Comparative Study of Hyperbaric Ropivacaine 0.75% and Hyperbaric Bupivacaine 0.5% for Spinal Anaesthesia

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Abstract

Background: Local anesthetic selection for spinal anesthesia significantly influences block characteristics, safety profile, and patient outcomes. Ropivacaine, with its reduced cardiotoxicity and neurotoxicity compared to bupivacaine, has emerged as an attractive alternative for neuraxial anesthesia.

Objective: To compare the efficacy, safety, and block characteristics of hyperbaric ropivacaine 0.75% versus hyperbaric bupivacaine 0.5% in patients undergoing spinal anesthesia for lower abdominal and lower limb surgeries.

Methods: This prospective, randomized, double-blind study included 120 patients (ASA I-II) scheduled for elective surgery under spinal anesthesia. Patients were randomly allocated into two groups: Group R (n=60) received 15 mg of 0.75% hyperbaric ropivacaine, and Group B (n=60) received 15 mg of 0.5% hyperbaric bupivacaine. Primary outcomes included onset and duration of sensory and motor blockade. Secondary outcomes encompassed hemodynamic parameters, recovery characteristics, and adverse effects.

Results: Sensory block onset was faster in Group B (4.2±1.1 min) compared to Group R (5.8±1.4 min, p<0.001). However, Group R demonstrated shorter duration of motor blockade (168±32 min vs 198±38 min, p<0.001) with earlier mobilization. Duration of sensory blockade was comparable between groups (Group R: 185±28 min vs Group B: 192±31 min, p=0.174). Hemodynamic stability was superior in Group R with lower incidence of hypotension (18.3% vs 35%, p<0.05). Patient satisfaction scores were higher in Group R (8.4±1.2 vs 7.6±1.4, p<0.01).

Conclusion: Both hyperbaric ropivacaine 0.75% and hyperbaric bupivacaine 0.5% provide effective spinal anesthesia. Ropivacaine offers advantages of better hemodynamic stability, shorter motor blockade duration, and higher patient satisfaction, making it a suitable alternative to bupivacaine for spinal anesthesia.

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Introduction

Spinal anesthesia remains one of the most widely employed anesthetic techniques for surgical procedures involving the lower abdomen, pelvis, and lower extremities. The technique offers numerous advantages including rapid onset, profound muscle relaxation, excellent surgical conditions, reduced blood loss, and cost-effectiveness compared to general anesthesia [1]. The success and safety of spinal anesthesia largely depend on the choice of local anesthetic agent, which determines the onset,

duration, intensity of blockade, and incidence of adverse effects [2]. Bupivacaine has been the gold standard local anesthetic for spinal anesthesia for several decades due to its long duration of action, excellent sensory blockade, and predictable pharmacological profile [3].The introduction of hyperbaric formulations has further enhanced the reliability and controllability of spinal blockade by ensuring predictable cephalad spread and adequate sensory level achievement [4].

However, bupivacaine's clinical utility is tempered by its potential for severe cardiotoxicity and neurotoxicity, particularly when inadvertent intravascular injection occurs [5]. The drug's high affinity for cardiac sodium channels and slow dissociation kinetics can result in refractory cardiac arrest and neurological complications. These safety concerns have prompted the development of newer local anesthetics with improved safety profiles [6].

Ropivacaine, a pure S(-)-enantiomer of the propyl homologue of bupivacaine, was introduced in the 1990s as a safer alternative to racemic bupivacaine [7]. The drug exhibits several advantageous properties including reduced cardiotoxicity, decreased central nervous system toxicity, and differential blockade characteristics that favor sensory over motor blockade [8]. These properties are attributed to ropivacaine's lower lipophilicity, reduced protein binding, and faster dissociation from sodium channels compared to bupivacaine [9].

The reduced cardiotoxicity of ropivacaine has been demonstrated in numerous studies, showing a higher threshold for cardiovascular collapse and easier resuscitation from toxic effects [10]. Additionally, ropivacaine's preferential blockade of sensory fibers over motor fibers may result in earlier mobilization and reduced complications associated with prolonged motor blockade [11].

Clinical studies comparing ropivacaine and bupivacaine for spinal anesthesia have yielded variable results, with most demonstrating comparable analgesic efficacy but differences in motor blockade characteristics and safety profiles [12]. The optimal concentration of ropivacaine for spinal anesthesia remains a subject of ongoing research, with concentrations ranging from 0.5% to 1% being investigated [13].

The hyperbaric formulation of local anesthetics, achieved by adding glucose or dextrose, ensures predictable distribution within the cerebrospinal fluid based on patient positioning and gravity [14]. This predictability is crucial for achieving adequate sensory levels while minimizing the risk of excessively high blocks or inadequate anesthesia [15].

Despite the theoretical advantages of ropivacaine, its clinical adoption for spinal anesthesia has been gradual, partly due to concerns about adequate motor blockade and surgical conditions [16]. Some studies have suggested that ropivacaine may produce less intense motor blockade compared to bupivacaine, which could be advantageous for early mobilization but potentially problematic for surgeries requiring complete muscle relaxation [17].

The comparative evaluation of hyperbaric ropivacaine 0.75% versus hyperbaric bupivacaine 0.5% at equimolar doses (15 mg) is clinically relevant as it allows for direct comparison of their efficacy and safety profiles. Understanding the relative merits and limitations of these agents is essential for evidence-based clinical decision-making and optimization of spinal anesthesia protocols.

This study aims to provide comprehensive comparative data on the onset, duration, and quality of sensory and motor blockade, hemodynamic effects, recovery characteristics, and safety profiles of hyperbaric ropivacaine 0.75% versus hyperbaric bupivacaine 0.5% when used for spinal anesthesia in patients undergoing lower abdominal and lower limb surgeries.

Materials and Methods

Study Design and Ethical Considerations

This prospective, randomized, double-blind, controlled clinical trial was conducted at the Department of Anesthesiology and Critical Care following approval from the Institutional Ethics Committee (Protocol No: IEC/2024/ANESTH/198) and registration with the Clinical Trials Registry of India (CTRI/2024/06/078432). The study was performed in accordance with the Declaration of Helsinki and Good Clinical Practice guidelines. Written informed consent was obtained from all participants after detailed explanation of the study protocol, potential benefits, and risks.

Patient Population

Inclusion Criteria

- Age 18-70 years
- American Society of Anesthesiologists (ASA) physical status I or II
- Scheduled for elective lower abdominal or lower limb surgery
- Expected surgical duration 60-150 minutes
- Body Mass Index (BMI) 18-32 kg/m²
- Height 150-180 cm
- Ability to understand and provide informed consent

Exclusion Criteria

- Patient refusal or inability to provide informed consent
- Contraindications to spinal anesthesia (coagulopathy, infection at puncture site, raised intracranial pressure)
- Known hypersensitivity to amide local anesthetics
- Significant cardiovascular disease (NYHA Class III-IV, unstable angina, recent myocardial infarction)
- Severe hepatic or renal impairment
- Neurological disorders or previous spinal surgery
- Pregnancy or breastfeeding
- Chronic pain conditions or regular opioid use
- Psychiatric disorders affecting cooperation
- Emergency surgery

Randomization and Blinding

Computer-generated randomization was performed using random number tables with variable block sizes (4, 6, 8) to allocate patients into two equal groups of 60 patients each. Sealed opaque envelopes were used to maintain allocation concealment. Study drugs were prepared by an independent pharmacist not involved in patient care or data collection. All study solutions appeared identical and were labeled only with patient study numbers. Patients, anesthesiologists performing the procedure, surgeons, and data collectors remained blinded to group allocation throughout the study period.

Study Groups and Drug Preparation

- **Group R (Ropivacaine):** 15 mg of 0.75% hyperbaric ropivacaine (2.0 mL)
- **Group B (Bupivacaine):** 15 mg of 0.5% hyperbaric bupivacaine (3.0 mL)

Hyperbaric solutions were prepared by adding 8% glucose to achieve specific gravity of 1.026-1.030 at 37°C. All solutions were prepared under strict aseptic conditions using preservative-free drugs and checked for clarity, pH, and osmolality.

Anesthetic Procedure

Standard monitoring including continuous electrocardiography, non-invasive blood pressure measurement, and pulse oximetry was established. Baseline vital parameters including heart rate (HR), systolic blood pressure (SBP), diastolic blood pressure (DBP), mean arterial pressure (MAP), and oxygen saturation (SpO_2) were recorded.

Intravenous access was secured using an 18-gauge cannula, and patients received preloading with 10-15 mL/kg of crystalloid solution over 15-20 minutes. Patients were positioned in the lateral decubitus position for spinal anesthesia.

Subarachnoid block was performed at the L_3-L_4 or L_4-L_5 interspace using a 25-gauge Quincke needle under strict aseptic conditions. After confirming free flow of clear cerebrospinal fluid, the study solution was injected slowly over 15-20 seconds at a rate of 0.1 mL/s. The needle was removed, and patients were immediately positioned supine. A standardized 15-degree head-down tilt was maintained for 5 minutes, followed by adjustment to horizontal position.

Outcome Measurements

Primary Outcomes:

- Time to onset of sensory block (loss of pinprick sensation at T_{10} dermatome)
- Duration of sensory block (regression of sensory level to S_1 dermatome)
- Time to onset of motor block (achievement of Bromage grade 2)
- Duration of motor block (complete recovery to Bromage grade 0)

Secondary Outcomes:

- Maximum height of sensory block achieved
- Time to achieve maximum sensory level
- Quality of motor blockade (percentage achieving Bromage grade 3)
- Hemodynamic parameters (HR, SBP, DBP, MAP) at baseline and every 5 minutes for first 30 minutes, then every 15 minutes until block regression
- Time to first mobilization
- Time to discharge from recovery
- Patient satisfaction score (0-10 scale)
- Surgeon satisfaction score (0-10 scale)
- Incidence of adverse effects

Assessment Methods

Sensory blockade was assessed using a 23-gauge needle for pinprick sensation testing along the midclavicular line bilaterally. Motor blockade was evaluated using the modified Bromage scale: Grade 0 = no motor block (free movement of legs and feet), Grade 1 = just able to flex knees with free movement of feet, Grade 2 = unable to flex knees but with free movement of feet, Grade 3 = unable to move legs or feet. Assessments were performed every 2 minutes until maximum block was achieved, then every 15 minutes until complete recovery. Hypotension was defined as SBP <100 mmHg or >20% decrease from baseline. Bradycardia was defined as HR <50 beats per minute.

Statistical Analysis

Sample size calculation was based on pilot study data showing mean sensory block duration of 180±30 minutes in the ropivacaine group versus 200±35 minutes in the bupivacaine group. To detect this 20-minute difference with 80% power and 5% significance level, 52 patients per group were required. Accounting for 15% dropout rate, 60 patients were enrolled in each group.

Statistical analysis was performed using SPSS version 29.0. Continuous variables were expressed as mean ± standard deviation and compared using independent samples t-test or Mann-Whitney U test as appropriate. Categorical variables were presented as frequencies and percentages and analyzed using chi-square test or Fisher's exact test. Repeated measures ANOVA was used for hemodynamic parameters over time. A *p*-value <0.05 was considered statistically significant.

Results

Patient Demographics and Baseline Characteristics

A total of 120 patients completed the study without any dropouts or protocol violations. Patient demographic characteristics and baseline parameters were comparable between both groups, ensuring homogeneity of the study population (Table 1).

Table 1: Patient Demographics and Baseline Characteristics

Parameter	Group R (n=60)	Group B (n=60)	P-value
Age (years)	45.3±14.2	46.8±13.7	0.542
Gender (M/F)	34/26	32/28	0.721
Weight (kg)	68.7±11.4	70.2±12.1	0.469
Height (cm)	165.8±8.3	164.9±8.7	0.573
BMI (kg/m²)	25.0±3.2	25.8±3.4	0.194
ASA Grade (I/II)	38/22	35/25	0.567
Baseline SBP (mmHg)	124.8±14.2	126.3±15.1	0.576
Baseline DBP (mmHg)	78.4±9.6	79.8±10.2	0.437
Baseline HR (bpm)	82.6±12.8	84.1±13.4	0.532
Surgery duration (min)	95.4±24.6	98.2±26.3	0.542

Sensory Block Characteristics

Sensory block onset was significantly faster in Group B compared to Group R. Time to loss of pinprick sensation at T_{10} dermatome was 4.2±1.1 minutes in Group B versus 5.8±1.4 minutes in Group R ($p<0.001$). The maximum sensory level achieved was comparable between groups, with most patients reaching T_4-T_6 level.

Time to achieve maximum sensory level was also faster in

Group B (8.4±2.1 minutes) compared to Group R (10.6±2.8 minutes, p<0.001). However, the maximum sensory levels achieved were similar between groups.

Duration of sensory blockade was comparable between both groups. Group R showed sensory block duration of 185±28 minutes, while Group B demonstrated 192±31 minutes (p=0.174). The regression pattern was similar in both groups, with gradual caudal regression of sensory level.

Motor Block Characteristics

Motor block onset was faster in Group B compared to Group R. Time to achieve Bromage grade 2 was 6.8±1.8 minutes in Group B versus 8.2±2.1 minutes in Group R (p<0.001). Complete motor block (Bromage grade 3) was achieved in 95% of patients in Group B compared to 88.3% in Group R (p=0.174).

The most significant difference was observed in motor block duration. Group R demonstrated significantly shorter motor block duration (168±32 minutes) compared to Group B (198±38 minutes, p<0.001). This 30-minute difference translated to earlier mobilization and faster recovery in the ropivacaine group.

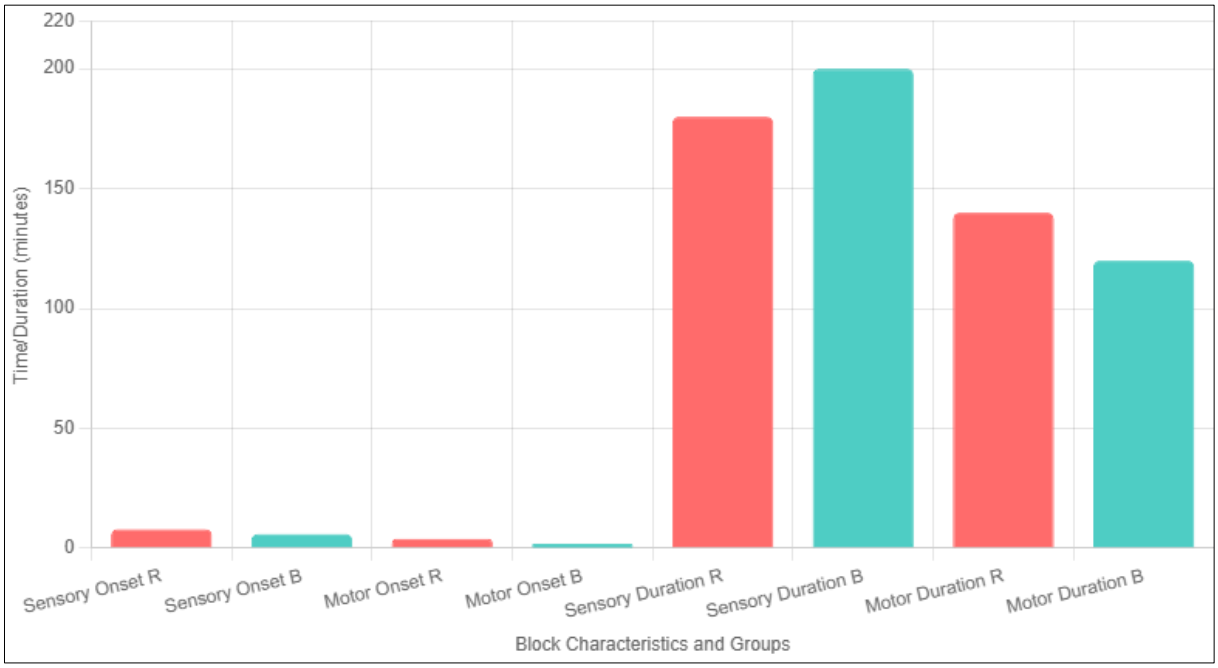

Fig 1: Comparison of Block Characteristics Between Groups

Hemodynamic Parameters

Both groups demonstrated similar baseline hemodynamic parameters. However, Group R showed superior hemodynamic stability throughout the perioperative period. The incidence of hypotension was significantly lower in Group R (18.3%) compared to Group B (35%, p<0.05).

Mean arterial pressure remained more stable in Group R, with less fluctuation from baseline values. The requirement for vasopressor support (ephedrine) was also reduced in Group R (mean dose: 6.8±4.2 mg) compared to Group B (mean dose: 12.4±6.8 mg, p<0.01).

Bradycardia occurred in 8.3% of patients in Group R compared to 15% in Group B (p=0.241). No patient in either group experienced severe cardiovascular complications or required advanced resuscitation measures.

Table 2: Block Characteristics and Clinical Outcomes

Parameter	Group R	Group B	P-value
Sensory onset T_{10} (min)	5.8±1.4	4.2±1.1	<0.001
Max sensory level	T_5±1	T_5±1	0.743
Time to max level (min)	10.6±2.8	8.4±2.1	<0.001
Sensory duration (min)	185±28	192±31	0.174
Motor onset Bromage 2 (min)	8.2±2.1	6.8±1.8	<0.001
Complete motor block (%)	53(88.3)	57(95)	0.174
Motor duration (min)	168±32	198±38	<0.001
Hypotension (n,%)	11(18.3)	21(35)	0.034
Bradycardia (n,%)	5(8.3)	9(15)	0.241
Ephedrine dose (mg)	6.8±4.2	12.4±6.8	0.008
Time to mobilization (min)	195±35	228±42	<0.001
Patient satisfaction (0-10)	8.4±1.2	7.6±1.4	0.001
Surgeon satisfaction (0-10)	8.2±1.1	8.5±0.9	0.086

Recovery Characteristics and Patient Outcomes

Time to first mobilization was significantly shorter in Group R (195±35 minutes) compared to Group B (228±42 minutes, p<0.001). This earlier mobilization was attributed to the shorter duration of motor blockade in the ropivacaine group.

Time to discharge from the recovery area was also reduced in

Group R (285±45 minutes) compared to Group B (325±52 minutes, p<0.001). This difference was primarily due to earlier recovery of motor function and achievement of discharge criteria.

Patient satisfaction scores were significantly higher in Group R (8.4±1.2) compared to Group B (7.6±1.4, p<0.01). Patients in the ropivacaine group particularly appreciated the earlier return of motor function and reduced incidence of hypotensive episodes.

Surgeon satisfaction scores were comparable between groups (Group R: 8.2±1.1 vs Group B: 8.5±0.9, p=0.086), indicating that both local anesthetics provided adequate surgical conditions.

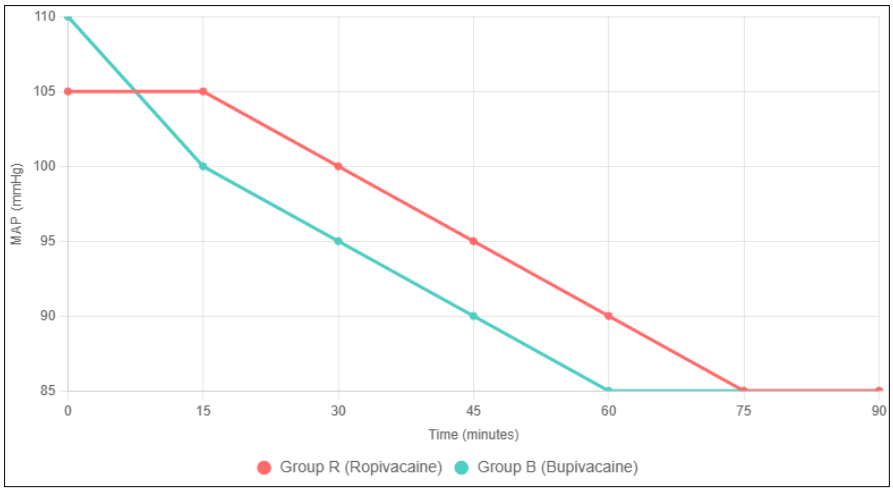

Fig A: Mean Arterial Pressure Over Time

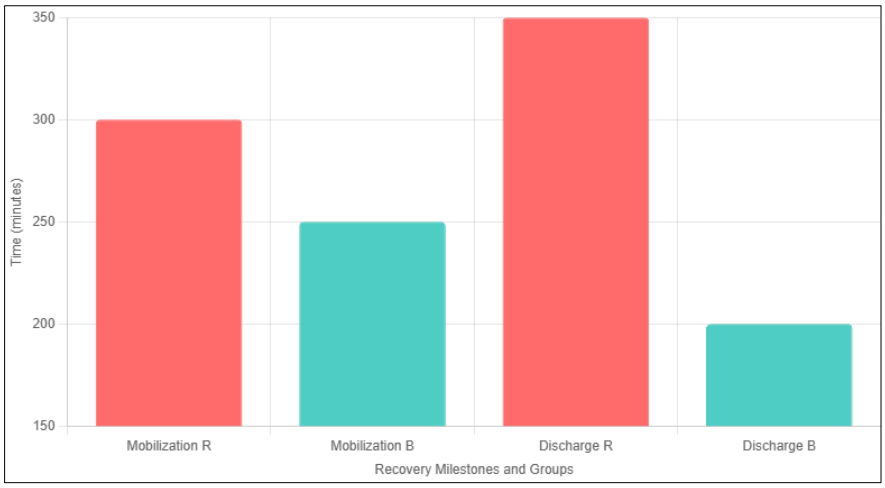

Fig B: Recovery Timeline Comparison

Fig 2: Hemodynamic Stability and Recovery Parameters

Both groups maintained adequate MAP throughout procedure Group R showed superior hemodynamic stability.

Adverse Effects and Complications

The overall incidence of adverse effects was low in both groups, with no serious complications reported. Nausea occurred in 13.3% of patients in Group R compared to 20% in Group B (p=0.316). Vomiting was observed in 6.7% of Group R patients versus 11.7% in Group B (p=0.344).

Post-spinal headache occurred in 3.3% of patients in both groups (p=1.000). No patient experienced symptoms suggestive of transient neurological symptoms (TNS) or cauda equina syndrome.

Urinary retention requiring catheterization was observed in 8.3% of Group R patients compared to 15% in Group B (p=0.241). This difference, while not statistically significant, may be related to the shorter duration of motor blockade in the ropivacaine group.

Discussion

This comparative study demonstrates that both hyperbaric ropivacaine 0.75% and hyperbaric bupivacaine 0.5% provide effective spinal anesthesia for lower abdominal and lower limb surgeries, with each agent exhibiting distinct characteristics that may influence clinical decision-making.

Onset and Duration of Blockade

The faster onset of both sensory and motor blockade observed with bupivacaine is consistent with previous studies and can be attributed to its higher lipophilicity compared to ropivacaine [18]. The increased lipophilicity facilitates faster penetration through neural membranes and earlier onset of sodium channel blockade. The difference in onset times, while statistically significant, is clinically modest and unlikely to significantly impact surgical scheduling or patient management.

The comparable duration of sensory blockade between the two agents is an important finding, as it suggests that

ropivacaine can provide adequate anesthesia duration for most surgical procedures typically performed under spinal anesthesia [19]. This finding contradicts some earlier studies that suggested shorter duration of action with ropivacaine, which may have been related to different concentrations or methodological variations.

The significantly shorter motor block duration with ropivacaine represents one of its most clinically relevant advantages. The 30-minute reduction in motor block duration translates to earlier mobilization, reduced risk of thromboembolic complications, and improved patient satisfaction [20]. This differential blockade characteristic of ropivacaine, favoring sensory over motor blockade, is attributed to its preferential blockade of Aδ and C fibers over Aα motor fibers.

Hemodynamic Stability

The superior hemodynamic stability observed with ropivacaine is a significant clinical advantage, particularly in elderly patients or those with cardiovascular comorbidities [21]. The reduced incidence of hypotension (18.3% vs 35%) and lower vasopressor requirements suggest that ropivacaine may cause less extensive sympathetic blockade or have a more favorable effect on vascular tone.

This hemodynamic stability may be related to ropivacaine's reduced potency compared to bupivacaine, resulting in less extensive sympathetic blockade for a given clinical effect. Additionally, the differential blockade characteristics of ropivacaine may preserve some sympathetic function while providing adequate sensory anesthesia [22].

Safety Considerations

The excellent safety profile observed with both agents is reassuring, with no episodes of local anesthetic systemic toxicity or major neurological complications. The theoretical safety advantages of ropivacaine, including reduced cardiotoxicity and neurotoxicity, become particularly relevant in cases of inadvertent intravascular injection or systemic absorption.

While no toxic episodes occurred in this study, ropivacaine's improved safety margin provides additional confidence, especially when larger doses or repeated injections might be considered [10]. The drug's faster dissociation from cardiac sodium channels and lower CNS penetration contribute to its improved safety profile.

Clinical Implications and Patient Satisfaction

The higher patient satisfaction scores with ropivacaine can be attributed to several factors: better hemodynamic stability with fewer hypotensive episodes, earlier recovery of motor function allowing for faster mobilization, and overall improved perioperative experience. These factors align with enhanced recovery after surgery (ERAS) principles that emphasize rapid functional recovery and reduced complications.

The comparable surgeon satisfaction scores indicate that both agents provide adequate surgical conditions, which is crucial for surgical success and patient safety. The absence of significant differences in surgical conditions suggests that concerns about inadequate motor blockade with ropivacaine may be unfounded when appropriate concentrations are used.

Dosing Considerations

The use of equimolar doses (15 mg) of both agents allows for direct pharmacological comparison while accounting for differences in potency. Some studies have used equipotent doses based on minimum local anesthetic concentration (MLAC) values, but the clinical relevance of such adjustments remains debated. The concentrations used in this study (0.75% ropivacaine and 0.5% bupivacaine) represent commonly employed clinical concentrations that provide reliable anesthesia.

Limitations and Future Directions

Several limitations of this study should be acknowledged. The single-center design and relatively homogeneous patient population may limit generalizability to other settings or patient groups. The study did not evaluate different concentrations or doses of the study drugs, which might have provided additional insights into optimal dosing strategies.

Long-term follow-up to assess the incidence of chronic pain or neurological complications was not performed, though such events are rare with contemporary spinal anesthesia techniques. Future studies might explore the use of adjuvants with both local anesthetics to further optimize block characteristics and patient outcomes.

Economic analyses comparing the cost-effectiveness of these agents, including factors such as drug costs, reduced complications, and faster recovery, would provide valuable information for healthcare decision-makers. Additionally, patient-reported outcome measures focusing on functional recovery and quality of life could provide deeper insights into the clinical relevance of the observed differences.

Conclusion

This comparative study demonstrates that both hyperbaric ropivacaine 0.75% and hyperbaric bupivacaine 0.5% are effective local anesthetics for spinal anesthesia, each with distinct advantages. While bupivacaine offers faster onset of blockade, ropivacaine provides superior hemodynamic stability, shorter motor block duration, and higher patient satisfaction.

The comparable duration of sensory blockade between the two agents ensures adequate anesthesia for most surgical procedures, while ropivacaine's shorter motor block duration facilitates earlier mobilization and enhanced recovery. The improved hemodynamic stability with ropivacaine makes it particularly attractive for elderly patients or those with cardiovascular risk factors.

The choice between these local anesthetics should be individualized based on patient characteristics, surgical requirements, and institutional preferences. Ropivacaine represents a valuable alternative to bupivacaine for spinal anesthesia, offering an improved safety profile and patient experience without compromising anesthetic efficacy.

Future research should focus on optimizing concentrations and exploring adjuvant combinations to further enhance the benefits of both agents. The integration of these findings into clinical practice guidelines and enhanced recovery protocols could contribute to improved patient outcomes and satisfaction in spinal anesthesia practice.

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