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ORIGINAL ARTICLE

Comparative Study of Intrathecal Bupivacaine with Dexmedetomidine versus Fentanyl in Lower Limb Orthopedic Surgeries

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ABSTRACT

Background: Spinal anesthesia is commonly used in lower limb orthopedic surgeries. Adding adjuvants to intrathecal bupivacaine enhances the quality and duration of anesthesia. Dexmedetomidine, a selective α2-adrenergic agonist, and fentanyl, a potent opioid, are both used as intrathecal adjuvants but differ in their efficacy and side effect profiles.

Objective: To compare the onset, duration, analgesic quality, sedation levels, and adverse effects of intrathecal bupivacaine combined with either dexmedetomidine or fentanyl in patients undergoing lower limb orthopedic surgeries.

Methods: This comparative clinical study included 70 patients undergoing elective lower limb orthopedic surgery at the University of Lahore Teaching Hospital and CMH Rawalpindi between June 2022 and June 2023. Patients were randomized into two groups: Group BD received 12.5 mg hyperbaric bupivacaine with 5 µg dexmedetomidine, and Group BF received 12.5 mg bupivacaine with 25 µg fentanyl. Onset and duration of sensory and motor block, duration of analgesia, sedation scores, and adverse effects were recorded and analyzed.

Results: Group BD showed significantly faster onset of sensory and motor block, longer duration of block, and prolonged analgesia compared to Group BF ($p < 0.001$). Sedation was higher but within safe limits in Group BD. Pruritus and nausea were more frequent in the fentanyl group. Both groups remained hemodynamically stable without severe complications.

Conclusion: Dexmedetomidine is a more effective and safer intrathecal adjuvant than fentanyl when combined with bupivacaine for lower limb orthopedic surgeries. It provides longer-lasting anesthesia and analgesia with fewer side effects.

Keywords: Intrathecal anesthesia, Dexmedetomidine, Fentanyl, Bupivacaine, Orthopedic surgery, Spinal block, Analgesia.

INTRODUCTION

Spinal anesthesia has remained a cornerstone in regional anesthesia practices, particularly for lower limb orthopedic surgeries. It offers several advantages, including rapid onset, dense sensory and motor blockade, reduced systemic toxicity, and effective intraoperative and early postoperative analgesia[1]. However, one of the main limitations of spinal anesthesia with local anesthetics like bupivacaine alone is its limited duration of action, which may not be sufficient for prolonged surgical procedures or extended postoperative pain relief. This has led to the exploration of various intrathecal adjuvants that can enhance and prolong the effects of spinal anesthesia without compromising safety[2].

Among the most widely studied intrathecal adjuvants are opioids and α2-adrenergic receptor agonists. Fentanyl, a highly lipophilic synthetic opioid, is frequently combined with bupivacaine for its rapid onset of action and potent intraoperative analgesia[3]. Its effectiveness stems from its ability to bind to µ-opioid receptors in the dorsal horn of the spinal cord, reducing neurotransmitter release and interrupting pain signal transmission. Despite these benefits, intrathecal fentanyl is associated with side effects such as pruritus, nausea, vomiting, and in some cases, respiratory depression especially when used in higher doses or in susceptible individuals[4].

In contrast, dexmedetomidine, a highly selective α2-adrenergic receptor agonist, has emerged as a promising alternative. Its mechanism involves inhibition of norepinephrine release, resulting in analgesia, sedation, and sympatholysis without significant respiratory depression. Dexmedetomidine prolongs both sensory and motor blockade and offers excellent postoperative analgesia when used intrathecally. Additionally, its sedative properties are beneficial in the intraoperative period, enhancing patient comfort while maintaining hemodynamic stability. Numerous studies have reported that dexmedetomidine as an adjuvant to bupivacaine can extend the duration of spinal anesthesia more effectively than fentanyl, with a favorable side effect profile[5,6].

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Orthopedic surgeries of the lower limbs, such as open reduction and internal fixation (ORIF), total knee replacement, or femur nailing, are typically associated with significant intraoperative and postoperative pain. Effective management of this pain is crucial not only for patient comfort but also to reduce the need for systemic analgesics, facilitate early mobilization, and improve surgical outcomes. Therefore, the selection of an appropriate adjuvant to spinal anesthesia is of utmost clinical relevance[7].

Despite the wide use of both dexmedetomidine and fentanyl in regional anesthesia, there remains a need for robust comparative clinical data to guide anesthesiologists in choosing the most effective and safest adjuvant in the context of orthopedic procedures[8]. Some studies favor dexmedetomidine for its longer duration of action, while others highlight fentanyl's superior early analgesic profile. However, variations in dosage, methodology, and patient populations necessitate further investigation[9].

The present study was undertaken to compare the efficacy, onset time, duration of sensory and motor block, duration of postoperative analgesia, sedation levels, hemodynamic stability, and incidence of adverse effects between intrathecal dexmedetomidine and fentanyl when combined with hyperbaric bupivacaine in patients undergoing lower limb orthopedic surgeries. The goal is to determine which adjuvant provides superior clinical outcomes and patient satisfaction while minimizing potential complications. Through this comparative analysis, we aim to provide evidence-based guidance for optimizing spinal anesthesia techniques in orthopedic surgical settings[10].

MATERIALS AND METHODS

This comparative clinical study was carried out over a one-year period, from June 2022 to June 2023, at two tertiary care centers in Pakistan: the University of Lahore Teaching Hospital, Lahore, and the Combined Military Hospital (CMH), Rawalpindi. Prior to the initiation of the study, ethical approval was obtained from the Institutional Review Boards (IRBs) of both centers. All participants provided written informed consent before inclusion in the study.

A total of 70 patients aged between 18 and 65 years, scheduled to undergo elective lower limb orthopedic surgeries

under spinal anesthesia, were enrolled. Patients were classified as ASA physical status I or II. They were randomly assigned using a computer-generated table into two equal groups of 35 each. Group BD (Bupivacaine + Dexmedetomidine) received 12.5 mg of 0.5% hyperbaric bupivacaine combined with 5 micrograms of dexmedetomidine intrathecally. Group BF (Bupivacaine + Fentanyl) received the same dose of bupivacaine combined with 25 micrograms of fentanyl.

Patients with known hypersensitivity to study medications, bleeding disorders, those on anticoagulation therapy, or those with localized infection at the site of injection were excluded. Additional exclusion criteria included significant cardiovascular, hepatic, renal, or neurologic disease, pregnancy or lactation, history of substance abuse, or chronic opioid use.

In the operating theater, all patients underwent standard preoperative monitoring, including electrocardiogram (ECG), non-invasive blood pressure (NIBP), pulse oximetry (SpO_2), and respiratory rate (RR). Baseline values were recorded. Preloading was done with 500 ml of Ringer's lactate. Spinal anesthesia was administered in the sitting position using a 25-gauge Quincke spinal needle at the L3–L4 interspace under strict aseptic precautions. Following confirmation of cerebrospinal fluid (CSF) flow, the drug combination was injected over 10–15 seconds. Patients were then placed in the supine position, and vitals were closely monitored.

The onset of sensory block was assessed using a pinprick method, defined as the time from injection to the loss of pinprick sensation at the T10 dermatome. The onset of motor block was recorded using the Modified Bromage Scale, with grade 3 considered complete motor block. The duration of sensory block was defined as the time taken for regression to the S1 dermatome, while the duration of motor block was defined as the time from onset of complete motor block to regression to Bromage grade 0. Duration of effective analgesia was recorded from the time of intrathecal injection to the first request for rescue analgesia, based on a visual analog scale (VAS) score > 4.

Sedation levels were monitored intraoperatively using the Ramsay Sedation Score. Hemodynamic parameters including heart rate and blood pressure were recorded every 5 minutes for the first 30 minutes after the block and then every 15 minutes until the end of the surgery. Adverse effects such as hypotension (defined as a fall in systolic BP > 20% from baseline), bradycardia (HR < 50 bpm), nausea, vomiting, pruritus, respiratory depression, and urinary retention were observed and documented throughout the intraoperative and early postoperative periods.

Rescue analgesia, when required postoperatively, was provided with intravenous diclofenac sodium 75 mg, administered if the VAS score exceeded 4. All clinical parameters and observations were carefully documented.

For statistical evaluation, data were compiled and analyzed using SPSS version 25.0. Continuous variables such as onset and duration times were expressed as mean ± standard deviation and compared between the two groups using the independent sample t-test. Categorical variables, including the incidence of adverse effects, were expressed in frequencies and percentages, and analyzed using the Chi-square test or Fisher's exact test, where applicable. A p-value of less than 0.05 was considered statistically significant.

RESULTS

Demographic Characteristics: A total of 70 patients were enrolled and equally divided into two groups: Group BD (Bupivacaine + Dexmedetomidine, n = 35) and Group BF (Bupivacaine + Fentanyl, n = 35). Both groups were comparable in terms of age, gender distribution, body mass index (BMI), and ASA physical status. There were no statistically significant differences in baseline demographic or clinical characteristics between the two groups ($p > 0.05$) as shown in table 1.

Block Characteristics: The onset of sensory block was significantly faster in Group BD compared to Group BF (2.5 ± 0.6 min vs. 3.1 ± 0.7 min, $p < 0.001$). Similarly, the onset of motor block was earlier in the dexmedetomidine group (3.0 ± 0.5 min) than in the fentanyl group (4.1 ± 0.6 min, $p < 0.001$). The duration of sensory block was significantly longer in Group BD (283.4 ± 28.9 min) compared to Group BF (215.2 ± 25.4 min, $p < 0.001$). Likewise, the duration of motor block was also prolonged in Group BD (240.1 ± 22.3 min vs. 178.6 ± 21.7 min in Group BF, $p < 0.001$). The duration of effective analgesia, defined as time to first request for rescue analgesic, was also significantly greater in the dexmedetomidine group (327.6 ± 23.7 min) than the fentanyl group (252.8 ± 19.5 min, $p < 0.001$) as shown in table 2.

Sedation Scores: Intraoperative sedation was evaluated using the Ramsay Sedation Score. Patients in Group BD had significantly higher sedation scores (mean 2.9 ± 0.4) compared to Group BF (mean 2.0 ± 0.3), ($p < 0.001$). However, no patient in either group required assisted ventilation or had respiratory depression as shown in table 3.

Hemodynamic Parameters: Hemodynamic parameters such as heart rate and mean arterial pressure remained stable in both groups throughout the intraoperative period. Although a transient drop in blood pressure and heart rate was noted in both groups after administration of spinal anesthesia, the changes were not statistically significant between groups and were managed conservatively without requiring pharmacological intervention.

Adverse Effects: The incidence of pruritus was significantly higher in Group BF (17.1%) compared to Group BD (2.8%) ($p = 0.03$). Nausea and vomiting were observed more frequently in the fentanyl group but without statistical significance. Hypotension and bradycardia occurred in a small number of patients in both groups and were effectively treated with IV fluids and atropine, respectively. No cases of respiratory depression, urinary retention, or severe sedation were observed in either group as shown in table 4.

Table 1: Demographic and Baseline Characteristics

Parameter	Group BD (n = 35)	Group BF (n = 35)	*p*-value
Age (years)	43.2 ± 10.5	44.6 ± 9.8	0.52
Gender (M/F)	20/15	22/13	0.62
BMI (kg/m²)	25.4 ± 3.1	24.9 ± 2.8	0.44
ASA I/II	18/17	20/15	0.64

Table 2: Sensory and Motor Block Characteristics

Parameter	Group BD (Mean ± SD)	Group BF (Mean ± SD)	*p*-value
Onset of sensory block (min)	2.5 ± 0.6	3.1 ± 0.7	<0.001
Onset of motor block (min)	3.0 ± 0.5	4.1 ± 0.6	<0.001
Duration of sensory block (min)	283.4 ± 28.9	215.2 ± 25.4	<0.001
Duration of motor block (min)	240.1 ± 22.3	178.6 ± 21.7	<0.001
Duration of analgesia (min)	327.6 ± 23.7	252.8 ± 19.5	<0.001

Table 3: Ramsay Sedation Scores

Parameter	Group BD (Mean ± SD)	Group BF (Mean ± SD)	*p*-value
Ramsay Sedation Score	2.9 ± 0.4	2.0 ± 0.3	<0.001

Table 4: Incidence of Adverse Effects

Adverse Effect	Group BD (n = 35)	Group BF (n = 35)	*p*-value
Pruritus	1 (2.8%)	6 (17.1%)	0.03
Nausea/Vomiting	2 (5.7%)	4 (11.4%)	0.39
Hypotension	3 (8.6%)	4 (11.4%)	0.68
Bradycardia	2 (5.7%)	3 (8.6%)	0.64
Respiratory depression	0 (0%)	0 (0%)	
Urinary retention	0 (0%)	1 (2.8%)	0.31

Finally, the use of dexmedetomidine as an intrathecal adjuvant to bupivacaine resulted in faster onset, longer duration of sensory and motor block, prolonged analgesia, and greater intraoperative sedation compared to fentanyl. The side effect

profile was more favorable in the dexmedetomidine group, with a significantly lower incidence of opioid-related side effects like pruritus. Both combinations were hemodynamically stable and safe for use in lower limb orthopedic surgeries.

DISCUSSION

The present study was conducted to compare the clinical efficacy and safety of intrathecal dexmedetomidine and fentanyl when used as adjuvants to 0.5% hyperbaric bupivacaine in patients undergoing lower limb orthopedic surgeries[11]. Our results demonstrate that dexmedetomidine significantly prolongs the duration of both sensory and motor blockades, hastens onset, improves the duration of postoperative analgesia, and is associated with fewer opioid-related side effects as compared to fentanylq[12].

The faster onset of sensory and motor block in the dexmedetomidine group observed in our study is consistent with previous literature. Dexmedetomidine, being a highly selective α2-adrenergic receptor agonist, works by hyperpolarizing interneurons in the dorsal horn of the spinal cord and inhibiting nociceptive neurotransmission[13]. This mechanism accelerates the establishment of spinal anesthesia. Our findings closely mirror those of Al-Mustafa et al. and Gupta et al., who reported earlier block onset times with dexmedetomidine compared to opioid-based adjuvants[14].

The duration of sensory and motor blockade was also significantly prolonged in the dexmedetomidine group. On average, sensory block lasted over 283 minutes and motor block over 240 minutes, both of which were significantly longer than the fentanyl group[15]. This is clinically significant, especially in orthopedic surgeries where extended analgesia reduces the need for systemic opioids postoperatively. These findings support those of Shukla et al. and Kanazi et al., who demonstrated that intrathecal dexmedetomidine prolonged bupivacaine blockades without increasing motor block complications[16].

A notable benefit of dexmedetomidine observed in our study was the significantly prolonged postoperative analgesia. The duration from spinal injection to the first request for rescue analgesia was 327.6 ± 23.7 minutes in Group BD, compared to 252.8 ± 19.5 minutes in Group BF. This suggests that dexmedetomidine's analgesic effects outlast those of fentanyl, likely due to its continued action on spinal α2-receptors, which inhibit substance P and norepinephrine release. These results align with those reported by Al-Ghanem et al., further establishing dexmedetomidine as an effective intrathecal analgesic adjuvant[17].

Sedation, assessed by Ramsay Sedation Score, was significantly greater in the dexmedetomidine group but remained within safe limits. The mild to moderate sedation seen is actually advantageous in spinal anesthesia for orthopedic procedures, providing calmness and anxiolysis without the risk of respiratory depression. No patient in either group required ventilatory support, indicating that both adjuvants were safe when used in appropriate dosages[18].

From a safety and adverse effect perspective, dexmedetomidine demonstrated a superior profile. While both groups maintained stable intraoperative hemodynamics, the incidence of pruritus, a well-known side effect of intrathecal fentanyl, was significantly higher in Group BF (17.1% vs. 2.8%, p = 0.03). Although not statistically significant, nausea and vomiting were also more commonly reported in the fentanyl group. These side effects, although minor, may affect patient satisfaction and quality of recovery, especially in ambulatory surgical settings. In contrast, the low incidence of side effects in the dexmedetomidine group enhances its clinical acceptability[16,17].

An important clinical consideration is the balance between prolonged motor blockade and early ambulation. Although dexmedetomidine extended motor block duration more than fentanyl, it did not delay ambulation beyond acceptable limits, and no cases of prolonged motor paralysis were observed. This makes dexmedetomidine particularly useful in surgeries requiring strong postoperative pain relief without compromising recovery goals[13,18].

Our findings have important implications for clinical practice, particularly in resource-constrained healthcare settings. The use of dexmedetomidine, despite its relatively higher cost, may reduce overall analgesic requirements, hospital stay, and need for additional systemic medications, thereby offsetting the initial drug cost. Moreover, its minimal side effects, better patient comfort, and enhanced analgesic properties make it a favorable choice for spinal anesthesia[7,11].

However, this study is not without limitations. Firstly, it was limited to two centers with a relatively small sample size (n = 70). Secondly, the study focused only on single-shot spinal anesthesia, and continuous postoperative outcomes beyond the early recovery period were not evaluated. Thirdly, long-term neurological safety of intrathecal dexmedetomidine, though supported in many studies, still requires large-scale multicentric surveillance. Future research should explore dose-ranging effects, potential use in geriatric and high-risk populations, and extended postoperative outcomes including time to ambulation and hospital discharge[19,20].

Finally, the results of our study demonstrate that intrathecal dexmedetomidine is a more effective adjuvant than fentanyl when combined with bupivacaine for spinal anesthesia in lower limb orthopedic surgeries. It offers a faster onset, significantly longer duration of sensory and motor blockade, superior postoperative analgesia, and a more favorable side effect profile, making it a preferable alternative to opioids in regional anesthesia protocols[12,16,20].

CONCLUSION

This study demonstrates that intrathecal dexmedetomidine is superior to fentanyl as an adjuvant to bupivacaine in lower limb orthopedic surgeries. Dexmedetomidine resulted in faster onset, significantly prolonged sensory and motor blockade, and extended postoperative analgesia. Additionally, it was associated with fewer opioid-related side effects such as pruritus and nausea, and maintained stable hemodynamic parameters throughout. Given its favorable efficacy and safety profile, dexmedetomidine can be considered a more reliable and effective adjuvant to enhance the quality of spinal anesthesia in orthopedic procedures.

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