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Analgesic Efficacy of Fentanyl versus Dexmedetomidine for Postoperative Pain Management Following Posterior Spinal Stabilization Surgery: A Prospective Comparative Study at Dr. Zainoel Abidin General Hospital, Banda Aceh

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Abstract

Background: Posterior spinal stabilization is a major surgical procedure associated with significant postoperative pain. Effective analgesia is essential to prevent excessive physiological stress, hemodynamic instability, and postoperative inflammatory responses. Fentanyl and dexmedetomidine are commonly used analgesics, yet comparative evidence in posterior stabilization surgery remains inconsistent.
Objective: This study aimed to evaluate the effectiveness of both agents in terms of analgesia, hemodynamic stability, and inflammatory biomarkers (NLR, PLR).
Methods: A prospective comparative study was conducted on 16 patients undergoing posterior spinal stabilization at Dr. Zainoel Abidin General Hospital. Patients were allocated into two postoperative analgesia groups: fentanyl (2 mcg/kg bolus followed by 1 mcg/kg/h infusion) and dexmedetomidine (1 mcg/kg bolus followed by 0.4 mcg/kg/h infusion). Pain intensity (NRS), hemodynamics (HR, SBP, DBP, RR, SpO_2), and inflammatory markers (NLR, PLR) were assessed at 2, 6, 12, 24, and 48 hours postoperatively.
Results: Baseline characteristics were comparable between groups ($p > 0.05$). Both groups demonstrated significant reductions in postoperative pain from 2 to 48 hours. No clinically meaningful differences in NRS were found, except at 12 hours ($p = 0.011$), which was not sustained at later time points. Hemodynamic parameters remained stable; differences in diastolic blood pressure at 24 and 48 hours were statistically significant but clinically negligible. NLR and PLR values decreased progressively in both groups, with no significant intergroup differences.
Conclusion: Fentanyl and dexmedetomidine provide comparable analgesic efficacy, hemodynamic stability, and inflammatory modulation in postoperative management following posterior spinal stabilization. Both agents are safe and effective for postoperative analgesia in this setting.

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INTRODUCTION

Postoperative pain is one of the main challenges in patient management after surgery, especially in orthopedic procedures such as posterior stabilization of the spine (Macintyre et al., 2022). Uncontrolled pain not only impacts patient comfort, but can also prolong recovery time, increase the risk of complications, as well as slow down the initial mobilization that is important in postoperative rehabilitation. Based on data from the World Health Organization (WHO), about

80% of patients who undergo surgical procedures experience postoperative pain, with 10 to 20% of them at risk of chronic pain if not managed properly (WHO, 2023) (Park et al., 2023). In Indonesia, a report from the Ministry of Health shows that the incidence of postoperative pain in orthopedic patients, including those undergoing spinal stabilization, ranges from 40 to 60%. This high prevalence underscores the importance of the right approach in postoperative pain management to improve patient clinical outcomes (Suarjaya, 2023).

Beyond immediate discomfort, inadequately controlled postoperative pain directly impairs patient quality of life: it delays early mobilization critical to spinal rehabilitation, prolongs intensive care stay, increases the risk of respiratory complications due to splinting, and significantly elevates the risk of progression to chronic post-surgical pain—a condition affecting 10–20% of surgical patients (Park et al., 2023). Existing analgesic strategies carry important limitations: opioid-based regimens such as fentanyl are effective but associated with dose-dependent respiratory depression, nausea, constipation, and opioid tolerance risk; non-opioid agents offer safer profiles but may be insufficient as monotherapy for the high pain intensity characteristic of posterior spinal procedures. This treatment gap motivates investigation of dexmedetomidine as an opioid-sparing alternative.

Posterior stabilization of the spine is a common surgical procedure performed in patients with vertebral instability due to trauma, degeneration, or other pathological conditions such as spondylolisthesis and vertebral fractures (Inose et al., 2022). This technique aims to improve the structure of the spine to restore mechanical stability and prevent further neurological complications. However, this procedure often causes severe pain resulting from soft tissue trauma, manipulation of nerve structures, and postoperative local inflammation. If pain is not adequately controlled, patients can experience increased physiological stress that impacts blood pressure, heart rate, as well as hormonal balance, all of which can affect the recovery process. Therefore, the selection of effective analgesic modalities is an important aspect in the treatment of postoperative patients of posterior stabilization (N. Liu et al., 2024; Yudianto & Fernanda, 2024).

For the subjective evaluation of postoperative pain intensity, the Numeric Rating Scale (NRS) is used as the primary tool to assess pain intensity. NRS is a simple numerical scale in which patients are asked to rate their pain level on a scale from 0 to 10, where 0 indicates "no pain" and 10 indicates "the worst pain imaginable." This scale is easy for patients to understand and use, and allows for quick and efficient pain measurement (Nugent et al., 2021).

A study by Shafshak (2021) compared NRS with the Visual Analog Scale (VAS) in assessing chronic low back pain. The results showed that both scales had a significant positive correlation ($r = 0.92$, $p < 0.001$) and a high level of agreement. However, NRS is considered more practical because it is easier for patients to use and understand, as well as faster in administration and interpretation of results (Shafshak & Elnemr, 2021). In addition to subjective pain assessment through NRS, evaluation of the body's physiological response to surgical trauma is also important in measuring the effectiveness of analgesic therapy. One of the approaches used is to monitor systemic inflammatory biomarkers such as the Neutrophil-to-Lymphocyte Ratio (NLR) and the Platelet-to-Lymphocyte Ratio (PLR). NLR is calculated as the ratio of neutrophil count to lymphocyte count, while PLR is the ratio of platelet count to lymphocyte count in the peripheral blood. The increase in these two ratios reflects the activation of the immune system and the inflammatory stress that occurs due to the surgical procedure. Rathee (2023) showed that high NLR and PLR values postoperatively correlated with excessive inflammation and uncontrolled pain.

In clinical practice, fentanyl and dexmedetomidine are two analgesic agents that are often used to treat postoperative pain (Ahmed & Khan, 2022; Show et al., 2022). Fentanyl, which belongs to the group of strong opioids, works by binding to μ-opioid receptors in the central nervous system to produce a rapid and potent analgesic effect. The advantage of fentanyl lies in its ability to effectively control acute pain, especially in the early postoperative period. However, long-term opioid use is often associated with a variety of adverse side effects, such as respiratory depression, nausea, vomiting, constipation, and the risk of dependence. Therefore, alternatives or multimodal approaches in pain management are increasingly becoming a concern in the medical world (Cooney & Quinlan-Colwell, 2020; Moharari et al., 2021).

Alternatively, dexmedetomidine has been developed as an analgesic agent that works through a different mechanism. This drug is a selective alpha-2 adrenergic receptor agonist that acts on the central nervous system to reduce pain transmission and produce sedative and anxiolytic effects without causing respiratory depression (Alsultan, 2024; Paul, 2021). The advantage of dexmedetomidine lies in its ability to lower overall opioid needs, reduce the incidence of opioid-related side effects, as well as provide better hemodynamic stability in postoperative patients. The resulting sedative effects can also help patients feel more comfortable without causing excessive sedation that can hinder recovery (X. Liu et al., 2021).

Although fentanyl and dexmedetomidine have been widely used in different types of surgery, the relative effectiveness of both in the context of posterior stabilization of the spine is still a matter of debate. Studies comparing these two agents show mixed results. Kodali (2022) reported that the use of dexmedetomidine can lower postoperative pain scores as well as reduce dependence on opioids compared to fentanyl. However, other studies have also found that fentanyl provides better pain control in the first 24 hours postoperatively, albeit with a higher rate of side effects than dexmedetomidine. These differences in findings suggest that the optimal selection of analgesics should take into account the individual aspects of the patient, the expected level of pain, as well as the side effect profile of each drug (Ding et al., 2021).

The inconsistency in prior comparative findings may reflect differences in study populations, dose regimens, surgical complexity, and outcome measurement time points—all of which vary across existing trials. Critically, no prior study has simultaneously examined NRS pain scores, hemodynamic parameters, and inflammatory biomarkers (NLR, PLR) as integrated outcome domains in a prospective repeated-measures design specifically targeting posterior spinal stabilization. This multiparameter approach constitutes the methodological novelty of the present study and directly addresses the explanatory gap in the existing literature.

Taking into account the challenges in postoperative pain management in patients undergoing posterior stabilization as well as differences in results in previous studies, this study aimed to compare the effectiveness of fentanyl and dexmedetomidine in reducing postoperative pain in patients at Dr. Zainoel Abidin General Hospital, Banda Aceh.

The central research problem this study addresses is: among adult patients undergoing posterior spinal stabilization, does fentanyl or dexmedetomidine produce superior analgesic efficacy, hemodynamic stability, and inflammatory modulation during the 48-hour postoperative period? The findings are expected to provide evidence-based guidance for analgesic agent selection in this specific high-pain surgical context, supporting development of institution-specific postoperative pain management protocols.

METHOD

This study employed a prospective comparative observational design with repeated measures, conducted at the High Care Unit (HCU) of Dr. Zainoel Abidin General Hospital, Banda Aceh, from October 1 to November 15, 2025. The study received ethics approval from the Health Research Ethics Committee of FK Unsyiah and institutional clearance from the Research and Development Division of the hospital.

Study Population and Sampling: The target population comprised adult patients undergoing elective posterior spinal stabilization during the study period. Consecutive sampling was applied, enrolling all patients who met eligibility criteria during the observation window.

Inclusion criteria included (1) adult patients (18–65 years); (2) elective posterior spinal stabilization surgery; (3) ASA physical status I–III; (4) willingness to participate with written informed consent. Exclusion criteria included (1) allergy or contraindication to fentanyl or dexmedetomidine; (2) pre-existing chronic pain requiring opioid therapy; (3) hemodynamic instability at baseline; (4) inability to communicate NRS scores; (5) incomplete data records. A total of 16 patients met all criteria and were enrolled with no dropouts, yielding a final sample of n = 16 (8 per group).

Treatment Groups: Patients were allocated by clinical indication and anesthesiologist's decision to either: Fentanyl group (n = 8): 2 mcg/kg IV bolus postoperatively, followed by continuous infusion at 1 mcg/kg/h; or Dexmedetomidine group (n = 8): 1 mcg/kg IV bolus over 10 minutes, followed by infusion at 0.4 mcg/kg/h.

Operational Definitions: (1) Pain intensity: assessed using the Numeric Rating Scale (NRS,

0–10), a validated tool demonstrated to correlate strongly with VAS ($r = 0.92$, $p < 0.001$) Shafshak (2021), measured at 2, 6, 12, 24, and 48 hours postoperatively. (2) Hemodynamic stability: HR, SBP, DBP, RR, and SpO_2 were recorded at each time point. (3) Inflammatory biomarkers: Neutrophil-to-Lymphocyte Ratio (NLR) and Platelet-to-Lymphocyte Ratio (PLR) measured from blood samples preoperatively and at 24 and 48 hours postoperatively.

Statistical Analysis: Continuous variables were compared using independent t-tests (normally distributed) or Mann-Whitney U tests (non-normally distributed). Categorical variables were analyzed using chi-square or Fisher's exact test. Repeated-measures General Linear Model (GLM) was applied to assess time-by-group interactions across all time points. Levene's test was used to assess variance homogeneity. All analyses were performed using SPSS version [X]; statistical significance was set at $p < 0.05$.

RESULTS AND DISCUSSION

Results

Data collection was carried out from October 1 to November 15, 2025, at the High Care Unit of RSUDZA. The research was conducted after an ethics review by the Health Research Ethics Committee of FK Unsyiah and approval from the Research and Development Division of Dr. Zainoel Abidin Hospital. During this period, there were 16 participants who met the inclusion criteria and were willing to be research subjects. No participants were excluded from this study, so the total sample size was 16. Furthermore, medical record data were collected in the form of characteristic data (gender, age, BMI), hemodynamics, and NRS (pain score) at 2, 6, 12, 24, and 48 hours postoperatively, as well as NLR and PLR values before surgery and at 24 and 48 hours after surgery. The data obtained were then statistically analyzed using SPSS version 25.0.

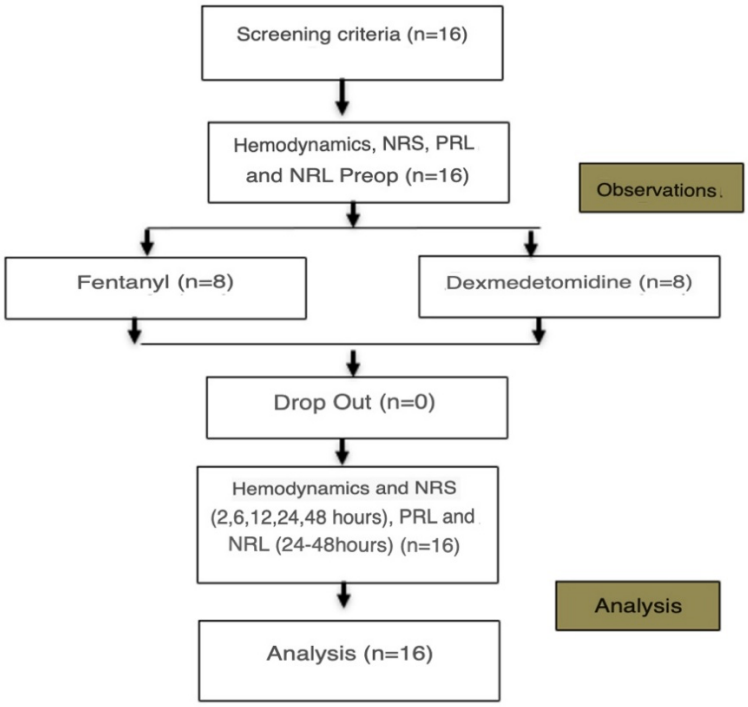

Figure 1. Research Flow Diagram (Consort diagram)

Research Subject

The characteristics of the research subjects in this study include age, sex, weight, height and nutritional status data contained in table 1.

Table 1. Characteristics of Research Subjects

Characteristics	Dexmedetomidine (n=8)		Fentanyl (n=8)		P Value
	n	%	n	%	
Age(mean±SD), Year	44.13 ± 13.38		49.64 ± 16.23		0.986b
Gender, n(%)					0.392a
Male- Male	6	75%	4	50%	
Women	2	25%	4	50%	
Weight	59.35 ± 11.51		65.96 ± 21.80		0.461b
Height	161.63 ± 12.28		164.88 ± 9.99		0.571b
Nutritional Status					0.343a
Underweight	1	12.5%	2	25.0%	
Normoweight	6	75.0%	3	37.5%	
Overweight	1	12.5%	1	12.5%	
Obesity I	0	0%	3	25.0%	

aChi-Square test bUnpaired t test

The average age in the dexmedetomidine group was 44.13 ± 13.38 years, while in the fentanyl group it was 44.00 ± 15.03 years. The p-value of the independent t-test results was 0.986, indicating no significant difference between the two groups. Age homogeneity suggests that potential differences in pain perception, inflammation, or physiological responses between groups are not caused by age factors, so the comparison of the analgesic effects of the two drugs is more valid. Theoretically, age affects nociceptor sensitivity, the function of nociceptive A-delta and C fibers, and pain modulation capacity in the descending pathway. Older individuals tend to have a higher inflammatory response due to decreased lymphocyte activity and increased neutrophils (inflammaging) — conditions that can increase NLR and PLR postoperatively. In adults of productive age, as in this study, the inflammatory response was relatively stable, so the differences in NLR/PLR between groups were more reflective of the analgesic effects of the drug than the effects of age. With equivalent age, this study is free from age bias on pain intensity and inflammatory biomarkers.

The sex distribution in the dexmedetomidine group consisted of 6 males (75%) and 2 females (25%). In the fentanyl group, the composition was 4 males (50%) and 4 females (50%). The Chi-square test yielded a p-value of 0.302, so there was no significant difference between the two groups. In theory, gender can affect pain thresholds, analgesic tolerance, and inflammatory responses. The hormones estrogen and progesterone can increase nociceptive sensitization. Women have lower pain thresholds in various studies.

Activation of the sympathetic nervous system during pain is more pronounced in men, thus affecting hemodynamic parameters such as heart rate and postoperative blood pressure. Fentanyl and dexmedetomidine exert their effects through opioid receptors and alpha-2 adrenergic receptors, respectively, the distribution of which can differ between males and females. Because the sex distribution is homogeneous, the interpretation of the analgesic effects of the two drugs is not influenced by hormonal variability or gender-based stress responses, so sex is not a confounding factor in assessing the effects of the two drugs.

The average body weight in the dexmedetomidine group was 59.35 ± 11.51 kg, while in the fentanyl group it was 65.96 ± 21.80 kg. The p-value of 0.461 shows that there is no significant difference. Body weight equivalence is important in drug pharmacokinetics because it affects the volume of distribution and elimination. With no significant difference in weight, the drug response between the two groups was ensured not to be affected by weight differences.

The average height of the dexmedetomidine group was 161.63 ± 12.28 cm, while in the fentanyl group it was 164.88 ± 9.99 cm. The p-value of 0.571 shows no significant difference. Height differences can affect physiological and metabolic parameters, but in this study, height was relatively homogeneous so that the validity of the comparison of the two drugs was maintained.

The distribution of Body Mass Index (BMI) in the two study groups showed different but not statistically significant variations. In the dexmedetomidine group, most patients were in the normal-weight category, which was 6 out of 8 patients (75%), followed by the underweight and overweight categories of 1 patient each (12.5%). There were no patients with Class I obesity in

this group. In the fentanyl group, the distribution pattern was more varied: 2 patients were underweight (25%), 3 patients were normal weight (37.5%), 1 patient was overweight (12.5%), and 2 patients had Class I obesity (25%).

Although there were differences in proportions between groups, especially in the normal-weight and obesity categories, statistical analysis using the Chi-square test showed a value of p = 0.343, which means that there was no significant difference between the categorical BMI distribution in the dexmedetomidine and fentanyl groups. Thus, the BMI characteristics can be considered homogeneous between the two groups and do not affect the comparison of analgesic effectiveness or the physiological response of the two drugs in this study.

Comparison of Hemodynamic Response, NRS, and Supporting Examinations (PLR and NLR) Following Administration of Dexmedetomidine and Fentanyl

In this study, a comparison of 2 drug groups (dexmedetomidine and fentanyl) was carried out across several variables. The researchers analyzed the changes in hemodynamics in each patient at 2, 6, 12, 24, and 48 hours after treatment in the High Care Unit (HCU), assessed the NRS (Numeric Rating Scale) pain score as a variable evaluating the effectiveness of both drug groups for analgesia, and also examined whether these two drug groups could reduce the inflammatory response at 24 and 48 hours post-administration.

RR Vital Sign Assessment of Dexmedetomidine and Fentanyl

Table 2. Comparison of Dexmedetomidine and Fenthanyl Against RR

	Dexmedetomidine	**Fentanyl**	**p Value**
RR 2 hour post OP	16.05 ± 1.67	16.87 ± 1.70	0.755
RR 6 hour post OP	15.54 ± 2.33	16.80 ± 2.44	0.970
RR 12 hour post OP	4.75 ± 3.30	16.08 ± 2.81	0.475
RR 24 hours post OP	16.20 ± 2.71	4.77 ± 3.40	0.442
RR 48 hours Post OP	16.41 ± 2.88	15.79 ± 2.65	0.587

RR values in both groups remained stable within the range of 15–17 breaths/minute across all time points. No statistically significant between-group differences were observed (p > 0.05 at all time points), indicating that neither fentanyl nor dexmedetomidine caused clinically meaningful respiratory rate changes in this population at the doses used.

a. Comparative trend of Respiratory rate of dexmedetomidine and Fentanyl groups

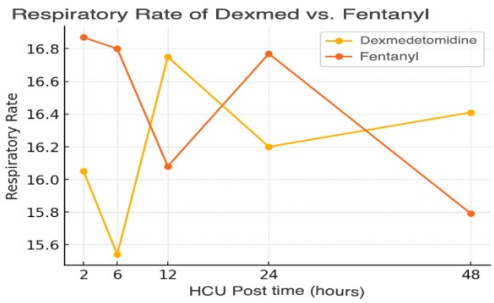

Figure 2. Comparative trend of Resporatoy rate of dexmedetomdin and Fenthanyl groups

RR remained relatively stable at 15–17 breaths/min, with no clinically significant differences between groups. SpO_2 remained high (>97%) throughout most of the monitoring period, indicating no severe respiratory depression in this population; small differences at 24 hours (Levene's p = 0.017) were not accompanied by a significant mean difference in GLM. This is consistent with the literature suggesting that fentanyl may decrease ventilation, but at the dose and setting of this study did not cause meaningful oxygenation depression. Dexmedetomidine provides sedation without severe respiratory depression.

Spo2 Vital Signs Assessment against Dexmedetomidine and Fentanyl

Table 3. Comparison of Dexmedetomidine and Fentanyl Against Spo2

	Dexmedetomidine	Fentanyl	p Value
TDS 2 hours post OP	126.96 ± 6.83	120.34 ± 10.84	0.149
TDS 6 hours post OP	121.47 ± 10.69	111.80 ± 11.62	0.580
TDS 12 hours post OP	119.65 ± 7.95	112.22 ± 12.40	0.354
TDS 24 hours post OP	125.69 ± 10.46	116.60 ± 12.79	0.377
TDS 48 hours Post OP	129.05 ± 6.72	121.31 ± 12.63	0.099

In Table 3, it was found that the 3-hour time variables with a p-value > 0.05 showed that oxygen saturation did not differ significantly between the two drug groups. Analysis showed that at the 24–48-hour phase there was a difference in the two drugs in saturation values, which reflected that fentanyl slightly lowered oxygen saturation at 24–48 hours of administration. Fentanyl may decrease ventilation, but at the dosage and setting of this study did not cause significant respiratory depression; dexmedetomidine provided sedation without severe respiratory depression.

a. Comparison trend of Spo2 groups of dexmedetomdin and Fenthanyl

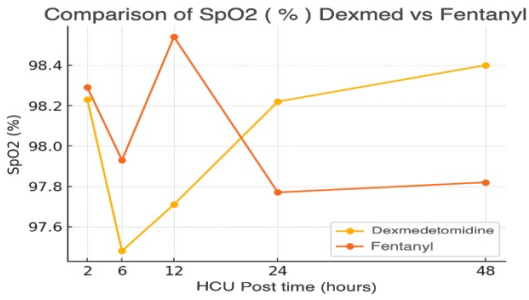

Figure 3. Comparison trend of Spo2 groups of dexmedetomdin and Fenthanyl

SpO_2 remained high (>97%) for most of the monitoring period, indicating no severe respiratory depression in this population; small differences at 24 hours (Levene's p = 0.017) were not accompanied by a significant mean difference in the GLM. This is consistent with the literature indicating that fentanyl may decrease ventilation but, at the dosage and setting of this study, did not cause meaningful oxygen desaturation; dexmedetomidine provides sedation without severe respiratory depression.

Comparison of Dexmedetomidine and Fentanyl Against HR

Table 4. Comparison of Dexmedetomidine and Fentanyl Against HR

	Dexmedetomidine	Fentanyl	p Value
HR 2 hours post OP	80.09 ± 7.53	77.52 ± 12.30	0.010
HR 6 hours post OP	70.05 ± 9.99	66.33 ± 17.67	0.121
HR 12 hours post OP	72.75 ± 9.10	70.93 ± 14.46	0.150
HR 24 hours post OP	79.04 ± 12.75	79.80 ± 11.64	0.944
HR 48 hours Post OP	79.47 ± 12.01	77.19 ± 11.15	0.546

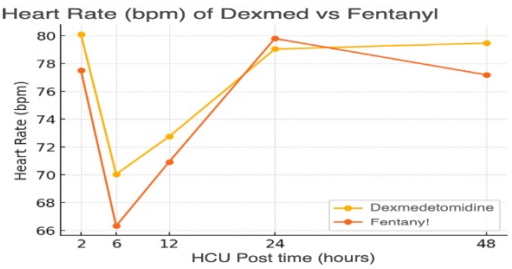

Figure 4. Comparison of Dexmedetomidine and Fentanyl Against HR

Table 4 and Figure 4 explain that there was a difference in the first 2–12 hours in the two groups of drugs, but again there was no difference in the 24–48 hours after administration. HR decreases in the early hours (the peak of the decline is seen around 6–12 hours) and then increases again in 24–48 hours. Both groups showed a similar pattern; Levene's test shows the heterogeneity of variance at 2 hours, so the interpretation at each time point must be careful. The initial decrease in HR over a period of 6–12 hours may be related to the effects of perioperative sedatives/analgesics, as well as a reduction in acute pain stimuli.

Dexmedetomidine theoretically lowers HR more due to the effects of central bradycardia. Fentanyl can lower HR through an analgesic effect that suppresses the stress response. However, these data showed that the HR patterns of the two groups were very similar, giving the impression that at the study doses, the difference in the effects of bradycardia was not large enough to produce a statistical difference, consistent with the theory that the hemodynamic effects of the two agents are "dose-dependent" and close to each other in the mild–moderate regimen.

Comparison of Dexmedetomidine and Fentanyl Against Blood Pressure

Table 5. Comparison of Dexmedetomidine and Fentanyl Against TDS and TDD

	Dexmedetomidine	**Fentanyl**	p Value
TDS 2 hours post OP	126.96 ± 6.83	120.34 ± 10.84	0.149
TDS 6 hours post OP	121.47 ± 10.69	111.80 ± 11.62	0.580
TDS 12 hours post OP	119.65 ± 7.95	112.22 ± 12.40	0.354
TDS 24 hours post OP	125.69 ± 10.46	116.60 ± 12.79	0.377
TDS 48 hours Post OP	129.05 ± 6.72	121.31 ± 12.63	0.099

Table 6. Comparison of Dexmedetomidine and Fentanyl Against TDD

	Dexmedetomidine	**Fentanyl**	p Value
TDD 2 hours post OP	77.73 ± 5.44	79.47 ± 5.49	0.939
TDD 6 hours post OP	76.63 ± 8.12	77.30 ± 8.66	0.650
TDD 12 hours post OP	74.72 ± 7.29	75.76 ± 7.88	0.709
TDD 24 hours post OP	74.70 ± 5.57	79.31 ± 11.89	0.004
TDD 48 hours Post OP	76.57 ± 8.33	79.09 ± 4.18	0.007

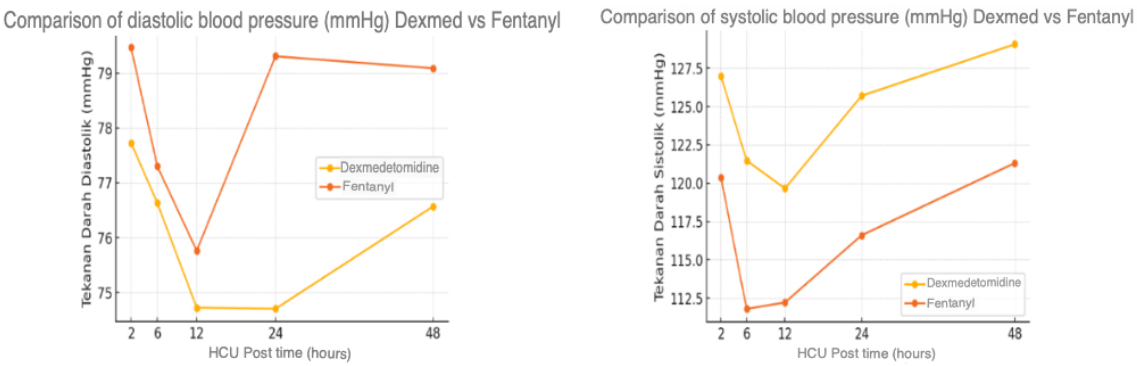

Figure 5. Comparison of Dexmedetomidine and Fenthanyl Against Blood Pressure

Tables 5 and 6 and Figure 5 explain that hemodynamic values (TDS and TDD) fluctuated throughout the postoperative HCU treatment period in both groups. TDS values in the dexmedetomidine group tended to be slightly higher at almost all measurement time points than in the fentanyl group (e.g., 2-hour TDS: 126.96 vs. 122.74 mmHg; 48 hours: 129.05 vs. 123.85 mmHg). Although this numerical difference appears to be consistent, the GLM test showed no mean difference between groups (p = 0.621) and no meaningful time×group interaction, indicating that the difference was not statistically significant.

The data showed that both agents produced similar hemodynamic stability, consistent with the hemodynamic theory of the research proposal. Dexmedetomidine has a sympathoinhibitory effect that can decrease noradrenergic activity, thereby lowering TDS; however, a transient increase in blood pressure may occur due to peripheral α2B-adrenergic receptor-mediated vasoconstriction at the beginning of administration. Fentanyl, acting as an opioid agonist, can lower the stress response and reduce TDS slightly without extensive fluctuations. Differences in actual hemodynamic effects between groups did not appear significant; the observed variation likely stems from patient heterogeneity and postoperative physiological responses.

Comparison of Dexmedetomidine and Fentanyl Against NRS

Table 7. Comparison of Dexmedetomidine and Fentanyl Against NRS

	Dexmedetomidine	**Fentanyl**	p Value
NRS 2 hours post OP	2.45 ± 0.52	2.22 ± 0.83	0.120
NRS 6 hours post OP	2.36 ± 0.67	2.00 ± 1.12	0.148
NRS 12 hour post OP	2.45 ± 0.52	1.89 ± 1.27	0.011
NRS 24 hour post OP	2.27 ± 0.65	1.67 ± 0.87	0.470
NRS 48 hours Post OP	0.91 ± 0.83	0.56 ± 0.73	0.810

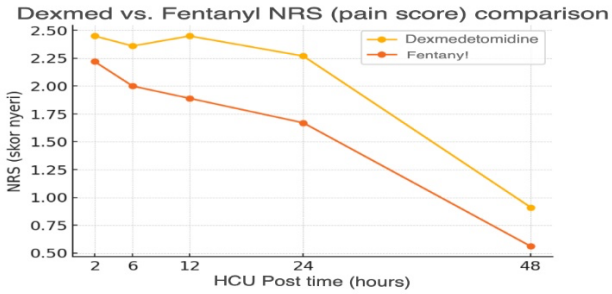

Figure 6. Comparison of Dexmedetomidine and Fentanyl Against NRS

In Table 7 and Figure 6, the average NRS decreased in both groups from hour to hour; in all NRS measurements, the mean value was relatively low (≤ 2.5) and reached <1 at 48 hours, indicating good pain control. GLM did not show a significant time × group interaction, indicating that the two agents provided statistically similar pain control in posterior spinal stabilization patients in this setting. Clinically, the numerical difference in the NRS was slightly lower in the fentanyl group at certain time points, but it was inconsistent and insignificant. According to the reference in Chapter 2 of this study, fentanyl was fast in acute analgesia, whereas dexmedetomidine provided analgesia and an opioid-sparing effect; at the final 48-hour measure, both gave comparable results.

Table 8. Comparison of Dexmedetomidine and Fentanyl Against NRL

	Dexmedetomidine	**Fentanyl**	p Value
NRL PRE OP	2.68 ± 0.40	3.06 ± 0.45	0.402
NRL 24 hour post OP	2.11 ± 0.73	2.85 ± 0.89	0.756
NRL 48 hours post OP	1.95 ± 0.68	2.33 ± 0.87	0.730

Table 9. Comparison of Dexmedetomidine and Fentanyl Against PRL

	Dexmedetomidine	Fentanyl	p Value
PRL PRE ON	133.45 ± 27.02	131.11 ± 19.50	0.708
PRL 24 hours post OP	124.55 ± 33.54	121.00 ± 25.67	0.353
PRL 48 hours post OP	117.73 ± 33.60	115.44 ± 28.60	0.562

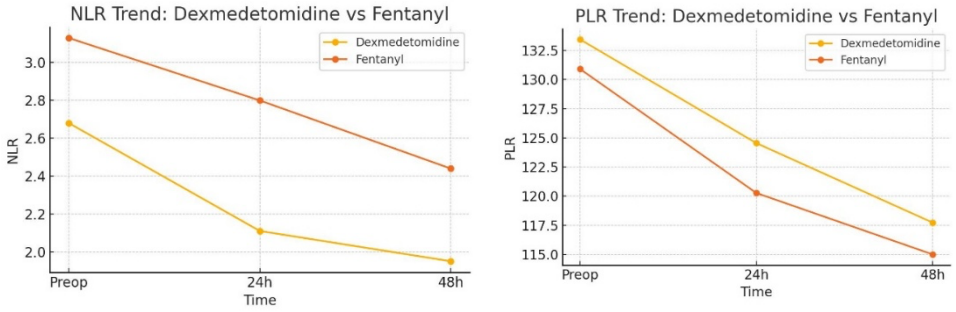

Figure 7. Comparison of Dexmedetomidine and Fentanyl Against NRL

Tables 8 and 9 and Figure 7, the two biomarkers (NLR and PLR) show a decrease from preop to 24 and 48 hours in both groups. Numerically, the dexmedetomidine group started with a slightly lower NLR (2.68 vs. 3.13 at preop) and continued decreasing until 48 hours (1.95), while fentanyl also decreased (from 3.13 preop to 2.80 at 24 hours, and further to 2.44 at 48 hours). GLMs did not show meaningful time × group interactions for NLR/PLR, meaning that both groups showed decreased NLR/PLR over time after surgery, and the differences between agents were not statistically significant. This is consistent, as dexmedetomidine has immunomodulatory effects (suppressing IL-6, TNF-α), so it is hypothesized to lower NLR/PLR, while fentanyl, through pain control, also lowers inflammatory stress. In these data, a reduction in inflammation was seen in both groups with similar effects. Both groups experienced a physiologically significant decrease in PLR, although not statistically significant. There was no difference between groups ($p > 0.05$). This indicates that both drugs can suppress postoperative inflammation and improve immune homeostasis.

Discussion

Side Effects of Research

The finding of equivalent analgesic efficacy between fentanyl and dexmedetomidine at most time points is broadly consistent with the literature on non-spinal surgical contexts. Ding (2021) found dexmedetomidine combined with butorphanol provided effective pain control in burn patients, supporting dexmedetomidine's analgesic versatility. However, our finding contrasts with Kodali (2022), who reported superior postoperative pain reduction with dexmedetomidine versus opioid-based regimens in cardiac surgery—differences likely attributable to distinct surgical trauma magnitudes and patient populations. The transient NRS difference at 12 hours ($p = 0.011$) favoring fentanyl is consistent with fentanyl's established superiority in acute pain control within the first 12–24 hours postoperatively Moharari (2021), reflecting its faster onset and potent μ-opioid receptor activity.

The attenuation of this advantage by 24–48 hours may reflect dexmedetomidine's sustained α-2 agonist modulation of pain transmission pathways Zhao (2020); Liu (2021), producing equivalent long-term analgesia through a different mechanistic route. The comparable NLR and PLR trajectories in both groups align with Wang (2019) and Xu (2022), who found that dexmedetomidine attenuates perioperative inflammatory responses—suggesting that in this sample, both drugs suppressed the inflammatory cascade to a similar degree, possibly because the surgical trauma magnitude was within the capacity of both agents to modulate.

Based on the overall results, the two drugs—fentanyl and dexmedetomidine—did not cause clinically significant side effects in patients undergoing posterior stabilization. All observed effects were minimal, predictable from the mechanisms of the drugs, and remained within physiological limits. As such, both can be considered safe to use in postoperative analgesia with

standard monitoring. RR values in both groups remained in the range of 15–17 times/minute with $p > 0.05$, indicating no respiratory depression with either drug. Fentanyl, which in theory has the potential to cause respiratory depression, did not show this at the study dose. Meanwhile, dexmedetomidine is known not to cause respiratory depression, and these findings are consistent with the literature.

Oxygen saturation remained >97% at almost the entire observation time. A small difference at 24 hours ($p = 0.036$) in the fentanyl group was visible, but had no clinical significance because it was not persistent and remained within normal limits. This indicates the respiratory safety of both agents in the context of postoperative analgesia. Dexmedetomidine can theoretically cause bradycardia and hypotension, while fentanyl can decrease the stress response. However, in this study, the HR of the two groups decreased slightly at 6–12 hours and then stabilized, with no significant difference ($p > 0.05$). SBP did not differ significantly between groups ($p > 0.05$). DBP differed at 24 and 48 hours ($p < 0.05$), but remained within the physiological range and showed no adverse clinical effects. Consistent decreases in NLR and PLR in both groups indicated the absence of drug-induced increases in systemic inflammation. Dexmedetomidine, which has immunomodulatory potential, and fentanyl, through its analgesic effects, both reduce inflammatory stress with equal effectiveness.

It is important to distinguish between statistical significance ($p < 0.05$ in group comparisons) and clinical significance (a difference large enough to affect patient outcomes or management decisions). In this study, while some hemodynamic parameters showed statistically significant between-group differences at specific time points, the absolute magnitude of these differences remained within physiological limits and did not necessitate clinical intervention in any patient. This distinction—statistical vs. clinical significance—applies throughout the interpretation of hemodynamic findings in this paper.

This study has several limitations that need to be considered in the interpretation of the results. First, a relatively small sample size, covering only patients undergoing posterior stabilization during the study period, may limit the power of statistical analysis as well as the generalizability of findings to a wider population. The variability of clinical characteristics between patients also has the potential to affect outcomes, even though controls were implemented through inclusion and exclusion criteria.

Second, this study used a comparative observational design, so the potential for selection bias cannot be completely avoided. Differences in patients' baseline conditions, including comorbid factors, initial inflammatory status, and intraoperative and postoperative supplemental drug use, have the potential to affect pain response and inflammatory biomarkers.

Third, pain intensity was assessed using the NRS (0–10), a validated and widely used tool with demonstrated reliability in surgical populations. Nugent (2021) confirmed that NRS scores collected during routine care correlate strongly with research-administered patient-reported outcomes, while Shafshak (2021) established high agreement between NRS and VAS ($r = 0.92$, $p < 0.001$). Despite this validation, NRS remains inherently subjective and dependent on patient communication—factors including psychological state, anxiety, and prior pain experiences can introduce inter-subject variability that objective measures cannot fully capture.

Fourth, the inflammatory parameters used, namely NLR and PLR, are non-specific biomarkers that can be influenced by various factors such as subclinical infections, metabolic stress, hematological disorders, and the use of certain medications. This has the potential to lower the accuracy of the interpretation of the direct relationship between postoperative pain and NLR/PLR changes.

Fifth, this study did not evaluate other parameters that are also important in postoperative pain management, such as quantitative consumption of additional analgesics, sleep quality, duration of mobilization, and long-term functional outcomes. The evaluation focused only on the initial postoperative period and did not describe the long-term effects of fentanyl or dexmedetomidine use.

Sixth, variations in surgical techniques and operator experience in posterior stabilization can be confounding factors that cannot be completely controlled, given the variability in the duration of surgery, blood loss, and degree of tissue manipulation.

Taking these limitations into account, the results of this study provide an important preliminary picture of the comparative effectiveness of fentanyl and dexmedetomidine in postoperative pain following posterior stabilization, but further research with stronger study designs and larger sample sizes is needed.

CONCLUSION

This prospective comparative study evaluated fentanyl and dexmedetomidine across three integrated outcome domains—analgesic efficacy, hemodynamic stability, and inflammatory modulation—in 16 patients undergoing posterior spinal stabilization. Across 48 hours of postoperative monitoring, both agents produced progressive NRS reduction and maintained hemodynamic parameters within physiological limits. The only statistically significant between-group NRS difference emerged at 12 hours ($p = 0.011$), marginally favoring fentanyl, but was not sustained at 24 or 48 hours—indicating equivalent long-term analgesic outcomes. NLR and PLR decreased comparably in both groups ($p > 0.05$), confirming that neither agent demonstrated superior inflammatory modulation. Hemodynamic differences, though statistically significant at isolated time points for DBP, remained within clinically acceptable limits without necessitating intervention.

The clinical differentiation between these agents lies in their mechanistic profiles rather than efficacy outcomes: fentanyl provides faster μ-opioid receptor-mediated analgesia, particularly advantageous in the early postoperative period, while dexmedetomidine offers equivalent sustained analgesia through α2-agonism without opioid-related respiratory depression risk—an important safety advantage in patients with marginal respiratory reserve. Both agents demonstrated acceptable safety profiles with no clinically significant adverse events. In conclusion, fentanyl and dexmedetomidine are equivalent, safe analgesic options for postoperative pain management following posterior spinal stabilization. Agent selection may be appropriately individualized based on patient respiratory risk profile, sedation requirements, and institutional protocol preferences. Future studies with larger samples, randomized allocation, and objective pain measures are warranted to confirm these findings and guide protocol standardization.

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AUTHOR CONTRIBUTION STATEMENT

Tuanku Radhi Sura contributed to the conceptualization of the study, research design, data collection, analysis, and preparation of the original manuscript draft. Eka Adhiany was responsible for methodology development, data validation, and interpretation of the results. Rozi Fadhori contributed to the literature review, critical revision, and editing of the manuscript. All authors have read and approved the final version of the manuscript.

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