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Comparison of the effects of isobaric and hyperbaric bupivacaine on block characteristics, maternal hemodynamic profiles, postoperative pain score and time to first analgesic request following spinal anesthesia for elective cesarean section: A Multicenter Prospective Cohort Study

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Abstract

Background

Cesarean section is one of the most common surgical procedures performed worldwide and is frequently conducted under spinal anesthesia. The baricity of bupivacaine being isobaric or hyperbaric plays a critical role in determining its spread within the cerebrospinal fluid, thereby influencing the onset and level of sensory and motor blockade, maternal hemodynamic stability, and duration of postoperative analgesia. This study aimed to provide further evidence on this clinically important topic.

Objective

To compare the effects of isobaric versus hyperbaric bupivacaine on block characteristics, maternal hemodynamic profiles, postoperative pain scores, and time to first analgesic request following spinal anesthesia for elective cesarean section at selected public hospitals in Addis Ababa, Ethiopia, 2026.

Methods

A total of 64 eligible parturients who were scheduled for elective cesarean section under spinal anesthesia were included in two groups (n = 32 each). Both the isobaric and hyperbaric groups received 10–12.5 mg of bupivacaine. Data were collected via a pretested structured data collection tool and entered with EpiData 3.1 and analyzed via STATA version 17. Normality was checked with the Shapiro-wilk test. Descriptive statistics, independent t tests, Mann–Whitney U test, ordinal logistic regression, linear mixed-effects models, and Kaplan-Meier analysis were employed as appropriate. A p-value of < 0.05 was considered statistical significance.

Results

Hyperbaric bupivacaine provided significantly faster onset of sensory block to T6 (median 5 vs. 8 minutes) and faster achievement of complete motor block. It was also associated with higher sensory block levels and superior hemodynamic stability, as evidenced by smaller reductions in systolic, diastolic, and mean arterial pressure, particularly between 5 to 20 minutes after injection. In contrast, at 3 and 4 hours, the hyperbaric group had statistically significant with higher VAS scores than did the isobaric group (3 hour: $\beta = 2.53$, 95% CI: 1.43 to 3.63, $p < 0.001$; 4 hour: $\beta = 2.91$, 95% CI: 1.81 to 4.01, $p < 0.001$). Isobaric bupivacaine had longer time to first analgesic request (median 4.5–5 hours versus 3–4 hours, log-rank $p < 0.001$).

Conclusion

Hyperbaric bupivacaine offers faster onset, higher block level, and better hemodynamic stability, whereas isobaric bupivacaine provides prolonged postoperative analgesia.

BACKGROUND

A cesarean section (C/S) is a surgical method of childbirth in which the baby is delivered via incisions through the mother's abdomen and uterine wall. It is currently one of the most frequently performed obstetric surgeries globally(1).Cesarean section rates are high in many parts of the world, with an incidence reported in the Dominican Republic (58.1%), Brazil (55.7%), Egypt (51.8%), and Turkey (50.8%), with Latin America and the Caribbean having the highest regional average (42.8%)(2) ,32–45% in Thailand(3), 36% to 50% in Korea and 48% in Sweden (4) and in Addis Ababa, Ethiopia, cesarean section rate has risen to 45.8% in 2022 among public hospitals(5).

Spinal anesthesia (SA) remains the most frequently chosen anesthetic technique for elective cesarean section because it provides rapid onset of anesthesia, avoids airway manipulation, has lower costs and generally has fewer maternal respiratory complications compared to general anesthesia(6). Bupivacaine, especially its 0.5% formulation, is commonly used for spinal anesthesia in obstetric anesthesia, owing to its potency and duration of effect(7).

One key pharmacological variable is baricity, which refers to the density of the bupivacaine solution relative to cerebrospinal fluid(8). Differences in the baricity of spinal anesthetics are thought to affect the way local anesthetics are distributed and hemodynamic parameters within the cerebrospinal fluid which may affect the onset of block, the level of block, and the duration of sensory block as well as side effects(8, 9).

Compared with isobaric or plain solutions, hyperbaric bupivacaine, which is usually made heavier with dextrose and descends under gravity, tends to produce more predictable cephalic spread (4, 10). Isobaric bupivacaine, which has the same density as cerebrospinal fluid (CSF), remains relatively unaffected by gravity and patient positioning after intrathecal administration. This property leads to a more uniform but less predictable spread compared with hyperbaric solutions (4) (11).

The extent to which the sympathetic block spreads is influenced by the degree to which the anesthetic spreads, which is the main contributor. Thus, the baricity of bupivacaine may affect block characteristics, the timing of hemodynamic changes, and its duration which is usually measured by the postoperative pain score and time to first analgesia requirements (12, 13).

Hemodynamic instability, including hypotension is the most common complication following spinal anesthesia in parturients, with rates reported in many studies to be greater than 60% (14). Two studies conducted in Ethiopia reported that the prevalence of hypotension after spinal anesthesia among parturients who underwent cesarean section ranged from 55.5% to 64% (15, 16).

Despite several studies, there are inconsistencies regarding the effects of bupivacaine baricity on block onset, block level, duration, and the time to first requirement of postoperative analgesia(17–21). The ideal spinal anesthetic for cesarean delivery should provide rapid onset, adequate sensory block, sufficient duration of anesthesia, hemodynamic stability, and reduced need for postoperative analgesia. This study aids anesthetists select the most appropriate formulation according to clinical priorities such as surgical readiness, hemodynamic stability, or postoperative pain control. Optimized block characteristics may also reduce vasopressor use, decrease postoperative opioid requirements, improve maternal comfort, and facilitate early mother-infant bonding. Therefore, this study aimed to compare the effects of isobaric versus hyperbaric bupivacaine on block characteristics, maternal hemodynamic profiles, postoperative pain scores, and time to first analgesia request among parturients receiving spinal anesthesia for elective cesarean delivery.

METHODS

Study Design, Setting of the study

A multicenter prospective cohort study was conducted from **February 1, 2026, to April 30, 2026** at **Yekatit 12 Hospital Medical College**, **Menelik II Hospital**, and **ALERT Comprehensive Specialized Hospital**. Addis Ababa, Ethiopia,

Eligibility criteria

The study included parturients with term singleton pregnancies, classified according to American Society of Anesthesiologists (ASA) physical status classes II and III, age18–45 years(22), body mass index (BMI) less than 30 kg/m^2 (14) and scheduled for elective cesarean delivery. Pregnant women with twin or multiple pregnancies(23), complicated pregnancy (placenta previa and hypertensive disorders of pregnancy (pre-eclampsia, eclampsia) (24), failed spinal blocks who needed repeat spinal blocks and required conversion to general anesthesia , any contraindications for spinal anesthesia, the use of intrathecal bupivacaine dose greater than 12.5 mg (25) and the addition of intrathecal adjuvants (opioids or other drugs) to bupivacaine (26) were excluded from the study

Sample size and sampling procedure

The sample size for this study was calculated via maternal hemodynamic data from previous studies conducted in Ethiopia. (13). The reported MAP values were 78.91 ± 5.80 mmHg in the isobaric bupivacaine group and 83.06 ± 4.63 mmHg in the hyperbaric bupivacaine group. On the basis of these values, the effect size (Cohen’s d) was calculated via the formula(27) and was 0.79. Using G Power 3.1.9.7 software, with a significance level of 0.05 and 90% power, the total sample size was 58 participants, with 29 participants per group. To include dropouts in case there is, the sample will be increased by 10%, resulting in a final sample size of 32 participants per group, for a total of 64 participants.

Participants were recruited via a stratified-by-site systematic random sampling method with the three hospitals serving as strata. Prior to the study, a situational analysis was conducted over three months and revealed 190 eligible cases at Yekatit 12 Hospital Medical College, 170 at Menelik II Hospital, and 160 at ALERT Comprehensive Specialized Hospital (total = 520). At each hospital, an ordered list of all eligible parturients scheduled for elective cesarean section was prepared from the preoperative registry. A sampling interval (k) was then calculated and the sampling intervals (k) at Yekatit 12 Hospital Medical College: k = 9, Menelik II Hospital: k = 7, ALERT Hospital: k = 8. A random start (r) between 1 and k was selected via a random number generator. Starting from the randomly selected number, every k□□ eligible woman on the operation schedule list was approached until the required site quota was fulfilled.

Data collection tool and procedures

Data were collected **prospectively** via a **structured and pretested data collection tool** developed on the basis of the study objectives and findings from previous related literature. At each study site, trained anesthesia professionals who were not directly involved in administering anesthesia were identified as eligible, and informed consent was obtained prior to participation. Baseline sociodemographic and clinical data including age, weight, height, gestational age, gravity, parity and indication for C/S were recorded from the preanesthetic evaluation sheet.

Intraoperative data, including baseline vital signs were recorded **in real time**. The collected variables included the **type of bupivacaine administered** (isobaric or hyperbaric), **dose and volume**, time of injection**, level of sensory block**, sensory block onset was assessed via the pinprick method, and motor block onset was evaluated via the Bromage scale. The level of sensory block was assessed as the highest dermatome block reached. Hemodynamic parameters such as **systolic blood pressure (SBP), diastolic blood pressure (DBP), mean arterial pressure (MAP), and heart rate (HR) and peripheral oxygen saturation(SpO_2) were** recorded at baseline, and at **1, 3, 5, 10, 15, and then every 5 minutes until the end of surgery after final** injection. The postoperative pain score was assessed via visualize analog scale (VAS) from the time of arrival at the post anesthesia care unit(PACU), and all **analgesic drugs that were given within the first 8 hours post-operatively were documented.** All data collection forms were reviewed daily by the principal investigator for completeness and accuracy.

Data analysis procedures

The data were entered into EpiData version 3.1 and exported to Stata version 17 for analysis. The data were first checked for completeness and consistency. Descriptive statistics were used to summarize the participants' demographic, obstetric, intraoperative, and postoperative characteristics.

The normality of continuous variables was assessed via histograms and the Shapiro-Wilk test, whereas the homogeneity of variance was tested via Levene's test. Normally distributed continuous variables were presented as mean ± standard deviations (SDs), whereas skewed data are presented as medians with interquartile ranges (IQRs). Categorical variables are summarized as frequencies and percentages.

Comparisons between the isobaric and hyperbaric groups for onset times of sensory and motor block, height of sensory block, maternal hemodynamic changes, postoperative pain score, and time to first analgesia request were performed via independent samples t-tests (for normally distributed data) or Mann–Whitney U tests (for nonnormally distributed data).Ordinal logistic regression, and linear mixed-effects regression were used to analyze changes in hemodynamic variables over time and VAS scores over time and Kaplan–Meier analysis was also used. The results are reported as mean differences with 95% confidence intervals, and a p-value of < 0.05 was considered statistically significant. The findings presented via tables and figures for clarity.

RESULTS

Demographic, preoperative intraoperative and postoperative characteristics of the parturient

The baseline demographic, preoperative, intraoperative and postoperative characteristics of the study participants were analyzed to determine whether the two groups were comparable before the effects of the interventions on block-related outcomes, hemodynamics, postoperative pain scores and first analgesia requirements were evaluated.

Overall, the key baseline characteristics of the two groups were comparable. There were no statistically significant differences in demographic variables such as age, weight, height, or BMI ($p > 0.05$), indicating adequate baseline similarity between groups. Likewise, important preoperative and intraoperative variables including ASA physical status, parity, gestational age, baseline hemoglobin level, total fluid administered, blood loss, surgical duration, comorbid conditions and preloading and coloading fluid volume were no significantly different, as shown in Tables 1 and 2.

Table 1
Demographic characteristics of parturients in the two groups at selected public hospitals in Addis Ababa, Ethiopia, February 01- April30, 2026.

Variables	Isobaric bupivacaine groups(n = 32)	hyperbaric bupivacaine groups(n = 32)	P value
Age (yr.)	30.90 ± 4.82	31.31 ± 4.78	0.736*
Weight(kg)	70.44 ± 4.72	69.66 ± 5.39	0.539*
Height(m)	1.63 ± 0.05	1.64 ± 0.05	0.535*
BMI(Kg/m^2)	26.24 ± 1.72	25.70 ± 1,52	0.182*
Note: Values are presented as: Mean ± standard deviation, *= independent t test			

Table 2
Preoperative and intraoperative characteristics of parturients in the two groups at selected public hospitals in Addis Ababa, Ethiopia, February01- April 30, 2026.

Variables		Isobaric bupivacaine groups(n = 32)	hyperbaric bupivacaine groups(n = 32)	P value
ASA status	ASA II	27(84.3%0	26(81.25)	0.109**
	ASA III	5(15.63)	6(18.750	
Comorbidity diseases	GDM	3(9,38%)	2(6.25)	0.641*
Parity	I	6	6	0.827***
	II	10	6	
	III	7	9	
	>III	9	11	
Gestational age(week)s		38.65	38.71	0.824*
Indication for CS	Previous C/S	13(40.63%)	18(56.25%)	0.216***
	CPD	11(34.38%)	8(25%)	
	Malpresentation	8(25%)	4(12.5%)	
	Other	0	2(6.25)	
Total NPO(Hr.)		8.81	8.90	0.708*
Baseline maternal hemoglobin level (g/dl)		37.8	37.36	0.406*
Baseline maternal hematocrit level (%)		13.01	12.65	0.149*
Antibiotic Prophylaxis	Ampicillin(1g)	14(43.75%)	11(34.38)	0.590**
	Ceftriaxone(1g)	18(56.25)	21(65.63)	
Anesthetist experience (years)		7.62	8	0.584*
Preloading fluid volume(ml)		577.77	551.85	0.535*
Coloading fluid volume(ml)		355.55	388.88	0.564*
Intervertebral space used for needle insertion	L3-L4	3(9.38%)	2(6.25)	0.216***
	L4-L5	29(90.63)	30(93.75)	

Notes: Values are presented as: the mean, median, and number (percentage).*=independent sample t test, **=chi-square test ***=Fisher's exact test

Table 2
(Continued)

Spinal needle size (gauges)	**22–23**	**16**	**14**	**0.415***
	24–25	**16**	**18**	
Local anesthesia infiltration used	Not used	19(59.38%)	22(68.75%)	0.610**
	Used(lidocaine 2ml)	13(40.63%)	10(31.25%)	
Bupivacaine dosage(mg)		10.75	10.87	0.617*
Delivery time(min.)		4.53	4.37	0.436*
Physician status	Senior surgeon	10	8	0.578**
	Senior resident	22	24	
Uterotonic agents	Oxytocin(20iu)	32	32	
Intraoperative complications	Nausea and Vomiting	5(15.6%)	3(9.3%)	0.708***
	Headache	0	1(3.1%)	
APGAR score	1st minute	5.59	6.40	0.003*
	5th minute	7.87	8.12	0.120*
Vasopressor drugs used	Adrenaline(10mcg)	2	1	0.355***
	Noradrenaline(8mcg)	2	1	
Total intraoperative fluids (ml)		2125	2050	0.299*
Total blood loss (ml)		477.81	477.87	0.709*
Total surgery time(min.)		47.18	45	0.104*

Notes: Values are presented as: the mean, median, and number (percentage).*=independent sample t test ** =chia-square test ***=Fishers exact test

Block characteristics

Sensory block onset

The time to the T10 sensory block was rapid and similar between the two groups (median 3 min [IQR 2–3] in the isobaric group and 2 min [IQR 1–2] in the hyperbaric group, with p = 0.144.

In contrast, the time to T6 sensory block was statistically significant with a median onset time of 5 minutes (IQR 4–6) in the hyperbaric group and 8 minutes (IQR 6.5–9) in the isobaric group ($p < 0.001$). A statistically significant proportion of patients achieved T6 block within 20 minutes in the hyperbaric group (25%) compared with the isobaric group (18.7%).

Motor Block Onset

The onset of complete motor block (Bromage score 3) was also statistically significant between the groups. The mean onset time was 5.81 ± 1.31 minutes in the hyperbaric group versus 7.38 ± 1.36 minutes in the isobaric group (mean difference = 1.56 minutes, 95% CI 0.90–2.23, p < 0.001).

Table 3
Onset time of the sensory and motor block among patients receiving isobaric and hyperbaric bupivacaine groups at selected public hospitals in Addis Ababa, Ethiopia, February01-April30, 2026

Variable	Isobaric(n = 32)	Hyperbaric(n = 32)	Effect estimate	P-value
Onset to T10 sensory block (min)	3 (2–3)	2 (1–2)	1	0.1448**
Onset to T6 sensory block (min)	8 (6.5–9)	5 (4–6)	3	< 0.001**
Onset to Bromage 3 motor block (min)	7.38 ± 1.36	5.81 ± 1.31	1.57(95% CI 0.90–2.23)	< 0.001*
Notes: Values are presented as: the mean ± standard deviation, median (IQR) *= Independent t test, **= Mann-Whitney U test				

Level of sensory block between the groups

A mixed-effects ordinal logistic regression showed that baricity was statistically significant with respect to the sensory block level over time. After adjusting for height BMI and repeated measures within patients hyperbaric bupivacaine was associated with significantly greater odds of achieving higher sensory block levels than isobaric bupivacaine was (AOR = 6.23, 95% CI: 1.88–20.66, p = 0.003). Time was also a strong predictor of block progression with the strongest effect observed from 6 minutes onward (p < 0.001). The likelihood ratio test comparing the mixed-effects model with the standard ordinal logistic model was statistically significant (p < 0.001),

Hemodynamic Changes Following Spinal Anesthesia According to Baricity

Hemodynamic parameters including systolic blood pressure (SBP), diastolic blood pressure (DBP), mean arterial pressure (MAP), heart rate (HR) and peripheral oxygen saturation (SpO_2) were analyzed via linear mixed-effects regression. Each model included baricity, time and the interaction between baricity and time as fixed effects, while patient specific random intercepts were incorporated to account for repeated measurements over time. Although SBP, DBP and MAP, are interrelated, they were analyzed separately because they provide complementary clinical information. The MAP considered the primary hemodynamic outcome from this specific objective as it best reflects organ perfusion(28).

Systolic blood pressure (SBP)

Analysis of SBP revealed no statistically significant baseline difference between the isobaric and hyperbaric groups (β = −0.91 mmHg, 95% CI: −4.74 to 2.92, p = 0.643). Following spinal anesthesia, patients in the hyperbaric group experienced a statistically significant reduction in SBP, with the greatest decrease occurring at 10 minutes post injection (mean decrease of 28.06 mmHg, p < 0.001), followed by gradual recovery thereafter.

A statistically significant baricity and time interaction was observed, indicating that SBP trends differed significantly between the two groups over time. Compared with hyperbaric group, patients receiving isobaric bupivacaine experienced statistically significant reductions in SBP at 5 minutes (− 2.78 mmHg, p = 0.046), 10 minutes (− 5.41 mmHg, p < 0.001), 15 minutes (− 9.53 mmHg, p < 0.001), 20 minutes (− 9.59 mmHg, p < 0.001), 25 minutes (− 6.09 mmHg, p < 0.001), and 30 minutes (− 3.72 mmHg, p = 0.008). The largest differences between groups were observed at 15 and 20 minutes following spinal anesthesia. Compared with ordinary linear regression, the mixed-effects model demonstrated substantial between-subject variability (random intercept variance $\sigma^2 = 45.55$) and significantly improved model fit (Likelihood Ratio test, p < 0.001).

Diastolic blood pressure (DBP)

A statistically significant interaction between baricity and time was observed. Compared with hyperbaric group, patients receiving isobaric bupivacaine demonstrated statistically significant reductions in DBP at 10 minutes (− 2.38 mmHg, p = 0.020), 15 minutes (− 5.97 mmHg, p < 0.001), 20 minutes (− 5.69 mmHg, p < 0.001), and 25 minutes (− 3.25 mmHg, p = 0.001). The greatest intergroup differences were noted at 15 and 20 minutes post spinal anesthesia. The random intercept variance was considerable ($\sigma^2 = 17.64$), and the mixed-effects model statistically outperformed standard linear regression (LR test p < 0.001).

Mean arterial pressure (MAP)

The baseline MAP values were comparable between the two groups, with no statistically significant difference observed (β= −0.47 mmHg, 95% CI: −3.36 to 2.42, p = 0.751). In the hyperbaric group, the MAP decreased with a statistically significant following spinal anesthesia, reaching its maximal decline at 10 minutes (mean reduction of 23.34 mmHg, p < 0.001), before gradually recovering throughout the intraoperative period.

A statistically significant baricity and time interaction demonstrated differing MAP trajectories between the groups. Compared with hyperbaric bupivacaine, the isobaric group presented statistically significant reductions in MAP with differences in mean at 10 minutes (β = −3.16 mmHg, 95% CI: −5.27 to − 1.04, p = 0.003), 15 minutes (β = −7.63 mmHg, 95% CI: −9.74 to − 5.51, p < 0.001), 20 minutes (β = −7.34 mmHg, 95% CI: −9.46 to − 5.23, p < 0.001), 25 minutes (β = −4.53 mmHg, 95% CI: −6.64 to − 2.42, p < 0.001), 30 minutes (β = −2.69 mmHg, 95% CI: −4.80 to − 0.58, p = 0.013), 35 minutes (β = −2.44 mmHg, 95% CI: −4.55 to − 0.33, p = 0.024), and 45 minutes (β = −2.60 mmHg, 95% CI: −4.81 to − 0.38, p = 0.022). The most pronounced differences were observed from 10–25 minutes after spinal injection. Model fit was significantly superior to that of ordinary linear regression (LR test p < 0.001).

Heart rate (HR)

No statistically significant difference in heart rate was detected between the isobaric and hyperbaric groups (β = 1.31 beats/min, 95% CI: −3.08–5.71, p = 0.558). Following spinal anesthesia, patients in the hyperbaric group exhibited a statistically significant increase in heart rate, peaking at 5 minutes (β = 9.56 beats/min, 95% CI: 7.54–11.58 p < 0.001). At later time points (40–50 minutes), HR values were comparable to baseline levels.

A significant baricity and time interaction was identified, indicating differential HR responses over time between the two groups. Compared with hyperbaric bupivacaine, isobaric bupivacaine showed higher heart rates in the isobaric group at 10 minutes (β = +6.47 beats/min, 95% CI: 3.61 to 9.33, p < 0.001) and 15 minutes (β = +6.31 beats/min, 95% CI: 3.45 to 9.17, p < 0.001). The greatest intergroup differences were observed between 5 and 20 minutes post spinal anesthesia, as shown in Fig. 5D. The mixed-effects model demonstrated substantial between-subject variability ($\sigma^2 = 63.43$), significantly improved fit over ordinary linear regression (LR test p < 0.001), and highly significant overall fixed effects across time (Wald $\chi^2 = 1698.93$, p < 0.001).

Peripheral oxygen saturation; A linear mixed-effects regression model was used to evaluate changes in peripheral oxygen saturation (SpO_2) over time between the isobaric and hyperbaric bupivacaine groups. The absolute mean difference between the groups was less than 0.5%, indicating that the observed variation was clinically negligible. The SpO_2 trends remained stable and comparable throughout the intraoperative period in both groups, with oxygen saturation consistently remaining within normal clinical ranges. Therefore, there was no clinically meaningful difference in oxygen saturation between the two groups.

Postoperative pain scores (VAS scores)

It was analyzed via a linear mixed-effects regression model, including baricity as a fixed effect and time as a repeated within-subject factor, with patient ID modeled as a random intercept. The overall model was statistically significant (Wald $\chi^2(8) = 866.18$, p < 0.001), indicating a strong combined effect of baricity and time on postoperative pain scores.

The pain scores showed a statistically significant time-dependent increase relative to the first postoperative hour. At 2 hours postoperatively, the difference in the VAS score was not statistically significant (β = 0.34, 95% CI:–0.75–1.44, p < 0.540). However, at 3 and 4 hours, the hyperbaric group had statistically significant with higher VAS scores compared with the isobaric group (3 hour: β = 2.53, 95% CI: 1.43 to 3.63, p < 0.001; 4 hour: β = 2.91, 95% CI: 1.81 to 4.01, p < 0.001). A smaller but statistically significant difference persisted at 8 hours (β = 1.13, 95% CI: 0.03 to 2.22, p = 0.045). VAS scores increased progressively over time in both groups, reaching peak levels around the 5th and 6th postoperative hours before gradually declining thereafter.

5.4.2 Time to first postoperative analgesia requirements

Kaplan–Meier analysis demonstrated that the time to first postoperative analgesic requirement was shorter in the hyperbaric than in the isobaric group. The estimated median time to analgesic requirement was approximately 3–4 hours in the hyperbaric group, compared with approximately 4.5–5 hours in the isobaric group, indicating that hyperbaric bupivacaine was associated with an earlier onset of postoperative analgesic requirement by 1–1.5 hours, this difference was statistically significant (log-rank $\chi^2 = 29.62$, $p < 0.001$). Patients receiving hyperbaric bupivacaine had an approximately 3 times higher risk of requesting analgesia earlier than patients receiving isobaric bupivacaine did (HR = 2.87, 95% CI: 1.67–4.96, $p < 0.001$).

DISCUSSION

Block characteristics

Sensory and Motor Block Characteristics

In the present study, the onset time to T6 sensory block was significantly faster in the hyperbaric bupivacaine group than in the isobaric bupivacaine group. The median onset time was 5 minutes (IQR: 4–6) in the hyperbaric group and 8 minutes (IQR: 6.5–9) in the isobaric group. This finding is consistent with a systematic review conducted in the United Kingdom, which reported that intrathecal hyperbaric bupivacaine produced a more rapid onset of sensory blockade at the same level than did isobaric bupivacaine (17). Similarly, a comparative randomized controlled trial conducted in Ethiopia at Dilla University Hospital demonstrated that the hyperbaric group achieved maximum sensory block more rapidly than did the isobaric group, with median onset times of 3 (1) minutes and 4 (2) minutes, respectively with $p < 0.001$ [13]. The variation in onset times observed between the present study and the study conducted at Dilla University Hospital may be attributed to differences in study design and the dosage of bupivacaine administered.

However, the present findings contradict those of a study conducted in Belarus, which reported no statistically significant difference in the time to achieve complete sensory block between hyperbaric bupivacaine (median 3 minutes, IQR: 2.5–4) and isobaric bupivacaine (median 4 minutes, IQR: 3–5)(29). This discrepancy might be explained by differences in the surgical level requirements, dosage of bupivacaine, and patient positioning after surgeery between the studies.

The present study also differs from another comparative study conducted in Pakistan, which reported no significant difference in sensory block onset between the two groups [29]. The variation may be attributed to differences in the sensory block level used for assessment, as the present study evaluated onset to the T6 level, whereas the other study assessed blockade at the T4 level which might be due to interindividual pharmacodynamics variability and post spinal patient positioning.

The onset of motor block in the present study, it demonstrated that the onset of complete motor block (Bromage score 3) was significantly faster in patients who received hyperbaric bupivacaine than in those

who received isobaric bupivacaine. The mean onset time of complete motor block was 5.81 ± 1.31 minutes in the hyperbaric group, whereas it was 7.38 ± 1.36 minutes in the isobaric group. This finding suggests that hyperbaric bupivacaine provides a more rapid establishment of adequate motor blockade, which may facilitate earlier surgical readiness during cesarean section.

The findings of the present study are consistent with those of a systematic review and meta-analysis conducted in Canada, which reported that hyperbaric bupivacaine was associated with a relatively faster onset of motor blockade together with shorter durations of both sensory and motor block (11). Similarly, a comparative controlled study conducted in India demonstrated that the onset time of motor block was significantly longer in the isobaric group than in the hyperbaric group ($p < 0.05$), supporting the findings of the present study. A possible explanation for the faster onset of motor block observed with hyperbaric bupivacaine may be related to its greater density relative to cerebrospinal fluid, which facilitates more predictable gravitational spread within the intrathecal space and promotes rapid exposure of nerve roots to the local anesthetic agent. This may result in earlier establishment of both sensory and motor blockade than with isobaric solutions(21).

Level of sensory block between the groups

This study demonstrated that baricity had a significant effect on the level of sensory blockade achieved over time. Patients who received hyperbaric bupivacaine had significantly greater odds of attaining higher sensory block levels, particularly at T4 (18.7% to 9.4%) and T6 (25% to 18.7%), than did those who received isobaric bupivacaine. In addition, time was identified as a strong predictor of sensory block progression, indicating that sensory blockade evolved dynamically following the intrathecal administration of bupivacaine.

This finding is consistent with previous studies conducted in the United Kingdom (17), India [29], and Egypt(30), which reported that hyperbaric bupivacaine produced greater cephalad spread and achieved higher sensory block levels than isobaric solutions did. A study conducted in India demonstrated that 70% of patients in the hyperbaric group achieved a maximum sensory block level of T6, whereas only 53% of patients in the isobaric group reached the same level. The enhanced spread observed with hyperbaric bupivacaine may be explained by its higher density relative to cerebrospinal fluid, which facilitates gravity dependent distribution within the subarachnoid space, particularly in supine patients undergoing cesarean section. This allows wider cephalad spread of the local anesthetic agent and consequently results in higher dermatomal sensory blockade.

However, the present finding contradicts a single-center randomized controlled trial conducted in Ethiopia, which reported comparable peak sensory block heights between hyperbaric and isobaric bupivacaine groups [13]. The discrepancy between the findings may be attributed to differences in study design, spinal anesthesia techniques and patient positioning between the studies. In the former Ethiopian study, a pillow was placed beneath the patients immediately after spinal anesthesia administration, which may have limited the cephalad spread of hyperbaric bupivacaine. Since the spread of hyperbaric solutions is highly influenced by gravity, patient positioning can substantially affect

intrathecal drug distribution and the final sensory block height achieved. Therefore, head elevation using a pillow may have restricted the upward spread of the hyperbaric solution within the cerebrospinal fluid, resulting in sensory block levels comparable to those observed with isobaric bupivacaine.

Hemodynamic Changes Following Spinal Anesthesia According to Baricity

The present study revealed significant temporal changes in hemodynamic parameters following spinal anesthesia. Systolic blood pressure (SBP), diastolic blood pressure (DBP), and mean arterial pressure (MAP) declined progressively after intrathecal injection, with maximal reductions generally observed between 8 and 20 minutes. These findings align with the well-established physiological effects of spinal anesthesia, in which sympathetic blockade leads to peripheral vasodilation, reduced venous return, and hypotension.

Compared with isobaric bupivacaine, hyperbaric bupivacaine was associated with relatively better preservation of SBP, DBP, and MAP throughout the intraoperative period, with the most pronounced intergroup differences occurring between 10 and 25 minutes. These findings suggest that baricity plays a significant role in the hemodynamic response to spinal anesthesia.

These results are consistent with two studies conducted in Pakistan, which reported a more rapid onset of sensory block and greater decreases in SBP and MAP in the isobaric group between the 5th and 25th minutes. In one such study, the frequency of hypotension was substantially greater in the isobaric group (24.7%) than in the hyperbaric group (9.6%) (9, 19). Similarly, a single-center prospective cohort study in Ethiopia reported significantly greater hemodynamic instability in patients receiving isobaric bupivacaine.(13, 18)

However, the present findings contrast with those of a study from Bosnia and Herzegovina, which reported significantly greater reductions in blood pressure and heart rate in the hyperbaric group. The authors attributed this to more extensive cephalad spread of the hyperbaric solution, possibly due to differences in patient positioning, intrathecal drug distribution, local anesthetic dose, fluid management, and study population characteristics, which may explain these conflicting results (10).

The current findings are also not fully consistent with studies performed in Thailand(8), and Iran(20). The Thai study revealed no significant differences in the hemodynamic parameters between the two baricities. Conversely, the Iranian study reported a lower incidence and shorter duration of hypotension in the isobaric group. These discrepancies likely stem from variations in anesthetic technique, patient positioning, local anesthetic dose and volume, use of adjuncts, baseline patient physiology, and differing definitions and monitoring of hypotension.

Overall, hemodynamic responses related to blood pressure to spinal anesthesia are multifactorial. While baricity influences the extent and pattern of blocks, it interacts with multiple technique related and patient-specific factors, leading to heterogeneity across studies.

Heart rate responses also differed significantly between the two groups over time following spinal anesthesia. In the hyperbaric group, the heart rate initially increased after spinal block, which may represent a compensatory reflex response to the sudden reduction in systemic vascular resistance and blood pressure due to sympathetic blockade. However, the heart rate gradually decreased during later intraoperative periods as hemodynamic stabilization occurred.

Compared with the hyperbaric group, patients receiving isobaric bupivacaine demonstrated significantly higher heart rate values from 10 to 15 minutes post-spinal anesthesia. This finding may reflect a stronger compensatory sympathetic activation secondary to more pronounced or prolonged hypotensive episodes during this critical period of the peak block effect.

This pattern is consistent with evidence from previous studies indicating that spinal anesthesia induces rapid hemodynamic changes that stimulate baroreceptor-mediated reflex tachycardia, particularly during periods of marked blood pressure reduction(11). Furthermore, studies comparing baricities have demonstrated that greater hemodynamic instability is often associated with more pronounced autonomic compensatory responses, including transient increases in heart rate, especially in the early intraoperative phase(13).

Postoprative pain score and first analgesia request time

The present study demonstrated a clinically and statistically significant advantage of isobaric bupivacaine over hyperbaric bupivacaine in terms of postoperative analgesia. Linear mixed-effects modeling revealed that parturients receiving hyperbaric bupivacaine had significantly higher postoperative pain scores than did those receiving isobaric bupivacaine. Compared with the isobaric group, the hyperbaric group exhibited VAS scores that were 2.53 scores higher at 3 hours and 2.91 scores higher at 4 hours postoperatively. Kaplan–Meier survival analysis further confirmed a longer time to first analgesic request in the isobaric group (median 4.5–5 hours) than in the hyperbaric group (median 3–4 hours; $p < 0.001$), indicating a clinically meaningful delay of approximately 1–1.5 hours.

These findings suggest that isobaric bupivacaine provides prolonged sensory blockade and superior postoperative analgesia following spinal anesthesia for cesarean section.

The current results are also strongly supported by several studies demonstrating a longer sensory block duration and prolonged analgesia with isobaric bupivacaine. A systematic review and meta-analysis comparing hyperbaric versus isobaric bupivacaine following spinal anesthesia reported that isobaric formulations provided a significantly longer duration of sensory block (mean difference + 29.4 minutes) and motor block (+ 45.2 minutes) compared with hyperbaric solutions (11).

Consistent with the above findings, a study by Belarus reported that the duration of analgesia was substantially longer with a median analgesic duration of isobaric bupivacaine of 244 minutes (4 hours) than with hyperbaric bupivacaine with a median analgesic duration of 170 minutes (2.8 hours). This aligns closely with the 1–1.5 hour difference observed in the current study. The slower regression of

sensory blockade with isobaric solutions likely explains the delayed onset of pain and postponed need for rescue analgesia observed here.(29)

However, not all studies report a clear advantage for isobaric bupivacaine. A systematic review performed in Singapore comparing hyperbaric and isobaric bupivacaine for cesarean section revealed no significant difference in the need for supplemental analgesia between the two formulations. Several individual trials also reported comparable postoperative analgesic requirements.(4) Possible reasons for these discrepancies include differences in the bupivacaine dose and adjuvants on which many earlier studies used higher doses or added intrathecal opioids, such as fentanyl and morphine, which can mask differences in block duration attributable to baricity alone. The current study appears to have used plain bupivacaine without heavy opioid supplementation, potentially allowing baricity-related differences to become more apparent. The second factor might be patient positioning and the injection technique; variations in patient position immediately after injection (sitting vs. supine) significantly influence cephalad spread, particularly with hyperbaric solutions, which can alter the dermatomal level and duration of analgesia. Additionally the outcome measurement timing and definitions; of studies that assessed pain only intraopratively or at limited postoperative intervals may have missed the divergence that becomes evident between 3–6 hours, as clearly demonstrated by the linear mixed-effects modeling and Kaplan–Meier curves in this study. Additionally, population and setting factors, differences in maternal characteristics (e.g., BMI, parity, baseline pain sensitivity) and postoperative analgesia protocols (standardized multimodal regimens vs. on demand) can influence the time to first analgesic request.

LIMITATIONS OF THE STUDY

Pain outcomes were collected by clinical personnel aware of the anesthetic technique used, which may have introduced assessment bias. Pain assessment relies on subjective patient-reported outcomes, which may be susceptible to measurement bias. Additionally, there is a scarcity of similar prospective cohort studies on this topic, especially in low-resource African settings. This limited the ability to compare and contextualize the current findings during the discussion.

STRENGTHS OF THE STUDY

It was conducted in multicenter public hospitals, which improves its generalizability (external validity) and applicability to similar settings. The design enabled standardized and timely data collection, reduced recall bias, and enabled accurate and timely assessment of clinically important outcomes. Unlike most previous studies that focused on limited aspects of spinal block, this study comprehensively evaluated multiple outcomes in terms of block characteristics. Furthermore, the study used multivariable analysis and mixed effect models to adjust for potential confounders, which strengthened the robustness of the results.

CONCLUSION

Hyperbaric bupivacaine was associated with faster onset of sensory block to T6 and faster achievement of complete motor blockade. It also produced higher cephalad sensory block levels and provided relatively better hemodynamic stability, with less pronounced reductions in systolic, diastolic, and mean arterial pressures than the isobaric formulation did, particularly during the critical 5–20 minute period after injection. In contrast, isobaric bupivacaine offered a clinically important advantage in postoperative analgesia. Mothers in the isobaric group experienced significantly lower pain scores throughout the postoperative period and had a delayed need for the first analgesic by 1 to 1.5 hours than mothers' received hyperbaric bupivacaine. Peripheral oxygen saturation remained stable and comparable between both groups, indicating that baricity has a negligible effect on respiratory parameters when standard monitoring is applied.

Abbreviations

ASA	American Society of Anesthesiologists
AOR	Adjusted Odds Ratio
BMI	Body Mass Index
BS	Bromage scale
CI	Confidence Interval
CPD	Cephalo Pelvic Disproportion
CS	Cesarean Section
CSF	Cerebrospinal Fluid
DBP	Diastolic Blood Pressure
HR	Heart Rate
LA	Local Anesthetics
MAP	Mean Arterial Pressure
PI	Principal Investigator
RA	Regional Anesthesia
SA	Spinal Anesthesia
SBP	Systolic Blood Pressure
SD	Standard Deviation
SpO_2	Peripheral Oxygen Saturation
T4, T6, T8, T10	Thoracic dermatomes at 4, 6, 8, and 10
VAS	Visual Analog Scale

Declarations

Ethics approval and consent to participate

Ethical approval for the study was obtained from IRB of Addis Ababa University, College of Health Sciences (reference number: Anes PG /1/210/2025)

Consent for publication

Not applicable.

Data availability

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Clinical trial number: not applicable

Competing interests;

The authors declare no competing interests.

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Authors' contributions

YA: conceived and designed the study, analyzed the data, interpretation of the results and wrote the manuscript. AS, FF, ZB: statistical analysis, interpretation of the results, and revision of the manuscript and the final draft, provided advice throughout the study. All authors read and approved the final manuscript.

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Figures

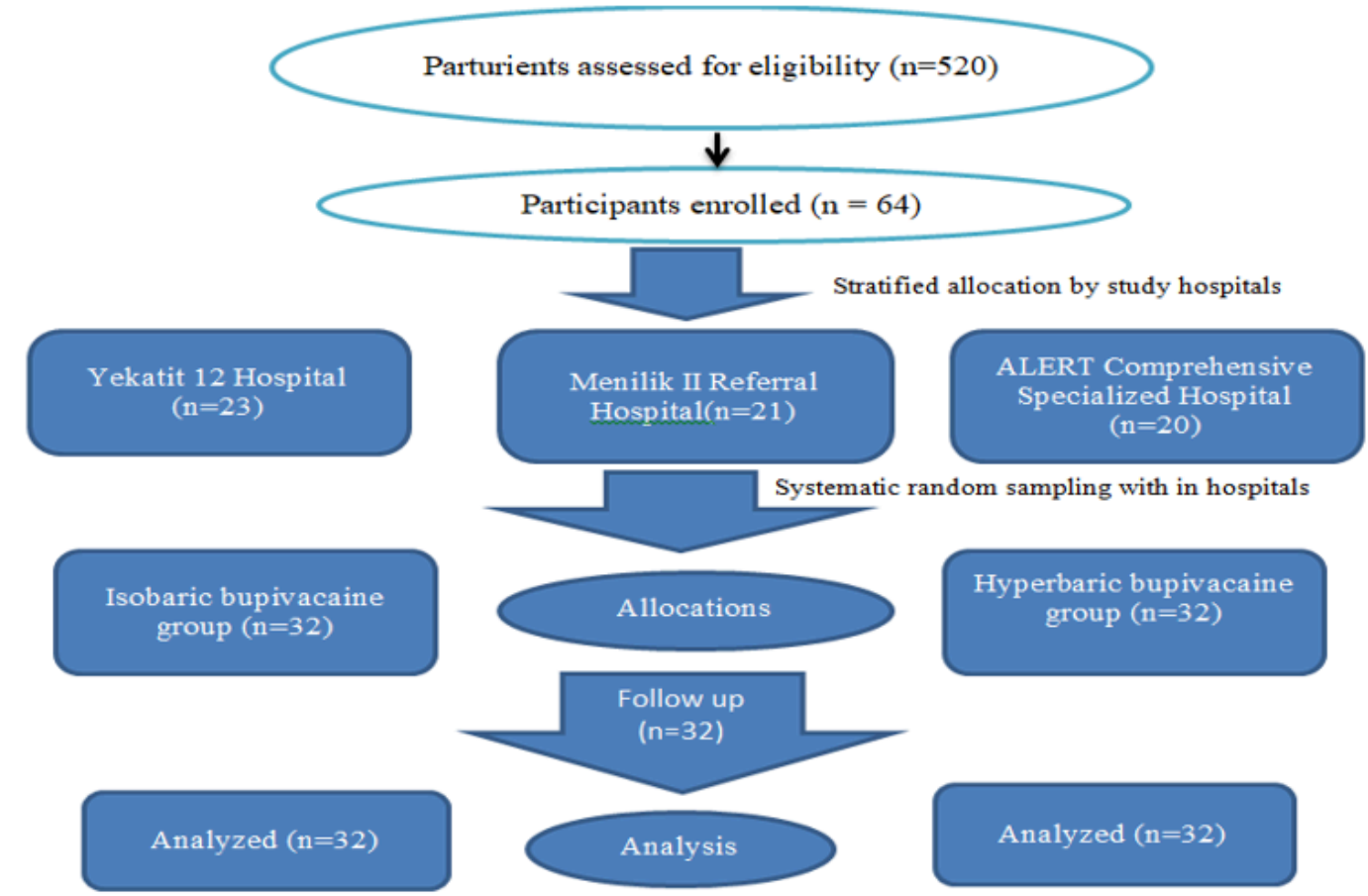


Figure 1

Enrollment flow chart of study participants selected via stratified by systematic random sampling technique at selected public hospitals in Addis Ababa, Ethiopia, 2026.

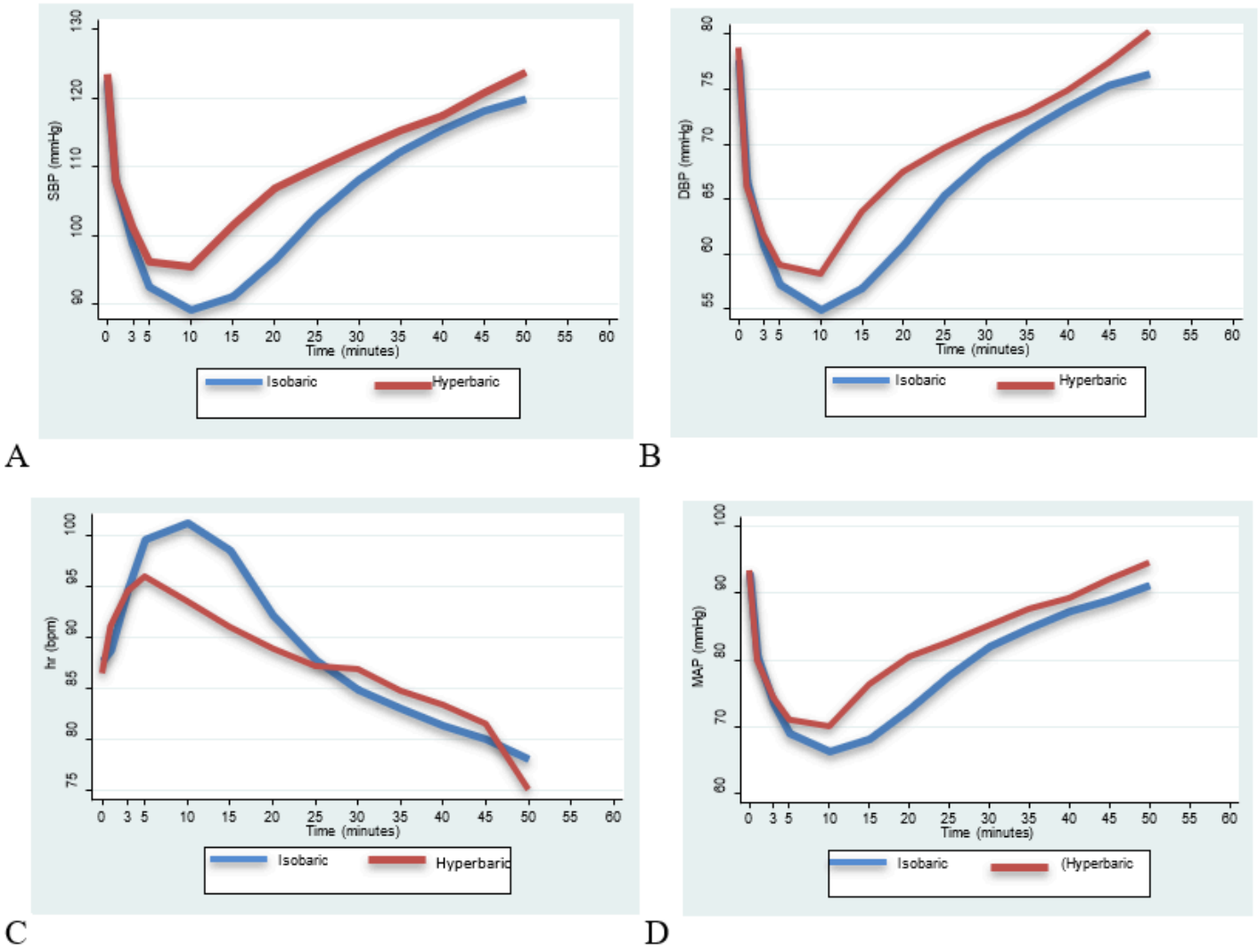
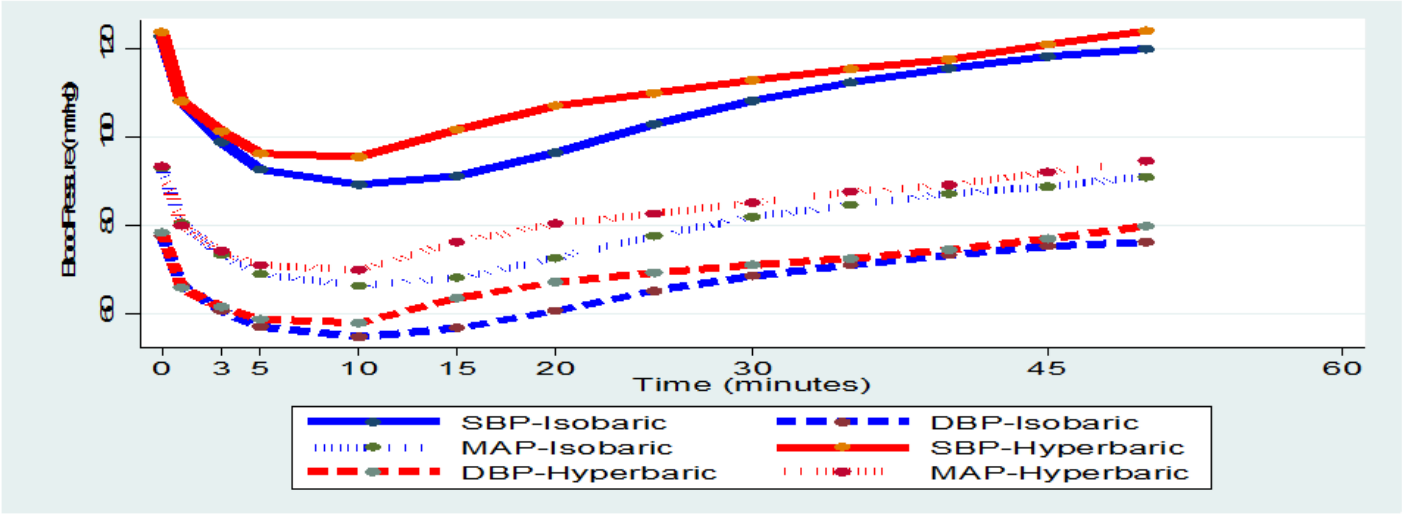


Figure 2

Trends in hemodynamic parameters among study participants at selected public hospitals in Addis Ababa, Ethiopia. Changes in (A) systolic blood pressure (SBP), (B) diastolic blood pressure (DBP), (C) mean arterial pressure (MAP),and (D) heart rate (HR) among the patients included in the study(n1=n2=32)



A

Figure 3

Comparative hemodynamic profiles of study participants at selected public hospitals in Addis Ababa, Ethiopia. The figure illustrates combined trends of the concurrent variation of SBP, DBP and MAP over time.

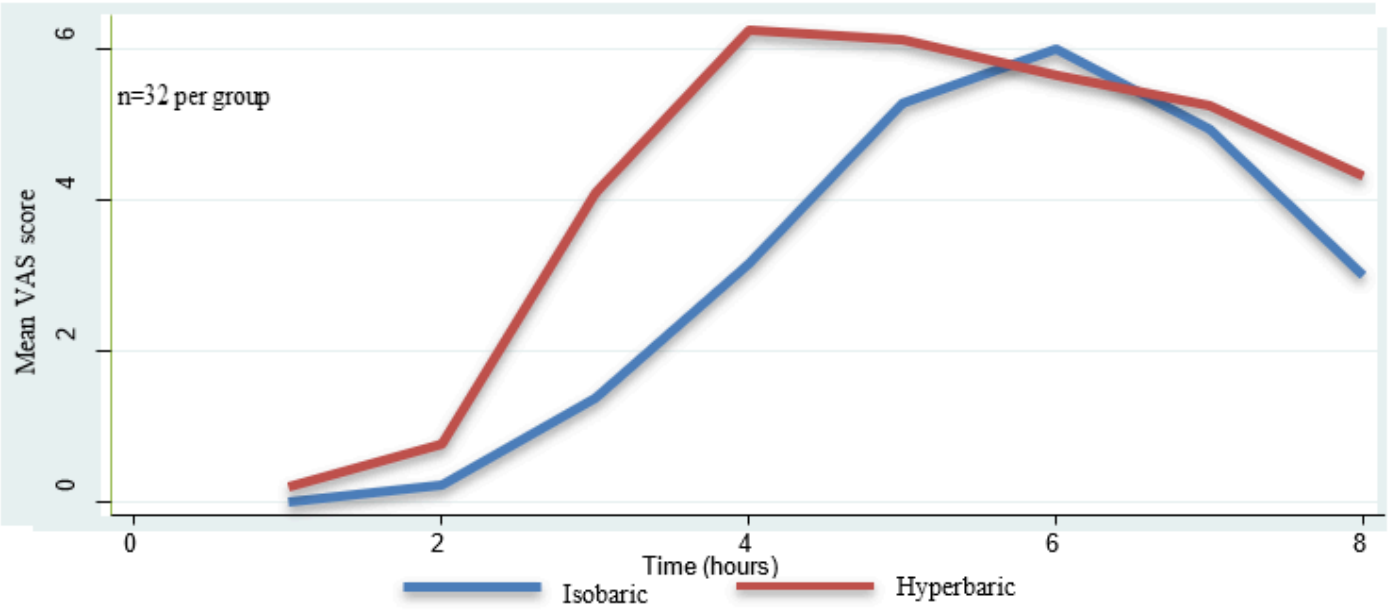


Figure 4

Comparison of postoperative VAS pain score trajectories between isobaric and hyperbaric bupivacaine at selected public hospitals in Addis Ababa, Ethiopia, February 01-April30,.2026.

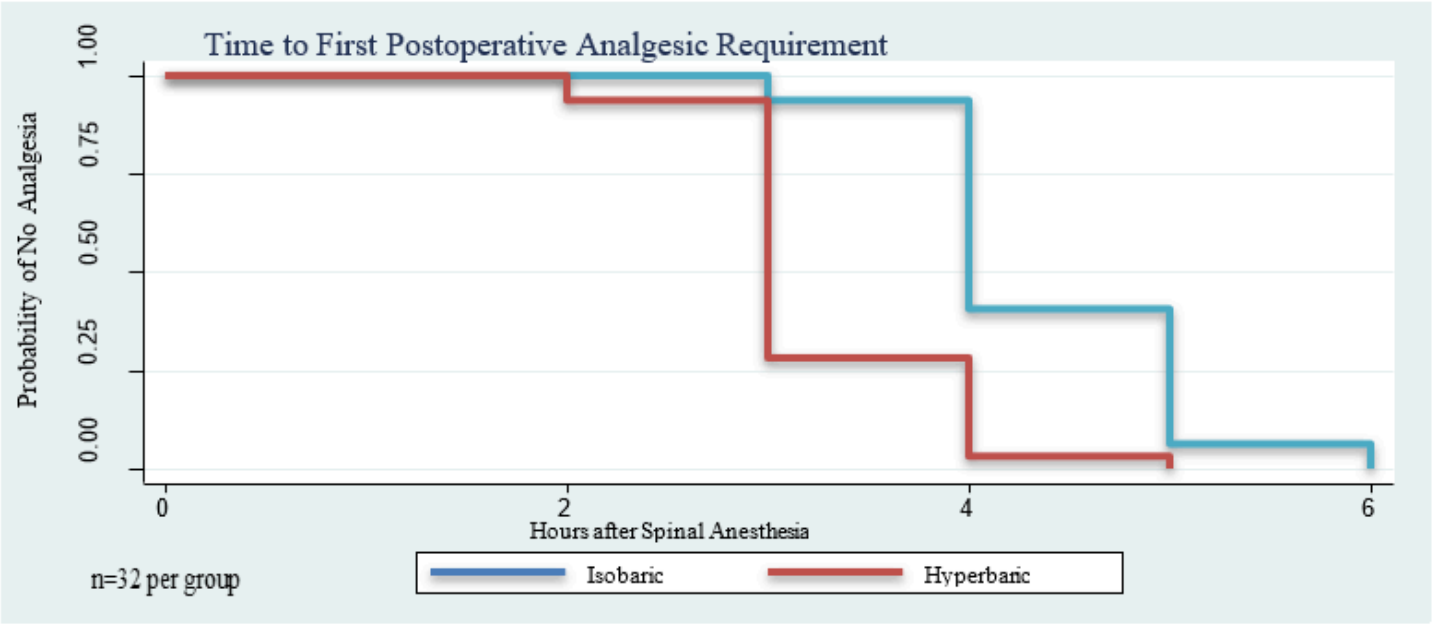


Figure 5

Kaplan–Meier survival curve of time to first postoperative analgesic requirement by baricity of bupivacaine among mothers undergoing cesarean section at selected public hospitals in Addis Ababa, Ethiopia, February 01-April30,2026