RESEARCH PAPER

Comparative Analysis of Analgesic and Hemodynamic Effects of Dexmedetomidine-Fentanyl versus Dexmedetomidine in Lower Limb Orthopedic Surgeries Under Regional Anesthesia: A Cross-Sectional Study

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ABSTRACT

Background: Optimization of spinal anesthesia using adjuvants is essential for improving analgesic efficacy and perioperative hemodynamic stability in orthopedic surgeries. Dexmedetomidine, an α2-adrenergic agonist, has gained attention as a neuraxial adjuvant, while fentanyl remains a commonly used opioid adjunct. This study aimed to compare the analgesic and hemodynamic effects of intrathecal dexmedetomidine–fentanyl combination versus dexmedetomidine alone in patients undergoing lower limb orthopedic surgeries.

Methods: This prospective randomized study was conducted at a tertiary care center in Chennai in 2022. Thirty patients (ASA I–II), aged 18–60 years, undergoing elective lower limb orthopedic surgeries under spinal anesthesia were enrolled and divided into two groups (n=15 each). Group A received dexmedetomidine (10 µg) with fentanyl (25 µg), while Group B received dexmedetomidine (10 µg) with saline. Sensory and motor block onset, duration of analgesia, hemodynamic parameters, and postoperative pain scores (VAS) were assessed.

Results: Group A demonstrated significantly faster onset of sensory block (6.6 ± 0.90 min vs 8.2 ± 0.97 min; p=0.0001) and motor block (7.13 ± 0.80 min vs 9.93 ± 0.92 min; p=0.0001) compared to Group B. The duration of analgesia was significantly prolonged in Group A (427.3 ± 89.25 min vs 265.0 ± 71.27 min; p=0.0001). Postoperative pain scores were significantly lower in Group A at 0, 6, and 24 hours ($p<0.01$). Hemodynamically, Group A exhibited lower heart rate and systolic blood pressure in the early intraoperative period ($p<0.05$), while both groups maintained overall stability without clinically significant adverse effects.

Conclusion: The combination of intrathecal dexmedetomidine and fentanyl provides superior analgesic efficacy, faster onset of blockade, and prolonged postoperative analgesia compared to dexmedetomidine alone, while maintaining stable hemodynamics. This combination represents an effective strategy for enhancing spinal anesthesia outcomes in lower limb orthopedic surgeries.

Keywords: Analgesia, Dexmedetomidine, Fentanyl, Spinal Anesthesia, Hemodynamics, Orthopedic Procedures, Postoperative Pain, Regional Anesthesia

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Introduction

Effective perioperative pain management is a fundamental component of modern anesthetic practice, significantly influencing surgical outcomes, patient satisfaction, and recovery profiles. Inadequate analgesia is associated with increased physiological stress responses, delayed

mobilization, prolonged hospitalization, and higher healthcare burden. Consequently, contemporary anesthetic approaches emphasize multimodal analgesia and optimization of regional techniques to enhance recovery and minimize systemic opioid requirements [1]. Neuraxial anesthesia, including spinal and epidural techniques, has become widely adopted due to its ability to provide dense sensory blockade, improved postoperative pain control, and favorable physiological stability compared to general anesthesia [2].

The pharmacological basis of neuraxial anesthesia relies on the use of local anesthetics, particularly long-acting agents such as ropivacaine and bupivacaine. Ropivacaine is increasingly preferred because of its improved safety profile, especially reduced cardiotoxicity and neurotoxicity, while maintaining effective sensory blockade with less motor impairment [3]. Despite these advantages, the duration of analgesia provided by local anesthetics alone is often limited, necessitating the use of adjuvants to prolong analgesic effects and improve block characteristics [4]. The addition of adjuvants to neuraxial blocks has therefore become a standard strategy to enhance the quality and duration of anesthesia while reducing the need for repeated dosing [5].

Opioids such as fentanyl have traditionally been used as neuraxial adjuvants due to their potent analgesic properties mediated via spinal opioid receptors. While effective, their use is frequently associated with adverse effects such as pruritus, nausea, vomiting, urinary retention, and respiratory depression, which may limit their clinical utility and affect patient comfort [6]. These limitations have prompted the search for alternative non-opioid adjuvants that can provide effective analgesia with a more favorable side-effect profile [7]. Among these, α2-adrenergic agonists have emerged as promising agents due to their analgesic, sedative, and sympatholytic properties [8].

Dexmedetomidine, a highly selective α2-adrenoceptor agonist, has gained significant attention as a neuraxial adjuvant. It exerts its analgesic effects by inhibiting the release of norepinephrine and modulating pain pathways at both spinal and supraspinal levels. At the dorsal horn of the spinal cord, dexmedetomidine enhances the effects of local anesthetics by reducing neuronal firing and prolonging sensory and motor blockade [9]. Additionally, its sedative properties, mediated through central α2-receptor activation, provide patient comfort without causing significant respiratory depression, making it a valuable adjunct in regional anesthesia [10].

Clinical evidence has increasingly supported the use of dexmedetomidine in neuraxial anesthesia. Intrathecal administration of dexmedetomidine as an adjuvant to bupivacaine has been shown to significantly prolong the duration of spinal block and improve postoperative analgesia compared to conventional regimens [11]. Furthermore, meta-analytic evidence indicates that both intravenous and intrathecal dexmedetomidine enhance the quality of spinal anesthesia, prolong block duration, and reduce postoperative analgesic requirements, with acceptable safety profiles [12].

More recent randomized controlled trials have evaluated dexmedetomidine in comparison with traditional opioid adjuvants. In epidural analgesia, dexmedetomidine has been shown to reduce the required dose of ropivacaine while maintaining effective analgesia, thereby demonstrating a dose-sparing effect and improved efficiency of local anesthetics [13]. Similarly, studies comparing dexmedetomidine with fentanyl as adjuvants to ropivacaine have reported superior duration and quality of analgesia with dexmedetomidine, along with a lower incidence of opioid-related adverse effects [14]. These findings suggest that dexmedetomidine may offer a safer and more effective alternative to opioids in neuraxial anesthesia.

The growing body of evidence has been reinforced by recent systematic reviews and meta-analyses. Dexmedetomidine, when used as an adjuvant to ropivacaine, has been shown to significantly prolong postoperative analgesia and improve overall analgesic outcomes without a substantial increase in adverse events [15]. Such high-level evidence highlights the evolving role of dexmedetomidine in enhancing the efficacy of regional anesthesia techniques and supports its incorporation into clinical practice.

Despite these promising findings, there remains variability in the choice of adjuvants for neuraxial anesthesia, particularly between dexmedetomidine and fentanyl. While fentanyl continues to be widely used due to its rapid onset and established efficacy, concerns regarding opioid-related side effects persist. On the other hand, dexmedetomidine, although advantageous, may be associated with hemodynamic changes such as bradycardia and hypotension, necessitating careful monitoring. Therefore, direct comparative evaluation of these agents is essential to determine the optimal adjuvant for improving analgesic outcomes while minimizing complications.

In this context, the present study aims to compare dexmedetomidine and fentanyl as adjuvants to ropivacaine in neuraxial anesthesia. By evaluating parameters such as duration of analgesia, quality of block, hemodynamic stability, and adverse effects, this study seeks to provide evidence-based insights that can guide clinical decision-making and contribute to improved perioperative care.

Methodology :

Materials and Methods

This prospective randomized study was conducted in 2022 at a **tertiary care center**, Sree Balaji Medical College and Hospital, Chennai, after obtaining approval from the Institutional Ethics Committee. Written informed consent was obtained from all participants prior to enrollment. A total of 30 adult patients scheduled for elective lower limb orthopedic surgeries under spinal anesthesia were included in the study. Patients aged between 18 and 60 years, of either sex, weighing between 40 and 80 kg, and classified as American Society of Anesthesiologists (ASA) physical status I or II were considered eligible for inclusion. Patients with ASA physical status III or IV, spinal deformities, psychiatric illness, pregnancy, chronic alcohol use, known hypersensitivity to study drugs, or those who declined consent were excluded from the study.

Participants were randomly allocated into two equal groups of 15 patients each. Group A received an intrathecal combination of dexmedetomidine 10 µg and fentanyl 25 µg along with hyperbaric bupivacaine, whereas Group B received dexmedetomidine 10 µg with 0.5 mL normal saline in combination with hyperbaric bupivacaine.

All patients underwent a detailed preoperative evaluation one day prior to surgery, which included history taking, general physical examination, and systemic examination with particular emphasis on cardiovascular, respiratory, and neurological systems. Routine investigations such as hemoglobin, total and differential leukocyte count, urine analysis, blood urea nitrogen, serum creatinine, bleeding time, and clotting time were performed. A thorough spinal examination was also conducted. Patients were instructed to remain nil per oral for at least 10 hours prior to surgery and were preloaded with 500 mL of normal saline before administration of anesthesia.

On arrival in the operating room, standard monitoring including non-invasive blood pressure, heart rate, electrocardiogram, and peripheral oxygen saturation was established. Under strict aseptic precautions, spinal anesthesia was administered in the sitting position using a 25-gauge Quincke spinal needle via the paramedian approach at the L3–L4 interspace. The study drugs were administered intrathecally as per group allocation along with hyperbaric bupivacaine.

Sensory blockade was assessed bilaterally using the pinprick method along the midclavicular line at 2-minute intervals until a block level of T10 was achieved, following which surgery was commenced. Motor blockade was evaluated using the Modified Bromage Scale. Intraoperatively, vital parameters including heart rate, blood pressure, and oxygen saturation were recorded at regular intervals, and continuous electrocardiographic monitoring was maintained.

Postoperatively, patients were observed in the recovery room where vital signs were monitored periodically. Pain intensity was assessed using standard pain scoring methods, and the duration of analgesia along with any adverse effects were recorded for comparative analysis between the two groups.

Results

A total of 30 patients were enrolled in the study and were randomly allocated into two groups of 15 each (Group A and Group B). The groups were comparable at baseline with respect to demographic characteristics, as detailed below. The demographic profile of the study population is summarized in Table 1. There were no statistically significant differences between the two groups in terms of age (p=0.57) or sex distribution. However, a significant difference was observed in Body Mass Index (BMI) between the groups (p=0.02).

Table 1. Patient Demographics and Baseline Characteristics

Characteristic	Group A (n=15)	Group B (n=15)	p-value
Age (years), Mean ± SD	41.4 ± 10.7	39.2 ± 10.53	0.57
Sex, n (%)			
Male	9 (60%)	10 (67%)	
Female	6 (40%)	5 (33%)	
BMI (kg/m²), Mean ± SD	22.4 ± 4.0	23.98 ± 4.16	0.02

Intraoperative vital signs, including heart rate (HR), systolic blood pressure (SBP), diastolic blood pressure (DBP), and SpO_2, were recorded at various time points (0, 15, 30, and 45 minutes). The heart rate was significantly lower in Group A compared to Group B at 0 minutes (p=0.0001) and 15 minutes (p=0.0011). No significant differences were observed at 30 and 45 minutes. **Systolic BP:** Group B had a significantly higher SBP at 0 minutes (p=0.0001) and 15 minutes (p=0.0142). The values were comparable between groups at later time points. **Diastolic BP:** DBP was comparable between groups at all time points except at 45 minutes, where a statistically significant difference was noted (p=0.0014). SpO_2 levels were largely comparable between the groups, with a significant difference observed only at the 30-minute time point (p=0.0001) (Table 2).

Table 2. Intraoperative Vital Parameters (Mean ± SD)

Parameter	Time	Group A (n=15)	Group B (n=15)	p-value
Heart Rate (bpm)	0 min	79.86 ± 4.91	88.73 ± 6.12	**0.0001**
	15 min	81.46 ± 4.57	89.00 ± 6.56	**0.0011**
	30 min	82.00 ± 6.85	83.53 ± 13.00	0.476
	45 min	80.26 ± 6.20	80.80 ± 4.60	0.7885
Systolic BP (mmHg)	0 min	118.00 ± 6.78	133.40 ± 9.39	**0.0001**
	15 min	124.80 ± 6.19	132.20 ± 8.68	**0.0142**
	30 min	128.60 ± 4.97	130.30 ± 7.32	0.4630
	45 min	126.86 ± 5.18	128.46 ± 6.71	0.4657
Diastolic BP (mmHg)	0 min	77.93 ± 8.27	83.06 ± 8.78	0.1106
	15 min	78.40 ± 8.08	82.80 ± 7.09	0.1428
	30 min	81.53 ± 6.69	78.26 ± 7.49	0.2177
	45 min	81.86 ± 5.66	80.53 ± 5.43	**0.0014**
SpO_2 (%)	0 min	97.06 ± 3.85	98.26 ± 2.66	0.3303
	15 min	99.46 ± 0.88	99.33 ± 0.94	0.6987
	30 min	98.80 ± 1.27	98.66 ± 1.95	**0.0001**
	45 min	99.60 ± 0.61	99.33 ± 0.94	0.3587

The onset of sensory and motor blockade was significantly different between the two groups. **Sensory Block:** The time to onset of sensory block was significantly shorter in Group A (6.6 ± 0.90 min) compared to Group B (8.2 ± 0.97 min) (p=0.0001). **Motor Block:** Similarly, the onset of motor block was significantly faster in Group A (7.13 ± 0.80 min) than in Group B (9.93 ± 0.92 min) (p=0.0001) (Table 3).

Table 3. Block Characteristics and Analgesia Outcomes (Mean ± SD)

Outcome	Group A (n=15)	Group B (n=15)	p-value
Sensory Block Onset (min)	6.6 ± 0.90	8.2 ± 0.97	**0.0001**
Motor Block Onset (min)	7.13 ± 0.80	9.93 ± 0.92	**0.0001**
Time to First Rescue Analgesia (min)	427.3 ± 89.25	265.0 ± 71.27	**0.0001**

The duration of postoperative analgesia, as measured by the time to first request for rescue analgesia, was significantly

longer in Group A (427.3 ± 89.25 min) compared to Group B (265.0 ± 71.27 min) (p=0.0001). Postoperative pain scores were assessed at 0, 6, and 24 hours. At all time points, Group A reported significantly lower VAS scores compared to Group B (0h: p=0.0056; 6h: p=0.0001; 24h: p=0.0007) (Table 4).

Table 4. Postoperative VAS Scores (Mean ± SD)

Time	Group A (n=15)	Group B (n=15)	p-value
0 hours	1.73 ± 0.85	2.7 ± 0.92	**0.0056**
6 hours	3.2 ± 0.85	4.9 ± 0.85	**0.0001**
24 hours	4.26 ± 1.06	5.8 ± 1.16	**0.0007**

Postoperative vital signs (SBP, DBP, HR, SpO_2) were monitored. The vast majority of measurements showed no significant difference between the groups. Isolated significant differences were observed in SBP at 30 minutes (p=0.0001), DBP at 0 minutes (p=0.0379), and HR at 45 minutes (p=0.0334). SpO_2 remained comparable between groups at all postoperative time points.

Discussion

The present study provides compelling evidence that the addition of fentanyl to intrathecal dexmedetomidine significantly enhances both block characteristics and postoperative analgesia in lower limb orthopedic surgeries. A striking observation in our cohort was the clear acceleration in onset of anesthesia, with sensory block achieved at 6.6 ± 0.90 minutes in the combination group versus 8.2 ± 0.97 minutes in the dexmedetomidine-only group (p = 0.0001). This approximately 20% reduction in onset time is clinically meaningful, particularly in high-throughput operating settings where rapid surgical readiness is advantageous. A similar pattern was observed for motor blockade (7.13 ± 0.80 vs 9.93 ± 0.92 minutes, p = 0.0001), reinforcing the early synergistic interaction between fentanyl and dexmedetomidine .

Beyond onset, the magnitude of prolongation in analgesia stands out as one of the most clinically relevant findings. Patients receiving the combination experienced a remarkably extended pain-free interval (427.3 ± 89.25 minutes) compared to those receiving dexmedetomidine alone (265.0 ± 71.27 minutes, p = 0.0001). This represents an increase of more than 160 minutes (~60% longer duration), effectively delaying the need for rescue analgesia well into the postoperative period. Importantly, this translated into consistently lower VAS scores at 0, 6, and 24 hours, indicating not just prolonged but also qualitatively superior analgesia .

These findings align closely with the experimental work of Marhofer et al. [16], who demonstrated that dexmedetomidine enhances the duration of nerve blockade by nearly 60–70% when added to ropivacaine. Although their study focused on peripheral nerve blocks, the physiological mechanism—augmentation of local anesthetic action via α2-mediated hyperpolarization—provides a strong explanatory basis for our observed prolongation. In our study, this intrinsic prolonging effect of dexmedetomidine appears to be further amplified by fentanyl, suggesting a layered pharmacodynamic synergy.

This concept of dual-mechanism enhancement is further supported by Bao et al. [17], who quantified an increase of more than 120 minutes in analgesic duration with dexmedetomidine due to both central and peripheral actions. When viewed alongside our findings (increase ~160 minutes), it becomes evident that intrathecal combination therapy may surpass the effects seen with dexmedetomidine alone, particularly in clinical settings involving spinal anesthesia.

At the level of pooled evidence, the network meta-analysis by Ollosu et al. [18] placed dexmedetomidine among the top-ranking intrathecal adjuvants, outperforming opioids in prolonging sensory block while maintaining a better side-effect profile. Our results complement this hierarchy—dexmedetomidine provides the backbone of prolonged analgesia, while fentanyl contributes an early-phase enhancement, effectively bridging the onset–duration continuum.

A similar trend is echoed in the meta-analysis by Quan et al. [19], where dexmedetomidine extended analgesia by over 100 minutes when combined with ropivacaine. However, our findings exceed this magnitude, suggesting that adding fentanyl may push the analgesic ceiling further, especially in adult orthopedic populations where nociceptive input is substantial.

Comparative trials provide additional insight into this interaction. Mahendru et al. [20] reported that dexmedetomidine alone produced longer block duration (~300–350 minutes) compared to fentanyl, establishing its superiority as a primary adjuvant. However, our data suggest that combining fentanyl with dexmedetomidine does not merely replicate but enhances this effect, extending analgesia beyond 400 minutes.

This is further corroborated by Khosravi et al. [21], who reported analgesic durations of approximately 420 minutes with dexmedetomidine versus 300 minutes with fentanyl. Notably, our combination group achieved values comparable to or exceeding dexmedetomidine alone in their

study, again emphasizing the additive benefit of fentanyl when used alongside dexmedetomidine.

Kalbande et al. [22] provide perhaps the closest parallel to our findings, demonstrating that the dexmedetomidine–fentanyl combination reduced onset time and prolonged analgesia by 30–40%. However, the degree of prolongation observed in our study (~60%) is even more pronounced, possibly reflecting differences in dosing strategy, patient population, or surgical stimulus.

Interestingly, not all studies demonstrate such clear superiority of combination therapy. Khan et al. [23] reported only modest differences in onset and duration between dexmedetomidine and fentanyl groups, suggesting overlapping efficacy. In contrast, our study shows highly significant differences ($p = 0.0001$ across multiple endpoints), indicating that the combination approach may overcome this equivalence and produce clinically distinct benefits.

Rahimzadeh et al. [24] similarly demonstrated that combining dexmedetomidine with fentanyl prolonged analgesia by 100–150 minutes, closely approximating our observed increase of over 160 minutes. This consistency across studies strengthens the argument for true pharmacological synergy rather than additive effect alone.

From a hemodynamic perspective, our study adds another dimension of clinical relevance. The combination group exhibited lower heart rate at baseline (79.86 vs 88.73 bpm; $p = 0.0001$) and at 15 minutes ($p = 0.0011$), along with significantly lower systolic blood pressure in the early intraoperative period. Despite this, no clinically significant instability was observed, and parameters normalized over time .

This pattern is well supported by Tarıkçı Kılıç et al. [26], who demonstrated that dexmedetomidine induces controlled sympatholysis, leading to reductions in heart rate and blood pressure without compromising oxygenation. Bajwa et al. [27] further confirmed that dexmedetomidine provides smoother hemodynamic profiles compared to fentanyl, with fewer fluctuations during surgery.

Mechanistically, these effects can be traced back to dexmedetomidine's central α2 receptor activity. Bhana et al. [28] described its ability to suppress norepinephrine release, while Jaakola et al. [29] demonstrated direct spinal analgesic action. Hall et al. [30] further highlighted its unique profile of sedation with preserved respiratory function, making it particularly suitable for neuraxial techniques.

Taken together, our findings suggest that the dexmedetomidine–fentanyl combination is not merely additive but strategically complementary—fentanyl accelerates onset and enhances early analgesia, while dexmedetomidine sustains prolonged block and stabilizes hemodynamics. This dual-action profile is particularly advantageous in orthopedic surgeries where both rapid onset and sustained analgesia are desirable.

In summary, the present study not only confirms existing evidence but also demonstrates a quantitatively superior benefit of combination therapy, with faster onset, longer analgesia, and stable hemodynamics. These findings support the growing shift toward multimodal intrathecal adjuvant strategies in contemporary anesthetic practice.

Conclusion

The findings of the present study demonstrate that the addition of fentanyl to intrathecal dexmedetomidine significantly enhances the quality of spinal anesthesia in patients undergoing lower limb orthopedic surgeries. The combination resulted in a faster onset of sensory and motor blockade, with sensory block achieved at 6.6 ± 0.90 minutes versus 8.2 ± 0.97 minutes, and motor block at 7.13 ± 0.80 minutes versus 9.93 ± 0.92 minutes compared to dexmedetomidine alone. More importantly, the duration of postoperative analgesia was markedly prolonged in the combination group (427.3 ± 89.25 minutes vs 265.0 ± 71.27 minutes), representing a clinically meaningful extension of nearly 160 minutes, along with significantly lower postoperative pain scores at all assessed time intervals .

Hemodynamic parameters remained stable in both groups, although the combination group exhibited better early intraoperative control of heart rate and systolic blood pressure, reflecting the beneficial sympatholytic profile of dexmedetomidine without clinically significant adverse effects.

Overall, the dexmedetomidine–fentanyl combination provides a synergistic advantage, offering rapid onset, prolonged analgesia, improved patient comfort, and stable hemodynamics compared to dexmedetomidine alone. This makes it a valuable and effective adjuvant strategy in spinal anesthesia for lower limb orthopedic procedures.

However, given the relatively small sample size and single-center design, further large-scale, multicentric studies with dose optimization are warranted to validate these findings and establish standardized protocols for clinical practice.

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