.2) [−4.6, −3.6]	0.122
POD 7	−5.0 (0.3) [−5.6, −4.4]	−4.3 (0.3) [−4.9, −3.7]	0.386

*Change in patient-reported "worst pain" level on the 11-point numeric rating scale between baseline and each postoperative day (POD). The values are reported as the mean, with the standard error of the mean in parentheses and the 95% CI in brackets. Adjusted p values (Bonferroni method) are shown for daily pairwise comparisons. Negative values reflect improvement from baseline pain.

On POD 1, 86% of Group LB+B were still "responders," compared with only 18% of those in Group R+D ($p < 0.001$). Although the percentage of "responders" declined in both groups on each successive day, a significant disparity ($p < 0.001$) favoring Group LB+B remained (Fig. 4-A). Likewise, there was a significant disparity in the percentage of patients who were opioid-free on POD 0, POD 1, and POD 2 between both cohorts, favoring Group LB+B (Fig. 4-B).

The overall treatment effects on the "responder" rate and the percentage of opioid-free patients for both cohorts demonstrated a p value of <0.001.

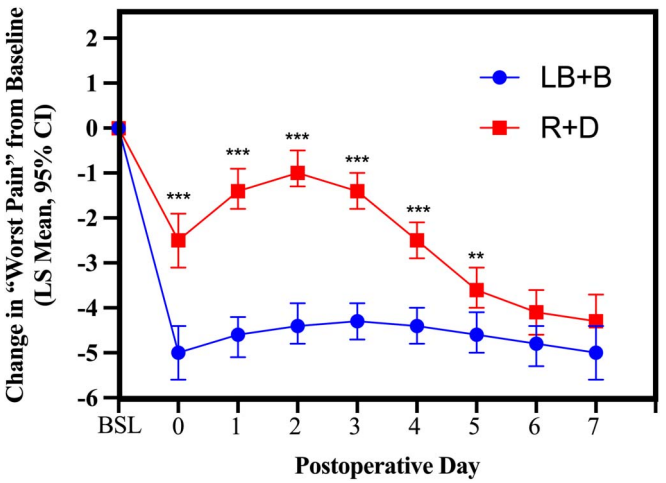

Fig. 2

Change in "worst pain" on 11-point numeric rating scale reported for 8 days following surgery relative to the preoperative "worst pain" reported at baseline (BSL). Negative scores represent reduction in pain. Group LB+B demonstrated an 87% reduction in "worst pain" from baseline for Group LB+B on POD 0. LB+B = liposomal bupivacaine + bupivacaine, R+D = ropivacaine + dexamethasone, LS = least squares, POD = postoperative day. **P < 0.01. ***P < 0.001.

Overall Benefit of Anesthesia

The average daily OBAS score was significantly lower for group LB+B as compared with Group R+D on each POD (Table VIII).

Complications

There were no intraoperative complications. Postoperatively, there were 2 complications in the experimental cohort. One patient in Group LB+B developed Horner syndrome, which resolved. One patient in Group LB+B developed hypoxia from transient phrenic nerve blockade and required hospitalization but was discharged on POD 3.

Discussion

The results of this RCT reveal that, when combined with a multimodal analgesic regimen, patients managed with brachial plexus blockade with use of LB+B had significantly lower "worst pain" scores on 6 of the 7 postoperative days studied, less rebound pain, less daily and cumulative opioid use, and higher overall benefit of anesthesia as compared with patients managed with brachial plexus blockade with use of R+D following arthroscopic rotator cuff repair. Clinicians have argued that analgesic interventions resulting in significant improvements do not necessarily meet clinically meaningful thresholds and thus have recommended that data should be analyzed according to MCID thresholds[28-31]. The MCID for postoperative acute pain was defined by Myles et al. as a score of 1.0 on a visual analog scale[26]. Therefore, our results suggest that LB+B is also associated with a clinically meaningful improvement in pain control as compared with R+D.

Despite some similarities with other recent randomized controlled trials (RCTs)[23,32], our study differed in terms of the effect of LB+B brachial plexus blockade on opioid consumption. For example, Vandepitte et al.[32] compared brachial plexus blockade with LB+B versus bupivacaine in an RCT for major shoulder surgery and demonstrated improvement in "worst pain" and OBAS scores throughout the first week in the LB+B cohort,

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TABLE VII Postoperative Opioid Consumption*

	Group LB+B	Group R+D	P Value
Average cumulative 8-day	48.5 (1.0) [46.5, 50.6]	190.1 (1.0) [186.1, 194.1]	<0.001
Average daily	2.8 (1.2) [1.9, 4.2]	19.6 (1.2) [13.5, 28.6]	<0.001
POD 0	1.8 (1.2) [1.2, 2.7]	13.0 (1.2) [8.9, 19.1]	<0.001
POD 1	4.8 (1.2) [3.2, 7.1]	42.7 (1.2) [29.4, 62.1]	<0.001
POD 2	4.4 (1.2) [3.0, 6.7]	33.5 (1.2) [23.0, 48.7]	<0.001
POD 3	2.9 (1.2) [2.0, 4.4]	18.9 (1.2) [13.0, 27.5]	<0.001
POD 4	3.0 (1.2) [2.0, 4.4]	20.6 (1.2) [14.1, 30.0]	<0.001
POD 5	2.8 (1.2) [1.9, 4.1]	11.1 (1.2) [7.6, 16.1]	<0.001
POD 6	1.8 (1.2) [1.2, 2.7]	4.2 (1.2) [2.9, 6.2]	0.010
POD 7	0.7 (1.3) [0.5, 1.1]	2.3 (1.2) [1.5, 3.4]	0.001

*The values in oral morphine equivalent dose (OMED) are given as the mean, with the standard error of the mean in parentheses and the 95% CI in brackets. Adjusted p values (Bonferroni method) are shown for daily pairwise comparisons. POD = postoperative day.

similar to our study. However, unlike our study, in which there was a 74% reduction in overall opioid consumption, Vandepitte et al.[32] did not find that improvements in "worst pain" and OBAS scores were associated with reduced opioid consumption. This finding may have been due to the opioid-prescribing practices of the authors and their instructions to patients regarding the utilization of opioids after surgery. We instructed patients to take opioids only for moderate or severe pain, discouraging scheduled consumption. Our study examined correlation coefficients between "worst pain" scores and OMED. The high correlation coefficient (0.64) across the study suggests that patients did not consume opioids randomly or by schedule but rather commensurate with their pain level.

We are aware of only 1 other RCT in which brachial plexus blockade with use of LB+B was compared with bupivacaine plus dexamethasone[33]. In that study, Baessler et al.[33] found no difference in visual analog scale (VAS) pain scores across 4 postoperative days, with the exception that LB combined with dexamethasone was associated with significantly less pain on POD 3 as compared with an admixture of standard bupivacaine plus dexamethasone. This finding is in contradistinction to our findings that patient-reported "worst pain" and "worst pain" as a change from baseline were significantly more favorable on POD 0 through POD 5 for Group LB+B as compared with Group R+D. One explanation may be the different methodology of querying pain scores. Baessler et al.[33] queried pain scores daily at 3 time points, which risks catching patients just prior to or after consuming opioids and therefore may bias results. Conversely, our study utilized "worst pain" per 24-hour period to capture the extreme of pain regardless of opioid utilization in that 24-hour period.

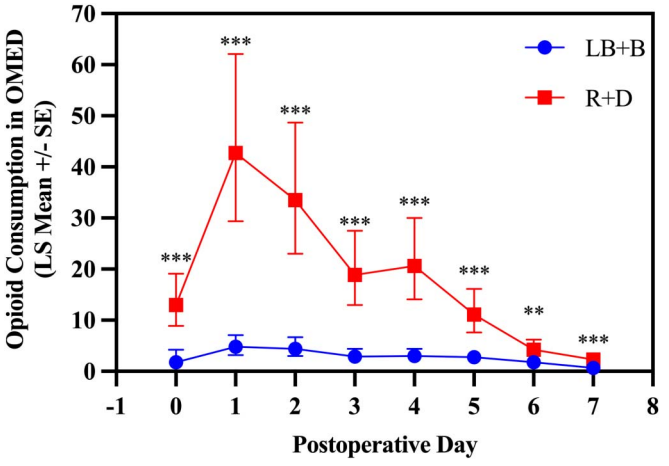

Fig. 3

Opioid dosage for Group LB+B and Group R+D, reported as oral morphine equivalent dose (OMED) according to time point from surgery. LB+B = liposomal bupivacaine + bupivacaine, R+D = ropivacaine + dexamethasone, POD = postoperative day, LS = least squares. **P < 0.01. ***P < 0.001.

Our study had several strengths. The study was an investigator-initiated randomized prospective trial and was not sponsored or funded by a drug company. The patients who were managed with LB were compared with patients who were managed with a long-lasting active injectate (not a placebo). The observed treatment effects were large and lasted for up to a week. We evaluated patient resilience and health quality and recorded specifics regarding surgical and brachial plexus blockade techniques. Furthermore, we quantified rotator cuff tear size and fatty infiltration of the muscle as surrogates for the severity of rotator cuff disease, with both cohorts having similar characteristics. The sustained effect of LB+B in the current study as compared with other studies may be explained by our brachial plexus blockade technique. Our approach for the superior trunk block included multiple points of deposition of the viscous LB, providing more areas of the brachial plexus with close contact to the slow-release bupivacaine as compared with other studies that may have utilized a traditional interscalene

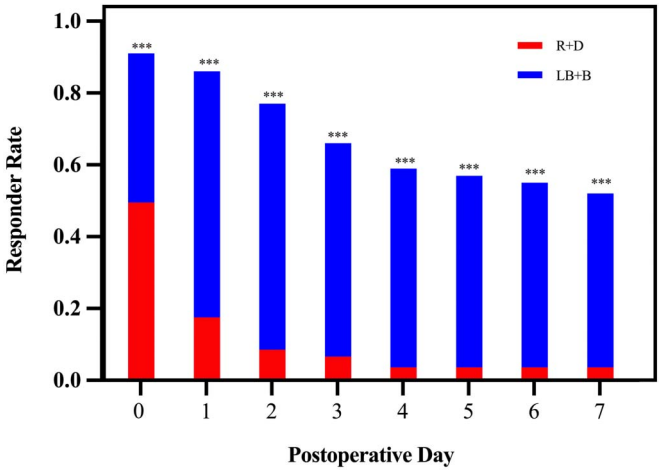

Fig. 4-A

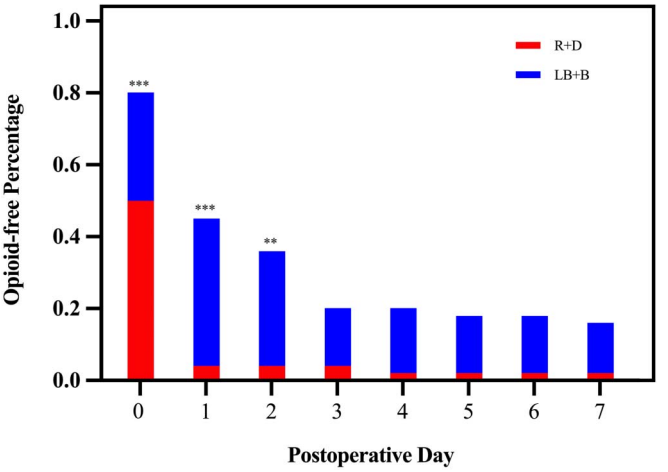

Fig. 4-B

Fig. 4-A Percentage of "responders" for each postoperative day. A responder was considered to be any patient who had a >50% reduction in "worst pain" on the numeric rating scale from baseline for that given day. ***P < 0.001. **Fig. 4-B** Percentage of patients who were opioid-free on any given day. "Opioid-free" was defined as not taking any opioids during that 24-hour period or prior to that 24-hour period. **P < 0.01. ***P < 0.001.

brachial plexus blockade approach with a single site of infiltration depending on diffusion. Previous RCTs of LB+B for brachial plexus blockade in the setting of shoulder surgery have not detailed if multiple points of deposition were utilized, which we believe is important for LB+B to have a maximal effect[32,33]. The diffusion of free bupivacaine released by LB may be limited by proximity to the nerve[34,35].

The current study had several limitations. First, much of the outcome data collected required patient recall, which may introduce bias. However, this recall bias would apply similarly in both cohorts. Second, there are limitations to utilizing "worst pain" as the outcome as the memory of pain may not be accurate[36]. Third, the non-liposomal local anesthetic was different in Group LB+B (bupivacaine) and Group R+D (ropivacaine), and the admixtures had different overall volumes. Ropivacaine and bupivacaine are not equipotent. Ropivacaine requires higher mass to achieve longer durations of action on par with bupivacaine. As the mass of the drug delivered to the neural tissue plays a role in block effectiveness, this may have affected efficacy. The administration of LB has been shown to be particularly technique-dependent as the diffusion potential is less than that of bupivacaine or ropivacaine[34,35]. Furthermore, the study was not blinded, which may introduce patient and provider bias. Finally, the complication rate in our study may be underestimated as our population consisted of patients who were predominantly classified as ASA 1 and 2 and therefore may not be generalizable to broader populations.

TABLE VIII Overall Benefit of Analgesia Score (OBAS)*

	Group LB+B	Group R+D	P Value
Average daily	1.4 (1.2) [1.0, 1.9]	4.6 (1.1) [3.6, 6.0]	<0.001
POD 0	0.8 (1.2) [0.6, 1.2]	2.8 (1.2) [2.0, 3.7]	<0.001
POD 1	1.8 (1.2) [1.3, 2.4]	5.2 (1.1) [4.0, 6.8]	<0.001
POD 2	2.1 (1.2) [1.6, 2.8]	5.7 (1.1) [4.4, 7.3]	<0.001
POD 3	1.6 (1.2) [1.2, 2.2]	4.8 (1.1) [3.7, 6.2]	<0.001
POD 4	1.3 (1.2) [0.9, 1.7]	4.5 (1.1) [3.4, 5.8]	<0.001
POD 5	1.3 (1.2) [1.0, 1.8]	3.8 (1.1) [2.9, 4.9]	<0.001
POD 6	1.4 (1.2) [1.0, 1.9]	2.9 (1.2) [2.2, 3.8]	0.003
POD 7	1.1 (1.2) [0.8, 1.6]	2.3 (1.2) [1.7, 3.1]	0.009

*The overall benefit of analgesia scores (OBAS) are given as mean, with the standard error of the mean in parentheses and the 95% CI in brackets. Adjusted p values (Bonferroni method) are given for daily pairwise comparisons. POD = postoperative day.

Conclusions

The use of LB in combination with bupivacaine was associated with improved analgesia, lower opioid requirements, and improved anesthesia efficacy over a longer duration compared with the combination of R+D among patients who received brachial plexus blockade for arthroscopic rotator cuff repair. These results should be compared with those of additional prospective trials investigating the use of LB in other clinical settings to establish efficacy and evaluate rates of complication.

Appendix

eA Supporting material provided by the authors is posted with the online version of this article as a data supplement at jbjs.org (http://links.lww.com/JBJSOA/A368). ■

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