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PERIOPERATIVE ANALGESIC EFFICACY OF THE ERECTOR SPINAE PLANE BLOCK WITHIN A MULTIMODAL ANESTHESIA PROTOCOL FOR OPEN THORACOLUMBAR SPINAL FIXATION SURGERY

Dimitrovski A.[1,2], Kuzmanovska B.[1,2], Toleska-Dimitrovska N.[3], Toleska-Doneska M.[4], Treneva-Nichevska M.[1], Gavrilovska Brzanov A.[1]

[1]*University Clinic for Traumatology, Orthopedic Diseases, Anesthesia, Reanimation and Intensive Care and Emergency Center - KARIL Skopje;*

[2]*Medical Faculty, Ss. Cyril and Methodius University, Skopje;*

[3]*University Clinic for Thoracic and Vascular surgery, Skopje, Macedonia;*

[4]*Wilhelmshaven Hospital, Klinikum Wilhelmshaven, Academic Teaching Hospital of the Faculty of Medicine, University of Hamburg, Germany.*

Abstract

Objective: Open thoracolumbar spinal fixation is associated with severe intraoperative and postoperative pain. Opioids are frequently used for perioperative analgesia in these procedures, but their use is associated with adverse effects, such as postoperative nausea and vomiting, sedation, pruritus, urinary retention, respiratory depression, and delayed recovery. Ultrasound-guided regional techniques, incorporated within a multimodal analgesic strategy, may improve perioperative pain control and reduce opioid requirements.

Materials and Methods: This randomized prospective interventional clinical study evaluated the perioperative analgesic effect of bilateral erector spinae plane block (ESPB) as part of multimodal anesthesia compared with opioid-based analgesia in patients undergoing open fixation for thoracic or lumbar vertebral fractures. Seventy patients were randomized into two groups: an opioid group (OG; n=35) and an ESPB with multimodal analgesia group (ESPB+MMA; n=35). Outcomes included intraoperative fentanyl consumption, postoperative tramadol requirements, postoperative Numerical Rating Scale (NRS) pain scores, postoperative nausea and vomiting (PONV), and neurological or psychotomimetic adverse effects.

Results: Patients in the ESPB+MMA group required only induction-dose fentanyl, whereas patients in the OG required 500-1200 mcg of fentanyl intraoperatively. Postoperative tramadol was required in only 4 patients (11.4%) in the ESPB+MMA group, compared with all patients in the OG, where total postoperative tramadol consumption ranged from 100 to 1500 mg. Postoperative pain scores were consistently lower in the ESPB+MMA group during the first 48 hours after surgery. PONV occurred in 14.3% of patients in the ESPB+MMA group and 31.4% of patients in the OG. No ESPB-related complications were recorded.

Conclusion: The combination of ESPB and multimodal analgesia provided effective perioperative analgesia, markedly reduced opioid consumption, lowered the incidence of PONV, and appeared safe in patients undergoing open thoracolumbar spinal fixation.

Keywords: *erector spinae plane block; multimodal analgesia; spine surgery; thoracolumbar fixation; postoperative pain.*

Introduction

Complex spinal procedures, including open spinal fixation, are associated with severe intraoperative and postoperative pain (1,2). Inadequately controlled postoperative pain may delay mobilization, increase the risk of venous thromboembolism, contribute to respiratory and cardiovascular complications, prolong recovery and hospital stay, and reduce patient satisfaction (2,3).

Insufficient treatment of acute postoperative pain is also an important risk factor for the development of chronic postoperative pain, which represents a major long-term burden for patients and healthcare systems (4,5). Opioids remain widely used for pain management in complex spine surgery; however, they are associated with numerous adverse effects, including somnolence, dizziness, postoperative nausea and vomiting, pruritus, urinary retention, respiratory depression, impaired wound healing, wound dehiscence, and short-term central muscle rigidity (4,6). Opioid-related adverse effects may impede enhanced postoperative recovery and prolong hospital stay (7,8).

Potent opioids may also lead to acute tolerance and opioid-induced hyperalgesia, which can paradoxically increase postoperative pain. Hyperalgesia is characterized by an exaggerated response to painful stimuli following opioid exposure and reflects nociceptive hypersensitization (9,10).

Multimodal analgesia combines drugs that act through different mechanisms within the nociceptive system, producing synergistic analgesic effects while reducing the required dose of each individual medication. Agents used in multimodal analgesia include ketamine, paracetamol, lidocaine, magnesium sulfate, dexamethasone and metamizole (11-14). Regional anesthetic techniques, including peripheral nerve and fascial plane blocks, are an important component of multimodal analgesia. Multiple randomized trials, systematic reviews and meta-analyses have shown that ESPB in spine surgery can reduce intraoperative and postoperative opioid consumption, lower postoperative pain scores, decrease PONV and improve patient satisfaction (15-18).

Objectives

The primary objective of this study was to evaluate the effect of ESPB as part of multimodal analgesia, compared with opioid-based anesthesia, on intraoperative and postoperative analgesia in patients undergoing open thoracolumbar spinal fixation.

Secondary objectives were to compare total intraoperative and postoperative opioid consumption, assess postoperative adverse effects including dizziness, diplopia, nystagmus, hallucinations and nightmares, and determine the incidence of PONV in both groups.

Materials and Methods

This was a randomized, prospective, interventional clinical study that included 70 patients scheduled for open thoracic or lumbar spinal fixation. Patients were randomized into two par-

allel groups of 35 patients each.

Eligibility Criteria

Inclusion criteria included hospitalization for open fixation of the thoracic or lumbar spine at two, three or four levels; age between18 and 65; and American Society of Anesthesiologists (ASA) physical status I-III.

Exclusion criteria were based on ASA physical status IV-V; allergy to fentanyl, tramadol, lidocaine, bupivacaine, magnesium sulfate, ketamine, paracetamol or metamizole; chronic use of benzodiazepines or opioids; pregnancy or breastfeeding; chronic pain; cardiac, renal or hepatic insufficiency; and psychiatric disease.

Randomization and Perioperative Protocol

During the preoperative visit, all patients were instructed on the use of the Numerical Rating Scale (NRS) for pain, where 0 indicates no pain and 10 indicates unbearable pain. Randomization was performed using a computer-generated allocation sequence. All patients received standard perioperative monitoring, treatment and care.

General anesthesia was induced according to a standardized protocol using midazolam 0.04 mg/kg for premedication, fentanyl 0.002 mg/kg, propofol 1-2 mg/kg and rocuronium 0.6 mg/kg. Anesthesia was maintained with balanced anesthesia using sevoflurane at approximately 1 MAC, aiming to keep mean arterial pressure within +/-20% of baseline.

Erector Spinae Plane Block

The erector spinae block (ESB) is a relatively simple and safe regional anesthetic technique widely used for perioperative analgesia in various surgical procedures.

Usually, a parasagittal approach is used for the Erector Spine Block, in which the ultrasound probe is placed parallel to the spine, 4-5 centimeters from the spinous processes of the vertebrae. At the lumbar level, a curved probe is typically used, whereas at the thoracic level, either a linear or curved probe may be used.

It is necessary to visualize the tips of the transfer processes. The ultrasound probe may also be positioned transversely over the spinous processes. After identifying the spinal processes, the probe is moved laterally by approximately 3-5 cm, in which the lamina and transverse processes are visualized.

After appropriate ultrasound-guided visualization of the transfer processes, most often in a cranio-caudal direction, or vice versa, a 10-centimeter hyperechoic needle is placed with the aim of touching the tip of the process. Then the needle is withdrawn a few millimeters, after which, following negative aspiration, the local anesthetic is injected and its craniocaudal spread is observed. (27)

Based on clinical studies performed on cadavers, as well as radiological examinations, the mech-1anism of the block's action has been assessed. The effect of the block is made possible through the spread of the local anesthetic, and its diffusion to the ventral and dorsal branches of the spinal nerves. The spinal nerves are in the anatomical space between the sheath of the erector

spinae muscle and the surrounding tissue compartments (27-28).

Study Groups

Patients in the opioid group (OG; n=35) received intermittent fentanyl for intraoperative analgesia.

Patients in the ESPB with multimodal analgesia group (ESPB+MMA; n=35) received bilateral ultrasound-guided ESPB after prone positioning and radiographic marking. The block was performed with 10 ml lidocaine 1% and 20 ml bupivacaine 0.25% on each side. Before induction, patients received dexamethasone 0.1 mg/kg and paracetamol 1 g. Immediately after intubation, ketamine 0.5 mg/kg was administered intravenously, followed by continuous intravenous magnesium sulfate 1.5 g. If blood pressure or heart rate increased by more than 30% from baseline during surgery in the absence of bleeding, fentanyl 50 mcg was administered.

Postoperative Management and Follow-up

Patients in the OG received metamizole 2 g every 12 hours and paracetamol 1 g every 8 hours for postoperative analgesia. Patients in the ESPB+MMA group received ketamine 0.1 mg/kg/hour as a continuous intravenous infusion for 48 hours, metamizole 2 g every 12 hours, paracetamol 1 g every 8 hours, and dexamethasone 8 mg daily for 3 days, followed by 4 mg daily for an additional 3 days. Postoperative pain was assessed using the NRS at 1, 4, 8, 12, 24, 36 and 48 hours after surgery. Tramadol 100 mg was administered as rescue analgesia when the NRS score exceeded 7. The following outcomes were monitored by the nurses from the Post Anesthesia Care Unit and the Traumatology Department, who did not know which patient belongs to which group. The following parameters were measured and recorded: pain at rest using NRS, total intraoperative and postoperative opioid consumption, PONV, and the postoperative occurrence of nystagmus, dizziness, diplopia, illusions and hallucinations.

Results

The study included 70 patients with thoracic or lumbar vertebral fractures scheduled for open spinal fixation. Patients were divided into the OG (n=35) and ESPB+MMA group (n=35). In the ESPB+MMA group, 23 patients (65.7%) were men and 12 (34.3%) were women; mean age was 51.2+/-11.7 years, and mean BMI was 28.4+/-2.8 kg/m2.

In the OG, 25 patients (71.4%) were men and 10 (28.6%) were women; mean age was 44.6+/-10.5 years, and mean BMI was 27.0+/-2.0 kg/m2. Mean duration of surgery was 182.6+/-23.8 minutes in the ESPB+MMA group and 192.9+/-42.6 minutes in the OG; the difference was not statistically significant ($p>0.05$).

Intraoperative Fentanyl Consumption

All patients in the ESPB+MMA group received only the induction dose of fentanyl and required no additional intraoperative fentanyl. In the OG, total intraoperative fentanyl consumption ranged from 500 to 1200 mcg (Table 1).

Table 1. Total intraoperative fentanyl consumption in the opioid group

Fentanyl dose (mcg)	Number of patients	%
500	1	2.9
700	2	5.7
800	7	20.0
900	9	25.7
1000	12	34.3
1100	2	5.7
1200	2	5.7

Level of Fixation

The most frequent level of fixation was L1 in both groups, followed by L2 and Th12 (Table 2)

Table 2. Level of fixation by study group

Level of fixation	ESPB+MMA n	ESPB+MMA %	OG n	OG %
L1	16	45.7	12	34.3
Th11	3	8.6	1	2.8
L2	8	22.9	11	31.4
Th12	7	20.0	5	14.3
L4	1	2.8	4	11.4
Th8	0	0.0	1	2.8

Postoperative Tramadol Consumption

In the ESPB+MMA group, postoperative tramadol was administered to 4 patients (11.4%): 3 patients received 100 mg and 1 patient received 200 mg. In the OG, all patients required postoperative tramadol, with total doses ranging from 100 to 1500 mg. The most common postoperative tramadol doses in the OG were 400 mg and 500 mg, each administered to 8 patients (22.9%) (Table 3).

Table 3. Total postoperative tramadol consumption

Tramadol dose (mg)	ESPB+MMA n	ESPB+MMA %	OG n	OG %
100	3	75.0	3	8.6
200	1	25.0	0	0.0
300	0	0.0	4	11.4
400	0	0.0	8	22.9
500	0	0.0	8	22.9

Tramadol dose (mg)	ESPB+MMA n	ESPB+MMA %	OG n	OG %
600	0	0.0	1	2.9
700	0	0.0	3	8.6
900	0	0.0	2	5.7
1000	0	0.0	1	2.9
1100	0	0.0	1	2.9
1200	0	0.0	2	5.7
1300	0	0.0	1	2.9
1500	0	0.0	1	2.9

Postoperative Pain Scores

Postoperative pain at rest was assessed using the NRS at 1, 4, 8, 12, 24, 36 and 48 hours after surgery. In the ESPB+MMA group, NRS scores ranged from 0 to 8, with an NRS score of 8 recorded in only one patient at 12 hours. An NRS score of 7 was recorded in four patients: one at 1 hour, two at 8 hours and one at 12 hours. In the OG, NRS scores ranged from 3 to 9. NRS 7 was recorded in 45.7% of patients at 1 hour, 57.1% at 4 hours, 60.0% at 8 hours, 22.9% at 12 hours and 14.3% at 24 hours. NRS 8 was recorded in 17.1% at 1 hour, 34.3% at 4 hours, 28.6% at 8 hours and 11.4% at 12 hours (Tables 4a and 4b).

Table 4a. Postoperative NRS pain scores in the ESPB+MMA group

NRS score	1 h n (%)	4 h n (%)	8 h n (%)	12 h n (%)	24 h n (%)	36 h n (%)	48 h n (%)
0	6 (17.1)	1 (2.9)	2 (5.7)	1 (2.9)	1 (2.9)		
1	1 (2.9)	4 (11.4)	1 (2.9)	1 (2.9)	3 (8.6)	6 (17.1)	8 (22.9)
2	4 (11.4)	4 (11.4)	3 (8.6)	3 (8.6)	10 (28.6)	10 (28.6)	7 (20.0)
3	8 (22.9)	11 (31.4)	12 (34.3)	16 (45.7)	12 (34.3)	12 (34.3)	14 (40.0)
4	8 (22.9)	14 (40.0)	11 (31.4)	8 (22.9)	9 (25.7)	6 (17.1)	4 (11.4)
5	5 (14.3)	3 (8.6)	5 (14.3)	2 (5.7)	1 (2.9)	1 (2.9)	
6	3 (8.6)	1 (2.9)	1 (2.9)				
7	1 (2.9)		2 (5.7)	1 (2.9)			
8				1 (2.9)			

Table 4b. Postoperative NRS pain scores in the opioid group

NRS score	1 h n (%)	4 h n (%)	8 h n (%)	12 h n (%)	24 h n (%)	36 h n (%)	48 h n (%)
3							5 (14.3)
4	1 (2.9)				4 (11.4)	13 (37.1)	17 (48.6)
5	1 (2.9)	2 (5.7)	6 (17.1)	15 (42.9)	16 (45.7)	11 (31.4)	

NRS score	1 h n (%)	4 h n (%)	8 h n (%)	12 h n (%)	24 h n (%)	36 h n (%)	48 h n (%)
6	11 (31.4)	3 (8.6)	1 (2.9)	17 (48.6)	11 (31.4)	6 (17.1)	2 (5.7)
7	16 (45.7)	20 (57.1)	21 (60.0)	8 (22.9)	5 (14.3)		
8	6 (17.1)	12 (34.3)	10 (28.6)	4 (11.4)			
9			1 (2.9)				

Postoperative Adverse Effects

PONV was observed in 5 patients (14.3%) in the ESPB+MMA group and in 11 patients (31.4%) in the OG (difference test, p=0.0884). Nystagmus or vertigo occurred in 3 patients (8.6%) in the ESPB+MMA group and was transient. No cases of nystagmus or vertigo were recorded in the OG (Table 5). No complications related to ESPB were recorded.

Table 5. Postoperative nausea and vomiting, and nystagmus/vertigo

Adverse effect	ESPB+MMA no n (%)	ESPB+MMA yes n (%)	OG no n (%)	OG yes n (%)
PONV	30 (85.7)	5 (14.3)	24 (68.6)	11 (31.4)
Nystagmus/ vertigo	32 (91.4)	3 (8.6)	35 (100.0)	0 (0.0)

Discussion

This randomized prospective interventional study evaluated the perioperative analgesic effect of bilateral ESPB as part of multimodal anesthesia in patients undergoing open thoracolumbar spinal fixation. The main finding is that the ESPB+MMA strategy reduced the need for intraoperative and postoperative opioids and was associated with lower postoperative pain scores during the first 48 hours after surgery compared with opioid-based analgesia.

In the ESPB+MMA group, patients required only the initial induction dose of fentanyl, and none required additional intraoperative fentanyl. By contrast, patients in the OG required total intraoperative fentanyl doses between 500 and 1200 mcg. The difference in postoperative opioid requirement was also pronounced: only 4 patients in the ESPB+MMA group required rescue tramadol, whereas all patients in the OG required tramadol postoperatively, with doses up to 1500 mg. These findings support the opioid-sparing effect of ESPB when integrated into a structured multimodal analgesic regimen.

The postoperative NRS findings further support the analgesic benefit of the combined ESPB+MMA approach.

In the ESPB+MMA group, severe pain scores were uncommon and transient, with only one patient reaching an NRS score of 8 and four reaching an NRS score of 7 during the observation period. In the OG, severe pain scores were frequent during the early postoperative period, particularly at 1, 4 and 8 hours after surgery. The lower pain intensity in the ESPB+MMA group likely reflects the combined effect of the fascial plane block and systemic multimodal analgesic

agents acting at different levels of nociceptive transmission.

An important methodological point should be emphasized. In the present study, the analgesic effect of ESPB was not evaluated as an isolated intervention because the block was administered as one component of a predefined multimodal analgesic protocol. Therefore, the observed reduction in pain scores and opioid consumption should be interpreted as the effect of the combined ESPB+MMA strategy rather than the independent pharmacodynamic effect of the fascial plane block alone. Nevertheless, the marked difference between groups supports the clinical value of incorporating ESPB into multimodal analgesia for open thoracolumbar fixation.

Although the independent analgesic effect of ESPB could not be isolated in our protocol, several studies in spinal surgery have directly evaluated ESPB as an analgesic intervention. In these studies, ESPB was associated with lower postoperative pain scores, reduced time-dependent opioid consumption, delayed need for rescue analgesia, and lower rates of opioid-related adverse effects. The meta-analysis by Liu et al., which included 19 randomized clinical trials, concluded that ultrasound-guided ESPB provides effective short-term postoperative analgesia in lumbar spine surgery (15). Fu et al. also demonstrated that ESPB is effective and safe for perioperative pain management in lumbar spinal surgery and reduces opioid consumption and opioid-related adverse effects (16).

Similarly, Duan et al. reported that patients receiving ESPB for spinal surgery had lower intraoperative opioid requirements and a lower incidence of PONV (17). Liang et al., in a systematic review and meta-analysis of 12 randomized trials including 696 patients, found that ESPB significantly reduced intraoperative and postoperative opioid consumption, postoperative pain scores, need for additional analgesia, and PONV (18). These findings provide external support for the analgesic contribution of ESPB within the combined protocol used in our study.

In the present study, the incidence of PONV was lower in the ESPB+MMA group than in the OG (14.3% versus 31.4%). Although the difference did not reach conventional statistical significance ($p=0.0884$), the direction of the effect is clinically relevant and consistent with opioid reduction. Lower opioid exposure is a plausible mechanism for reduced PONV, improved patient comfort, and potentially faster postoperative recovery.

Safety is an important consideration when applying regional anesthesia in patients undergoing spine surgery. In this study, no complications related to ESPB were observed. This is consistent with the retrospective analysis by Oezel et al., which included 342 consecutive patients undergoing lumbar spine surgery with ultrasound-guided ESPB and found no procedure-specific ESPB-related complications (19). ESPB is anatomically distant from the neuraxis and major vascular structures, which may contribute to its favorable safety profile when performed under ultrasound guidance by trained practitioners.

The multimodal regimen used in this study included ketamine, paracetamol, lidocaine, magnesium sulfate, dexamethasone and metamizole. Low-dose ketamine is particularly relevant in spine surgery because of its N-methyl-D-aspartate receptor antagonism and its potential to reduce central sensitization, opioid tolerance and opioid-induced hyperalgesia. Jouguelet-Lacoste et al. concluded that low-dose ketamine, administered as a bolus or continuous infusion, reduces opioid requirements and provides effective postoperative analgesia without major complications when used for up to 48 hours postoperatively (20). Zhou et al., in a meta-analysis of 30 randomized trials including 1865 patients undergoing spine surgery, found that perioperative

low-dose ketamine reduced postoperative opioid consumption and pain scores at 24 and 48 hours without increasing adverse effects (21).

Dexamethasone and magnesium sulfate were also relevant components of the multimodal protocol used in our study. Dexamethasone may contribute to postoperative analgesia through anti-inflammatory effects, reduction of tissue edema and inhibition of prostaglandin-mediated nociceptive sensitization, while also reducing PONV. In lumbar spine surgery, Sharma et al. reported that a single preoperative intravenous dose of dexamethasone improved intraoperative and early postoperative analgesia (22). In addition, the meta-analysis by De Oliveira et al. showed that systemic single-dose dexamethasone, particularly at doses above 0.1 mg/kg, reduced postoperative pain and opioid consumption and supported its role as an adjunct within multimodal analgesic strategies (23). In the context of our protocol, dexamethasone may have contributed to opioid sparing and to the lower incidence of PONV observed in the ESPB+MMA group.

Magnesium sulfate acts primarily as an N-methyl-D-aspartate receptor antagonist and calcium-channel modulator. By attenuating central sensitization and reducing excitatory neurotransmission, magnesium may enhance analgesia and reduce opioid requirements when used perioperatively. In an umbrella review, and updated meta-analysis of randomized controlled trials, Choi et al. found that perioperative magnesium generally improved postoperative pain-related outcomes, although the overall certainty of evidence varied and heterogeneity was substantial (24). More specifically for spinal surgery, the systematic review and meta-analysis by Jin and Zhao, including 10 randomized controlled trials with 641 patients, showed that intravenous magnesium sulfate reduced 24-hour postoperative pain scores and opioid consumption without significant hemodynamic differences between groups (25). These data support the use of magnesium sulfate as a rational adjunct in opioid-sparing multimodal analgesia for spine surgery.

Metamizole also contributed to the multimodal analgesic strategy. Korkmaz Dilmen et al. found that intravenous metamizole reduced postoperative pain intensity and morphine consumption after lumbar disc surgery (26). Its analgesic and spasmolytic effects make it a useful component of multimodal analgesia in spinal surgery, particularly when the goal is to reduce opioid exposure.

This study has several limitations. The sample size was relatively small and included patients undergoing fixation for thoracic or lumbar vertebral fractures, which may limit generalizability to other types of elective spine surgery. Another important limitation is that the isolated analgesic effect of ESPB could not be measured separately, because ESPB was combined with several systemic analgesic adjuncts within a multimodal protocol. Therefore, the study demonstrates the clinical effectiveness of the ESPB+MMA strategy rather than the independent effect size of ESPB alone. Long-term follow-up was not performed; therefore, the effect of ESPB+MMA on chronic postoperative pain could not be evaluated. Future studies with larger samples, factorial designs or separate comparator arms are needed to distinguish the individual contribution of ESPB from the effects of ketamine, dexamethasone, magnesium sulfate and other multimodal agents, and to define the optimal components of multimodal analgesic protocols for open spinal fixation.

Conclusion

Bilateral erector spinae plane block combined with multimodal analgesia provided effective intraoperative and postoperative analgesia in patients undergoing open thoracolumbar spinal fixation. Compared with opioid-based analgesia, this strategy reduced intraoperative fentanyl use, lowered

postoperative tramadol requirements, improved postoperative pain scores and was associated with a lower incidence of PONV. No block-related complications were observed. ESPB appears to be a safe and useful component of multimodal anesthesia for open thoracolumbar spinal fixation.

Declarations

Ethics approval and consent to participate: The study was approved by the relevant institutional ethics committee. Approval number and date: 03-2031/9 / 16.04.2024

Informed consent: Written informed consent was obtained from all participants included in the study.

Availability of data and materials: The data supporting the findings of this study are available from the corresponding author upon reasonable request.

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Author contributions: Co-autors contributed to study design, data collection, data analysis, interpretation of results and manuscript preparation.

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References

1. Lamperti M, Tufegdzic B, Avitsian R. Management of complex spine surgery. Curr Opin Anesthesiol. 2017;30:551-556.
2. Mendoza-Elias N, Dunbar M, Ghogawala Z, et al. Opioid use, risk factors, and outcome in lumbar fusion surgery. World Neurosurg. 2020;135:e580-e587. doi:10.1016/j.wneu.2019.12.073.
3. Rajan S, Devarajan J, Krishnaney A, et al. Opioid alternatives in spine surgery: a narrative review. J Neurosurg Anesthesiol. 2022;34(1):3-13. doi:10.1097/ANA.0000000000000708.
4. Armaghani SJ, Lee DS, Bible JE, et al. Increased preoperative narcotic use and its association with postoperative complications and length of hospital stay in patients undergoing spine surgery. Clin Spine Surg. 2016;29:E93-E98.
5. Dunn LK, Yerra S, Fang S, et al. Incidence and risk factors for chronic postoperative opioid use after major spine surgery: a cross-sectional study with longitudinal outcome. Anesth Analg. 2018;127:247-254.

6. Jones MR, Brovman EY, et al. Potential opioid-related adverse events following spine surgery in elderly patients. Clin Neurol Neurosurg. 2019;186.
7. White PF. The changing role of non-opioid analgesic techniques in the management of postoperative pain. Anesth Analg. 2005;101(5S):S5-S22.
8. Kha ST, Scheman J, Davin S, et al. The impact of preoperative chronic opioid therapy in patients undergoing decompression laminectomy of the lumbar spine. Spine (Phila Pa 1976). 2020;45(7):438-443. doi:10.1097/BRS.0000000000003297.
9. Velayudhan A, Bellingham G, Morley-Forster P. Opioid-induced hyperalgesia. Continuing Education in Anaesthesia, Critical Care & Pain. 2013;13:mkt045.
10. White PF. The changing role of non-opioid analgesic techniques in the management of postoperative pain. Anesth Analg. 2005;101(5S):S5-S22.
11. Waelkens P, Alsabbagh E, Sauter A, et al. Pain management after complex spine surgery: a systematic review and procedure-specific postoperative pain management recommendations. Eur J Anaesthesiol. 2021;38(9):985-994. doi:10.1097/EJA.0000000000001448.
12. Walker CT, Gullotti DM, Prendergast V, et al. Implementation of a standardized multimodal postoperative analgesia protocol improves pain control, reduces opioid consumption, and shortens length of hospital stay after posterior lumbar spinal fusion. Neurosurgery. 2020;87(1):130-136. doi:10.1093/neuros/nyz312.
13. Ntalouka MP, Brotis AG, Bareka MV, et al. Multimodal analgesia in spine surgery: an umbrella review. World Neurosurg. 2021;149:129-139. doi:10.1016/j.wneu.2021.02.040
14. Kurd MF, Kreitz T, Schroeder G, et al. The role of multimodal analgesia in spine surgery. J Am Acad Orthop Surg. 2017;25:260-268. doi:10.5435/JAAOS-D-16-00049.
15. Liu H, Zhu J, Wen J, et al. Ultrasound-guided erector spinae plane block for postoperative short-term outcomes in lumbar spine surgery: a meta-analysis and systematic review. Medicine (Baltimore). 2023;102(7):e32981. doi:10.1097/MD.0000000000032981.
16. Fu MY, Hao J, Ye LH, et al. Efficacy and safety of erector spinae plane block for perioperative pain management in lumbar spinal surgery: a systematic review and meta-analysis of randomized controlled trials. J Pain Res. 2023;16:1453-1475. doi:10.2147/JPR.S402931.
17. Duan M, Xu Y, Fu Q. Efficacy of erector spinae nerve block for pain control after spinal surgeries: an updated systematic review and meta-analysis. Front Surg. 2022;9:845125. doi:10.3389/fsurg.2022.845125.
18. Liang X, Zhou W, Fan Y. Erector spinae plane block for spinal surgery: a systematic review and meta-analysis. Korean J Pain. 2021;34(4):487-500. doi:10.3344/kjp.2021.34.4.487.
19. Oezel L, Hughes AP, Onyekwere I, et al. Procedure-specific complications associated with ultrasound-guided erector spinae plane block for lumbar spine surgery: a retrospective analysis of 342 consecutive cases. J Pain Res. 2022;15:655-661. doi:10.2147/JPR.S354111.
20. Jouguelet-Lacoste J, La Colla L, Schilling D, et al. The use of intravenous infusion or single dose of low-dose ketamine for postoperative analgesia: a review of the current literature. Pain Med. 2015;16(2):383-403. doi:10.1111/pme.12619.
21. Zhou L, Yang H, Hai Y, et al. Perioperative low-dose ketamine for postoperative pain management in spine surgery: a systematic review and meta-analysis of randomized controlled

trials. Pain Res Manag. 2022;2022:1507097. doi:10.1155/2022/1507097.

22. Sharma M, Gupta S, Purohit S, et al. The effect of intravenous dexamethasone on intraoperative and early postoperative pain in lumbar spine surgery: a randomized double-blind placebo-controlled study. Anesth Essays Res. 2018;12:803-808.

23. De Oliveira GS Jr, Almeida MD, Benzon HT, et al. Perioperative single-dose systemic dexamethasone for postoperative pain: a meta-analysis of randomized controlled trials. Anesthesiology. 2011;115(3):575-588. doi:10.1097/ALN.0b013e31822a24c2.

24. Choi GJ, Kim YI, Koo YH, Oh H-C, Kang H. Perioperative magnesium for postoperative analgesia: an umbrella review of systematic reviews and updated meta-analysis of randomized controlled trials. J Pers Med. 2021;11(12):1273. doi:10.3390/jpm11121273.

25. Jin Z, Zhao J. Effectiveness and impact of intravenous magnesium sulfate in spinal surgery: systematic review and meta-analysis. Front Pharmacol. 2025;16:1624119. doi:10.3389/fphar.2025.1624119.

26. Korkmaz Dilmen O, Tunali Y, Cakmakkaya OS, et al. Efficacy of intravenous paracetamol, metamizol and lornoxicam on postoperative pain and morphine consumption after lumbar disc surgery. Eur J Anaesthesiol. 2010;27(5):428-432. doi:10.1097/EJA.0b013e32833731a4.