Comparative Evaluation of Sensory and Motor Block Characteristics of Intrathecal 0.5% Hyperbaric Levo-Bupivacaine versus 0.75% Hyperbaric Ropivacaine in Infraumbilical Surgeries: A Prospective Observational Study

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ABSTRACT

Background:

Spinal anesthesia remains the gold standard for infraumbilical surgeries due to its ability to provide dense sensory and motor blockade with minimal systemic interference. For decades, racemic bupivacaine was the agent of choice; however, concerns regarding its potential for cardiotoxicity and neurotoxicity led to the development of pure S-enantiomers: Levo-bupivacaine and Ropivacaine. While both agents are widely used, debate persists regarding their equipotent doses and blockade characteristics. Levo-bupivacaine is often cited as being equipotent to bupivacaine, whereas Ropivacaine is considered less potent, necessitating higher concentrations. This study aims to evaluate and compare the anesthetic efficacy of 0.5% hyperbaric Levo-bupivacaine and 0.75% hyperbaric Ropivacaine.

Methods:

This prospective observational study was conducted at a tertiary care teaching hospital in Chennai, India, from March 2023 to March 2024. The study enrolled 58 patients aged 18–60 years, classified as ASA physical status I and II, undergoing elective infraumbilical surgeries. Patients were divided into two groups: Group L received 3 ml of 0.5% Levo-bupivacaine heavy, and Group R received 3 ml of 0.75% Ropivacaine heavy. The primary outcomes measured were the onset time, peak dermatome level, and total duration of sensory block (assessed by pinprick) and motor block (assessed by Modified Bromage Scale).

Results:

The demographic profiles were comparable between the two groups ($p > 0.05$). The mean onset of sensory block was 8.5 ± 1.2 min in Group L and 7.9 ± 1.3 min in Group R ($p=0.20$). Both groups achieved a median peak sensory level of T8. The total duration of sensory block was 180.5 ± 25.0 min for Levo-bupivacaine and 175.3 ± 24.5 min for Ropivacaine ($p=0.40$). Regarding motor blockade, the onset of complete motor block was 10.2 ± 1.5 min in Group L versus 9.8 ± 1.6 min in Group R ($p=0.30$), and the total duration of motor block was 150.7 ± 20.3 min versus 148.4 ± 19.8 min ($p=0.45$).

Conclusion:

Intrathecal 0.5% Levo-bupivacaine heavy and 0.75% Ropivacaine heavy exhibit clinically indistinguishable sensory and motor block characteristics. Ropivacaine, at a higher concentration (0.75%), provides an anaesthetic profile equipotent to 0.5% Levo-bupivacaine, making both viable options for infraumbilical surgeries.

Keywords: Spinal anaesthesia, Levo-bupivacaine, Ropivacaine, Sensory blockade, Motor blockade, Pharmacodynamics, Infraumbilical surgery.

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INTRODUCTION

Central neuraxial blockade, specifically spinal anaesthesia (subarachnoid block), is a cornerstone of modern anaesthesiology practice for infraumbilical procedures, including lower abdominal, gynaecological, urological, and lower limb orthopaedic surgeries [1]. The technique offers several distinct advantages over general anaesthesia, including the blunting of the surgical stress response, reduced intraoperative blood loss, decreased risk of deep vein thrombosis, and the maintenance of patient consciousness [2]. The efficacy of spinal anaesthesia is contingent upon the administration of local anaesthetic agents into the subarachnoid space, where they act by reversibly blocking sodium channels in the nerve roots, thereby interrupting the conduction of nociceptive and motor impulses [3].

For many years, hyperbaric racemic bupivacaine (a mixture of R- and S-enantiomers) was the most widely used long-acting local anaesthetic for spinal anaesthesia due to its high potency and reliable duration of action [4]. However, the pharmacological profile of racemic bupivacaine is marred by its association with severe, sometimes fatal, cardiotoxicity. This toxicity is primarily attributed to the R-enantiomer's high affinity for cardiac sodium channels, leading to refractory arrhythmias and myocardial depression that are notoriously difficult to resuscitate [5]. This safety concern catalyzed the search for safer alternatives, resulting in the development of pure S-enantiomers: Levo-bupivacaine and Ropivacaine.

Levo-bupivacaine is the pure S(-)-enantiomer of bupivacaine. It shares the same chemical formula and molecular weight as the racemic mixture but differs in its three-dimensional spatial arrangement [6]. Pharmacological studies have demonstrated that Levo-bupivacaine possesses a safety margin superior to that of bupivacaine, with a significantly higher lethal dose threshold for cardiac arrest [7]. Due to its high lipid solubility and protein binding capacity, Levo-bupivacaine exhibits a potency and duration of action that is historically considered comparable to racemic bupivacaine [8].

Ropivacaine is a long-acting amino-amide local anaesthetic that is structurally related to bupivacaine but distinct in that a propyl group replaces the butyl group on the piperidine ring [9]. Like Levo-bupivacaine, it is prepared as a pure S(-)-enantiomer. The structural modification renders Ropivacaine less lipophilic than bupivacaine. Lipophilicity is a critical determinant of a local anaesthetic's potency and its ability to penetrate nerve membranes [10]. Consequently, Ropivacaine is generally considered less potent than bupivacaine, often requiring higher concentrations or doses to achieve equipotent blockade [11]. However, this lower lipophilicity also confers a distinct advantage: a greater degree of sensorimotor differentiation, or "differential block," wherein sensory nerve fibres are blocked more densely than motor fibres, potentially allowing for earlier ambulation and recovery [12].

In clinical practice, the choice between these agents often depends on the desired duration of anaesthesia and the specific surgical requirements. While 0.5% Levo-bupivacaine is a standard concentration, Ropivacaine is frequently utilized at a higher concentration of 0.75% to compensate for its lower potency [13]. Although numerous studies have compared these drugs, conflicting data exist regarding their relative onset times and duration of blockade when hyperbaric solutions are used. Some literature suggests that Levo-bupivacaine provides a prolonged block suitable for lengthy procedures, while Ropivacaine offers a faster recovery profile ideal for ambulatory surgery [14].

The introduction of "heavy" or hyperbaric solutions—where glucose is added to the local anaesthetic to increase its density relative to cerebrospinal fluid (CSF)—adds another layer of complexity. Hyperbaric solutions rely on gravity to facilitate the spread of the drug within the subarachnoid space, theoretically providing a more predictable block height [15]. Understanding how the physicochemical properties of Levo-bupivacaine and Ropivacaine interact with hyperbaricity to influence clinical outcomes is vital for evidence-based anaesthetic planning.

This study was designed to provide a comparative evaluation of the sensory and motor blockade characteristics of 0.5% hyperbaric Levo-bupivacaine and 0.75% hyperbaric Ropivacaine. By adhering to a rigorous observational protocol, we aim to clarify

whether the theoretical pharmacological differences between these enantiomers translate into clinically significant differences in block quality for patients undergoing infraumbilical surgeries.

METHODOLOGY

Study Design and Setting

This prospective, hospital-based observational study was conducted in the Department of Anaesthesiology at Sree Balaji Medical College and Hospital, a tertiary care teaching institute in Chennai, Tamil Nadu, India. The data collection period spanned 12 months, from March 2023 to March 2024.

Ethical Considerations

The study protocol received formal approval from the Institutional Human Ethics Committee (Ref. No. 002/SBMCH/IHEC/2023/1936). The study adhered to the ethical principles outlined in the Declaration of Helsinki. All participants were provided with a detailed explanation of the spinal anaesthesia procedure, the drugs involved, and the potential risks and benefits. Written informed consent was obtained from each participant in their vernacular language prior to enrollment.

Study Population and Sample Size

The study population comprised adult patients scheduled for elective infraumbilical surgeries (including hernia repair, lower limb orthopaedic surgeries, and gynaecological procedures).

Based on a pilot survey and reference to a similar study by Kopacz et al. [16], which reported a standard deviation of onset time of approximately 1.5 minutes, the sample size was calculated. Using a power of 80% and an alpha error of 0.05, the required sample size was determined using the formula:

$$n = 2(Z_\alpha + Z_\beta)\sigma^2/d^2$$

Where Z_α is 1.96, Z_β is 0.84, σ is the standard deviation, and d is the expected difference. The calculated sample size was 58 patients, grouped into two equal cohorts of 29 patients each.

Selection Criteria

- **Inclusion Criteria:**
  - Patients aged between 18 and 60 years.
  - American Society of Anaesthesiologists (ASA) Physical Status I and II.
  - Patients scheduled for elective infraumbilical surgeries under spinal anaesthesia.
  - Height between 150 cm and 180 cm (to minimize variability in CSF volume and drug spread).
- **Exclusion Criteria:**
  - Patient refusal.
  - ASA Physical Status III or IV.
  - Contraindications to spinal anaesthesia (e.g., coagulopathy, raised intracranial pressure, severe hypovolemia).
  - Infection at the lumbar puncture site.
  - Known hypersensitivity to amide local anaesthetics.
  - Spinal deformities (e.g., kyphoscoliosis) that could affect drug spread.
  - Neurological deficits or diseases (e.g., multiple sclerosis).

Anaesthetic Procedure

Patients were kept fasting for 6 hours for solids and 2 hours for clear fluids. Upon arrival in the operating theatre, standard ASA monitors (Non-invasive blood pressure, Pulse oximetry, and ECG) were attached. Baseline vital signs were recorded. An 18-gauge intravenous cannula was secured, and patients were preloaded with Ringer's Lactate solution at 10-15 ml/kg to mitigate spinal-induced hypotension.

The patients were positioned in the sitting or lateral decubitus position depending on the surgical site and anesthetist's preference. Under strict aseptic conditions, the lumbar area was painted and draped. Local infiltration of the skin was performed with 2% Lignocaine. A 25-gauge Quincke spinal needle was introduced into the subarachnoid space at the L3-L4 or L4-L5 interspace via a midline approach. Successful dural puncture was confirmed by the free flow of clear cerebrospinal fluid (CSF).

Patients were assigned to one of two groups:

Group L: Received 3 ml of 0.5% Levo-bupivacaine heavy (15 mg).

Group R: Received 3 ml of 0.75% Ropivacaine heavy (22.5 mg).

The drug was injected over 10-15 seconds without barbotage. Immediately after injection, patients were positioned supine. The table was kept neutral. Supplemental oxygen was administered via a face mask at 4L/min.

Assessment of Block Characteristics

A blinded observer, unaware of the specific drug administered, performed the assessments to minimize bias.

1. **Sensory Blockade:**

Assessed using the pinprick method with a 22-gauge hypodermic needle.

Onset of Sensory Block: Defined as the time from intrathecal injection to the loss of sharp sensation at the T10 dermatome.

- **Peak Sensory Level:** The highest dermatome level where sensation was lost.
- **Time to Peak Level:** Time taken to reach the highest dermatome.
- **Duration of Sensory Block:** Defined as the time from the highest sensory level regression to the S1 dermatome (two-segment regression was also monitored).

2. **Motor Blockade:**

- Assessed using the Modified Bromage Scale:
  - 0: No motor block (able to flex hips/knees/ankles).
  - 1: Inability to raise extended leg (able to move knees/ankles).
  - 2: Inability to flex knee (able to move ankles only).
  - 3: Complete motor block (unable to move hips/knees/ankles).
- **Onset of Motor Block:** Time from injection to Bromage Grade 1.
- **Complete Motor Block Onset:** Time from injection to Bromage Grade 3.
- **Duration of Motor Block:** Time from onset of block until complete recovery (Bromage Grade 0).

Statistical Analysis

Data entry was performed using Microsoft Excel, and statistical analysis was conducted using SPSS (Statistical Package for the Social Sciences) software, version 21.0.

- **Descriptive Statistics:** Categorical variables (gender, ASA status) were expressed as frequencies and percentages. Continuous variables (age, BMI, block times) were expressed as Mean ± Standard Deviation (SD).
- **Inferential Statistics:** The Shapiro-Wilk test was used to check for the normality of data distribution. For normally distributed continuous variables, the independent samples t-test was used to compare means between the two groups. For categorical data, the Chi-square test or Fisher's Exact test was employed.
- A p-value of < 0.05 was considered statistically significant.

RESULTS

A total of 58 patients were enrolled and successfully completed the study protocol, with 29 allocated to Group L (Levo-bupivacaine) and 29 to Group R (Ropivacaine). There were no dropouts or failed spinal anaesthetics requiring conversion to general anaesthesia.

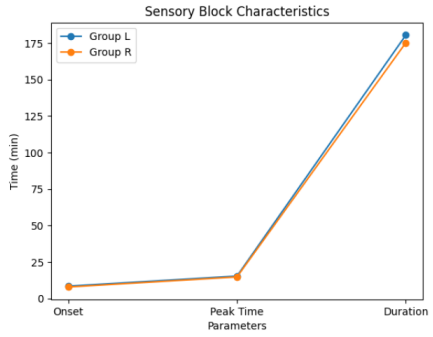
Table 1: Socio-demographic profile of the participants (N=58)

Age-wise distribution			
Age group (Years)	**Group L (0.5% Levo-Bupivacaine) n (%)**	**Group R (0.75% Ropivacaine) n (%)**	**p-value**
18-30	10 (34.5%)	12 (41.4%)	0.75
31-40	8 (27.6%)	7 (24.1%)	
41-50	7 (24.1%)	5 (17.2%)	
51-60	4 (13.8%)	5 (17.2%)	
Total	29	29	
Gender distribution			
Gender	**Group L (0.5% Levo-Bupivacaine) n (%)**	**Group R (0.75% Ropivacaine) n (%)**	**p-value**
Males	15 (51.7%)	16 (55.2%)	0.80
Females	14 (48.3%)	13 (44.8%)	
Total	29	29	
BMI distribution			
BMI group (kg/m²)	**Group L (0.5% Levo-Bupivacaine) n (%)**	**Group R (0.75% Ropivacaine) n (%)**	**p-value**
<18.5 (Underweight)	2 (6.9%)	3 (10.3%)	0.65
18.5 – 24.9 (Normal)	18 (62.1%)	16 (55.2%)	
25 – 25.9 (Overweight)	7 (24.1%)	8 (27.6%)	
≥ 30 (Obese)	2 (6.9%)	2 (6.9%)	
Total	29	29	
ASA distribution			

ASA Grade	Group L (0.5% Levo-Bupivacaine) n (%)	Group R (0.75% Ropivacaine) n (%)	p-value
ASA 1	17 (58.6%)	16 (55.2%)	0.78
ASA 2	12 (41.4%)	13 (44.8%)	
Total	29	29	

The demographic profile of the study participants is summarized in **Table 1**. The mean age of participants in Group L was comparable to that of Group R (p=0.75). The gender distribution was balanced, with males constituting 51.7% of Group L and 55.2% of Group R (p=0.80). Anthropometric data, specifically Body Mass Index (BMI), showed no significant variance between the groups (p=0.65). Similarly, the physiological status as defined by ASA grading was statistically matched (p=0.78). This homogeneity ensures that any observed differences in block characteristics can be attributed to the pharmacological agent rather than confounding patient factors.

Figure 1: Distribution of Sensory Block Characteristics



Comparison of sensory block parameters (mean values).

Figure 2 : Distribution of Sensory Block Characteristics

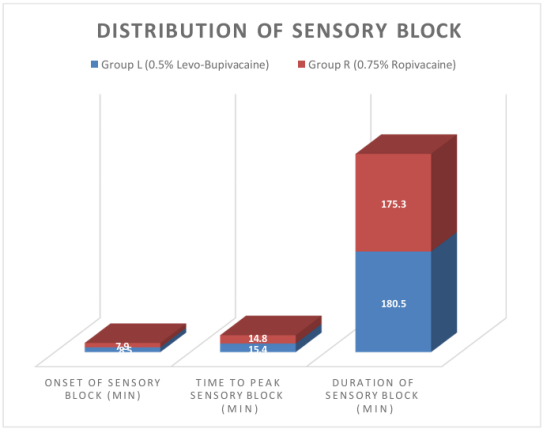


Table 2: Sensory Block Characteristics

Parameter	Group L (0.5% Levo-Bupivacaine)	Group R (0.75% Ropivacaine)	p-value
Onset of Sensory Block (min)	8.5 ± 1.2	7.9 ± 1.3	0.20
Peak Level of Sensory Block	T8	T8	0.95
Time to Peak Sensory Block (min)	15.4 ± 2.1	14.8 ± 2.0	0.25
Duration of Sensory Block (min)	180.5 ± 25.0	175.3 ± 24.5	0.40

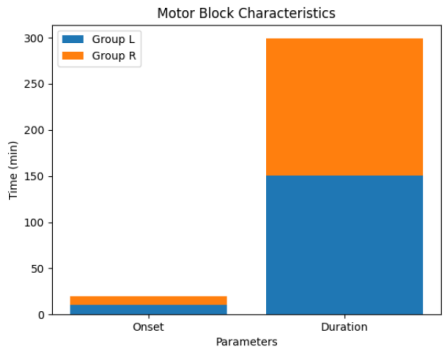
The characteristics of the sensory blockade are detailed in **Figure 1** and **Table 2**. The mean time to onset of sensory block was 8.5 ± 1.2 minutes in Group L and 7.9 ± 1.3 minutes in Group R. Although Group R demonstrated a slightly faster onset, the difference was not statistically significant (p=0.20).

The peak sensory level achieved was identical in both groups, with the median level being the T8 dermatome. This level is sufficient for the majority of infraumbilical surgeries. The time taken to reach this peak level was 15.4 ± 2.1 minutes for Group L and 14.8 ± 2.0 minutes for Group R (p=0.25).

The total duration of sensory block, a critical parameter for postoperative analgesia, was 180.5 ± 25.0 minutes in the Levo-bupivacaine group compared to 175.3 ±

24.5 minutes in the Ropivacaine group. The difference of approximately 5 minutes was not statistically significant (p=0.40).

Figure 3: Motor Block Characteristics



Comparison of motor block parameters (mean values).

Figure 4: Motor Block Characteristics

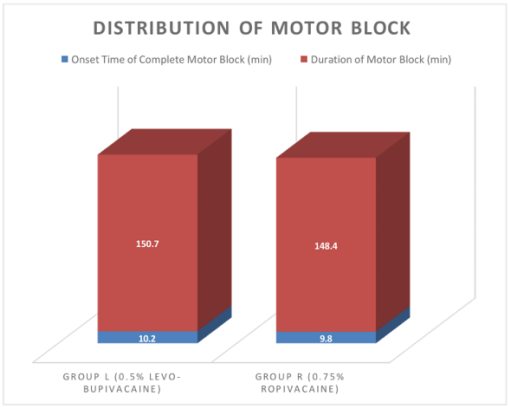


Table 3: Motor Block Characteristics

Parameter	Group L (0.5% Levo-Bupivacaine)	Group R (0.75% Ropivacaine)	p-value
Onset of Complete Motor Block (min)	10.2 ± 1.5	9.8 ± 1.6	0.30
Duration of Motor Block	150.7 ± 20.3	148.4 ± 19.8	0.45

The motor blockade profile is presented in **Figure 2** and **Table 3**. The onset of complete motor block (Bromage 3) occurred at a mean time of 10.2 ± 1.5 minutes in Group L and 9.8 ± 1.6 minutes in Group R (p=0.30).

The duration of motor block, defined as the time to regression to Bromage 0, was 150.7 ± 20.3 minutes for Group L and 148.4 ± 19.8 minutes for Group R. Similar to the sensory findings, the motor block duration was statistically comparable between the two groups (p=0.45).

DISCUSSION

The primary objective of this study was to compare the pharmacodynamic profile of 0.5% hyperbaric Levo-bupivacaine and 0.75% hyperbaric Ropivacaine in patients undergoing infraumbilical surgeries. The search for the "ideal" intrathecal agent continues to drive clinical research, with the goal of identifying an anaesthetic that provides rapid onset, reliable surgical anaesthesia, stable hemodynamics, and a recovery profile that facilitates early discharge [17]. Our results indicate that when utilized in hyperbaric formulations at the studied concentrations, Levo-bupivacaine and Ropivacaine possess remarkably similar block characteristics.

Pharmacological Basis of Comparison

To interpret our findings, one must understand the structural and physicochemical differences between the two drugs. Local anesthetics block nerve conduction by inhibiting voltage-gated sodium channels. Potency and duration of action are strongly correlated with lipid solubility, as highly lipophilic drugs penetrate the nerve membrane more easily [18]. Bupivacaine (and by extension Levo-bupivacaine) is highly lipophilic. Ropivacaine, with its propyl tail, is less lipophilic. Theoretically, this should make Ropivacaine less potent and shorter-acting [19].

However, potency is not a fixed variable; it is concentration-dependent. This study compared 0.5% (5 mg/ml) Levo-bupivacaine with 0.75% (7.5 mg/ml) Ropivacaine. This 2:3 concentration ratio is derived from previous minimum local analgesic concentration (MLAC) studies, suggesting that Ropivacaine is approximately 60% as potent as bupivacaine [20]. Our results validate this dosing strategy, as we found no statistically significant difference in block quality, suggesting that the increase in Ropivacaine concentration effectively bridges the potency gap caused by its lower lipophilicity.

Sensory Blockade Dynamics

We observed a mean sensory onset time of 8.5 minutes for Levo-bupivacaine and 7.9 minutes for Ropivacaine. While not statistically significant, the slightly faster onset in the Ropivacaine group could be attributed to the higher mass of drug administered (22.5 mg vs. 15 mg). According to Fick's law of diffusion, a higher

concentration gradient facilitates faster diffusion across biological membranes [21]. Our findings align with Gautier et al. [22], who reported comparable onset times for intrathecal Ropivacaine and Bupivacaine in ambulatory surgery.

Both groups achieved a peak sensory level of T8. The predictability of block height is crucial in spinal anesthesia to prevent high spinal complications (bradycardia, respiratory distress) or inadequate surgical anesthesia. The use of hyperbaric solutions in our study likely contributed to this consistency. Hyperbaric solutions, being denser than CSF, gravitate to the dependent areas of the spinal curvature (thoracic kyphosis), typically settling around the T6-T8 region when the patient is supine [23].

The duration of sensory block was 180.5 minutes for Levo-bupivacaine and 175.3 minutes for Ropivacaine. This contradicts the traditional teaching that Levo-bupivacaine, being more lipophilic, should provide a significantly longer block. However, our findings are supported by Chung et al. [24] and McNamee et al. [25], who also found no significant difference in duration between these agents in lower limb surgeries. It is possible that the higher dose of Ropivacaine used in our study saturated the nerve roots sufficiently to prolong the block to a duration matching that of Levo-bupivacaine. This is a favourable finding for clinicians, as it suggests Ropivacaine can be used for longer procedures without fear of premature block regression, provided the 0.75% concentration is used.

Motor Blockade and The "Differential Block" Phenomenon

One of the most touted advantages of Ropivacaine is its potential for "differential block"—a strong sensory block with varying degrees of motor sparing [26]. This property is highly desirable in obstetrics and day-care surgery, where early mobilization is prioritized. However, in our study, we observed dense motor blockade (Bromage 3) in both groups, with no significant difference in onset or duration (150.7 vs. 148.4 minutes).

The lack of significant motor sparing in the Ropivacaine group can be attributed to the concentration used. Differential blockade is most prominent at lower concentrations (e.g., 0.2% or 0.5%) [27]. At 0.75%, Ropivacaine behaves more like a traditional dense blocker, recruiting A-alpha motor fibres almost as effectively as it blocks C and A-delta sensory fibres. This dense motor block is advantageous for the surgeon, as it ensures complete muscle relaxation during procedures like hernia repair or orthopaedic manipulation, preventing sudden patient movement.

Our results contrast with Zaric et al. [28], who reported a significantly faster regression of motor block with Ropivacaine. Variations in study methodology, specifically the definition of motor recovery (Bromage 0 vs. Bromage 1) and the specific baricity of the solutions used, likely account for these discrepancies.

Clinical Implications

The choice between Levo-bupivacaine and Ropivacaine often hinges on safety and cost. Both drugs were developed to mitigate the cardiotoxicity of racemic bupivacaine. Levo-bupivacaine has a higher affinity for plasma proteins (>97%) compared to Ropivacaine (94%), which theoretically reduces the fraction of free drug available to cause systemic toxicity if accidental intravascular absorption occurs [29]. Conversely, Ropivacaine's faster dissociation from cardiac sodium channels offers a wider safety margin [30].

Since our study establishes clinical equivalence in efficacy, the decision may come down to economic factors and availability. In many settings, Levo-bupivacaine is slightly more expensive or less available than Ropivacaine. However, Ropivacaine requires a higher mass (22.5 mg vs. 15 mg) to achieve the same effect. Clinicians must balance these factors. For standard infraumbilical surgeries lasting 2-3 hours, both 0.5% Levo-bupivacaine heavy and 0.75% Ropivacaine heavy are excellent choices, providing reliable anaesthesia and muscle relaxation.

Limitations of the Study

While our study was rigorously designed, it has limitations. The sample size of 58 patients, though statistically powered for the primary outcome, may be too small to detect rare adverse events or subtle differences in block regression patterns. The study was conducted at a single centre, which may limit the generalizability of the findings to broader populations with different demographic characteristics. Furthermore, we did not evaluate patient satisfaction scores or surgeon satisfaction scores, which are important qualitative metrics for anaesthetic success. Finally, we did not extend the observation period to monitor for transient neurological symptoms (TNS), although both agents are known to have a very low incidence of TNS compared to Lidocaine [31].

CONCLUSION

The present study demonstrates that intrathecal 0.5% Levo-bupivacaine heavy and 0.75% Ropivacaine heavy exhibit comparable anaesthetic profiles for infraumbilical surgeries. There were no statistically significant differences in the onset, peak dermatome level, or duration of sensory blockade. Similarly, the onset and duration of motor blockade were statistically equivalent.

These findings suggest that Ropivacaine, when used in a hyperbaric 0.75% formulation, is equipotent to 0.5% hyperbaric Levo-bupivacaine. The theoretical lower potency of Ropivacaine is effectively offset by the increased concentration. Consequently, anesthesiologists can interchangeably use these two agents for lower abdominal and lower limb surgeries with the expectation of achieving high-quality surgical anaesthesia and muscle relaxation. The choice between the two should be guided by drug availability, cost-effectiveness, and individual patient safety considerations rather than differences in block efficacy.

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