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Systematic Review

Breathe Easier: Evaluating Serratus Anterior Plane Block for Rib Fracture Analgesia-A Systematic Review and Meta-analysis

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ABSTRACT

OBJECTIVE: Rib fractures may cause severe pain that impairs ventilation, increases pulmonary complications, and lengthens hospitalization. Conventional analgesic techniques have several limitations, whereas the serratus anterior plane block (SAPB) offers a simpler, ultrasound-guided regional anesthesia alternative. This systematic review and meta-analysis examined whether SAPB improves pain control and reduces opioid use and hospitalization duration.

MATERIAL AND METHODS: A systematic review and meta-analysis were performed in accordance with Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines. A literature search of PubMed, Scopus, EBSCO, Taylor & Francis, Web of Science, and ScienceDirect was conducted to identify randomized and observational studies comparing SAPB with opioid-based analgesia or other regional blocks in patients with rib fracture pain. The primary outcome was pain severity visual analogue scale/numeric rating scale (VAS/NRS) at predefined time points, whereas opioid consumption and hospital length of stay (LOS) served as secondary outcomes. Given the variability of pain assessment scales across studies (NRS 0-10 and VAS 0-100), continuous outcomes were pooled as standardized mean differences (SMDs) using a random-effects model. Seven studies comprising 611 patients met the inclusion criteria and were included in the analysis.

RESULTS: The meta-analysis showed that baseline pain scores were broadly comparable between SAPB and comparators, with no statistically significant difference overall (baseline SMD: 0.18; $P = 0.25$) or within either subgroup. Compared with opioids, SAPB was associated with significantly lower pain scores at 3 hours (SMD: –0.40; $P = 0.04$) and, in the opioid subgroup, at 12 hours (SMD: –0.44; $P = 0.002$). Overall pooled estimates at 6, 12, and 24 hours did not reach statistical significance owing to substantial heterogeneity (I^2 87–96%). Compared with other regional blocks, SAPB was associated with higher pain scores at 6 hours (SMD: 0.85; $P = 0.004$), whereas the comparison at 24 hours was inconclusive, with the overall estimate not statistically significant (SMD: –0.76; $P = 0.15$). A pooled analysis also showed a significant reduction in opioid consumption with SAPB (SMD: –0.35; 95% confidence interval: –0.67 to –0.02; $P = 0.04$). Findings on hospital LOS were inconsistent across studies and remain inconclusive.

CONCLUSION: Overall, low-certainty evidence suggests that SAPB may provide effective and longer-lasting analgesia, reduce opioid requirements, and support respiratory function, indicating a potential role as an adjunct in the management of rib fracture pain.

KEYWORDS: Rib fractures, serratus anterior plane block, regional anesthesia, opioids, pain management

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INTRODUCTION

Rib fractures are common thoracic injuries, occurring in more than 50% of blunt trauma cases and associated with significant morbidity, long-term disability, and mortality.[1] The annual incidence of rib fractures is estimated at 4–8 per 10,000 individuals in the United Kingdom.[2] The risk of complications increases proportionally with the number of ribs fractured.[1,3] Multiple rib fractures in elderly patients are more likely to require admission to intensive care and are associated with poor clinical outcomes.[4]

Most complications arise not only from structural injury but also from inadequately controlled pain. Severe pain can lead to impaired alveolar ventilation, manifested by shortness of breath or splinting. This impairment further compromises effective coughing, thereby increasing the risk of atelectasis, pneumonia, and even respiratory failure.[5] Therefore, early and adequate analgesic administration is a cornerstone in the management of patients with rib fractures.[6]

Analgesic treatment typically begins with systemic pharmacological therapy administered orally or intravenously, including paracetamol, nonsteroidal anti-inflammatory drugs, and opioids.[6] However, in patients with more severe injuries or certain comorbidities, systemic analgesics may provide inadequate pain control. Although effective, opioids are associated with well-recognized adverse effects, including respiratory depression, sedation, constipation, nausea and vomiting, delirium in elderly patients, and drug dependence.[3] Consequently, interventional techniques and regional anesthesia have emerged as effective alternatives that provide adequate analgesia while reducing opioid-related side effects.[1,3]

Given these considerations, regional techniques, such as the serratus anterior plane block (SAPB), have attracted increasing interest. The SAPB was first described as a regional analgesic technique for patients undergoing breast surgery by Blanco et al.[7] The technique was developed to provide analgesia for the lateral thoracic wall by blockade of the thoracic intercostal nerves and proposed as a simpler and potentially safer alternative to thoracic epidural analgesia (TEA) and paravertebral blockade. Since its introduction, SAPB has been increasingly adopted for other indications, including rib fracture analgesia, due to its ease of performance, favorable safety profile, and feasibility of bedside administration under ultrasound guidance.[7] SAPB, performed by administering local anesthetic into the plane between the serratus anterior muscle and the lateral thoracic wall, effectively blocks the lateral cutaneous branches of the intercostal nerves (T2–T9), resulting in extensive analgesia of the anterolateral chest wall. Additional advantages include the feasibility of catheter placement for continuous local anesthetic infusion and its reported relative safety in patients with coagulopathy.[8,9]

Early studies suggest that SAPB effectively reduces pain scores and opioid consumption and improves respiratory function.[10-12] However, most available evidence is derived from small-scale studies with heterogeneous designs, and the comparative effectiveness of SAPB versus systemic opioids or other regional analgesic techniques remains controversial. Moreover, data on clinically relevant outcomes such as mortality, hospital length of stay (LOS), and respiratory complications remain limited. To address these limitations, we conducted a systematic review and meta-analysis evaluating the effectiveness and safety of SAPB compared with opioids and other regional block techniques in patients with rib fractures, with particular emphasis on pain control, opioid-sparing effects, and impact on length of hospital stay.

Main Points

- Serratus anterior plane block (SAPB) may provide effective and sustained analgesia in patients with rib fractures, with a favorable safety profile and analgesic efficacy that appears comparable to, and possibly greater than, that of other regional techniques within the first 24 hours.
- SAPB supports pulmonary function and reduces opioid exposure, thereby contributing to improved respiratory outcomes and a meaningful opioid-sparing effect that may reduce opioid-related adverse events.
- The impact of SAPB on hospital length of stay remains inconclusive, with heterogeneous findings across studies. Further large-scale, well-designed randomized controlled trials are required to investigate this outcome.

METHODS

Study Design and Eligibility Criteria

This systematic review was conducted in accordance with the 2020 Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines.[13] Eligible studies included randomized controlled trials (RCTs) and observational studies (both prospective and retrospective cohort designs) evaluating the use of SAPB in patients with rib fractures. Studies were required to compare SAPB with other analgesic techniques, including systemic opioid therapy and alternative regional anesthesia approaches, such as TEA, paravertebral block (PVB), intercostal nerve block (ICNB), and erector spinae plane block (ESPB). Case reports, case series, narrative reviews, conference abstracts without full-text availability, and non-English-language publications were excluded. The protocol for this study has been registered in the International Prospective Register of Systematic Reviews (PROSPERO) with ID CRD420261287442.

Search Strategy

A comprehensive literature search was conducted across databases, such as PubMed, Scopus, EBSCO, Taylor & Francis, Web of Science, and ScienceDirect, to identify publications from January 2015 to June 2025. The search strategy employed the following keywords: “serratus anterior plane block” AND “rib fractures” AND (“regional anesthesia” OR “paravertebral block” OR “thoracic epidural” OR “erector spinae plane block”). Additionally, reference lists of relevant articles were manually searched to identify eligible studies (Figure 1).

Data Extraction and Statistical Analysis

Article screening and data extraction were performed independently by three authors using a predefined and

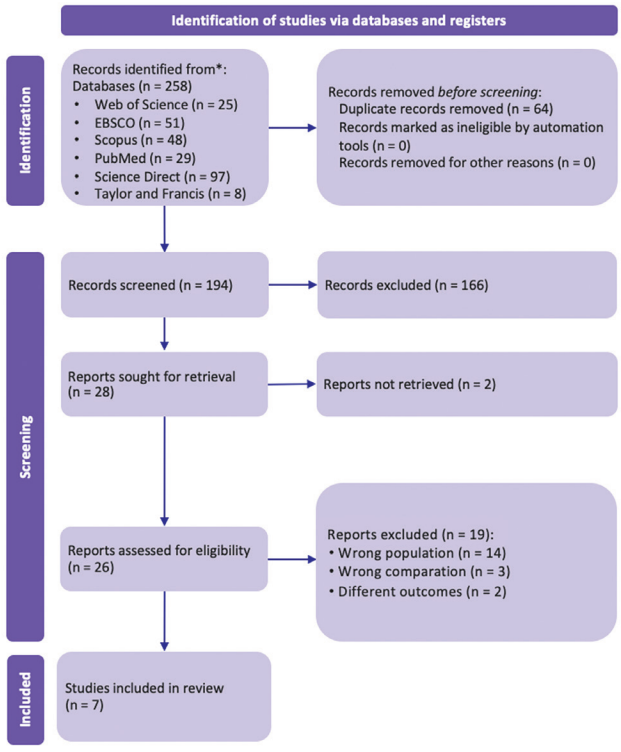


Figure 1. PRISMA 2020 flow diagram for included studies[13]

PRISMA: Preferred Reporting Items for Systematic Reviews and Meta-Analyses

standardized form. The extracted data included study design, patient characteristics, interventions and comparators, and reported outcomes. Any discrepancies during data evaluation were discussed until a consensus was reached.

Quantitative analyses focused on pain scores reported at multiple time points (baseline, 3 hours, 6 hours, 12 hours, and 24 hours). Continuous outcomes were pooled using standardized mean differences (SMDs) with 95% confidence intervals (CIs) under a random-effects model. Because the included studies measured pain on different scales, most using the numeric rating scale (NRS, 0–10) and one[14] using the visual analogue scale (VAS, 0–100), the SMD was selected as the effect measure. Expressing treatment effects in standard deviation (SD) units enabled valid comparison and pooling of outcomes derived from different pain scales within a single analysis. Because opioid consumption was reported in heterogeneous units (tramadol in milligrams and morphine in milligram equivalents), the SMD was selected to standardize effect estimates across studies. Where appropriate, VAS values were rescaled to a common 0–10 metric before standardization. When data were reported only as medians and interquartile ranges, they were converted to means and SDs using the methods described by Luo et al.[15] and Wan et al.[16] Where feasible, subgroup analyses were conducted to compare SAPB with other regional blocks and with opioid-based analgesia. Statistical heterogeneity was assessed using the I^2 statistic, with values greater than 50% considered indicative of substantial heterogeneity. Sensitivity analyses were considered in cases of substantial baseline imbalance or marked heterogeneity. All analyses were performed using Review Manager (RevMan) version 5.4.

Risk-of-Bias Assessment and Quality of Evidence

Risk of bias was assessed using the Cochrane Risk of Bias 2 (RoB 2) tool for RCTs and the Risk of Bias In Non-randomized Studies of Interventions (ROBINS-I) tool for non-randomized studies.[17,18] The RoB 2 tool assessed bias arising from the randomization process, deviations from intended interventions, the completeness and accuracy of outcome data, and selective reporting. The ROBINS-I tool additionally assessed bias due to confounding and participant selection. All assessments were conducted independently by two reviewers, with disagreements resolved by a third reviewer. The overall quality of evidence was assessed using the Grading of Recommendations Assessment, Development, and Evaluation (GRADE) approach.[19]

Interventions

The primary intervention evaluated was SAPB in patients with rib fractures. SAPB is performed under ultrasound guidance, with local anesthetic injected between the serratus anterior muscle and the lateral thoracic wall, with or without the placement of a catheter for continuous infusion. The comparators included systemic opioid therapy and other regional analgesic techniques such as TEA, PVB, ICNB, and ESPB.

Outcomes

The primary outcome was pain intensity, assessed using the VAS or the NRS at multiple time points, including baseline and 3, 6, 12, and 24 hours post-intervention. Secondary outcomes included total opioid consumption within the first 24 hours and hospital LOS.

RESULTS

Study Characteristics

This systematic review includes seven studies, published between 2021 and 2025, that were conducted in Italy, Türkiye, Egypt, the United States, and Australia. Among the included studies, five were RCTs,[11,12,14,20,21] one was a retrospective observational study,[22] and one was a prospective observational cohort study.[23] Sample sizes across the included studies ranged from 38 to 210 patients. All studies investigated SAPB as the primary intervention, including its superficial variant (S-SAPB). Comparator groups included the ESPB, the ICNB, intravenous patient-controlled analgesia (PCA) using tramadol, and standard care (Table 1).

Seven studies included in this review involved sample sizes ranging from 38 to 210 patients, with a balanced distribution between the intervention and control groups. The mean or median age of patients in the SAPB group ranged from 34.4±12.35 years to 71 (54–85) years, while in the control group ranged from 35.8±11.56 years to 71 (58–82) years. The proportion of male patients in the SAPB group ranged from 36.67% to 70.7%, whereas in the control group it ranged from 23.33% to 66.7%. The instruments used to assess pain intensity varied across studies, with most studies employing the NRS and one study using the VAS (Table 2).

In total, 611 patients were analyzed across the seven included studies (SAPB groups, n = 298; comparator groups, n = 313).

Table 1. Characteristics of included studies

No.	First author	Year	Country	Study design	Sample size, n	Intervention	Control
1	El Malla[20]	2022	Italy	Prospective randomized trial	50	SAPB	ESPB
2	Zengin[14]	2025	Türkiye	Prospective, randomized, assessor-blind study	60	SAPB	ICNB
3	Tekşen[11]	2021	Türkiye	Prospective controlled randomized trial	60	SAPB	IV PCA (tramadol)
4	Abu-Elwafa[21]	2021	Egypt	Randomized controlled study	40	SAPB	IV morphine
5	Serra[22]	2024	Italy	Retrospective observational study	156	SAPB	Standard care
6	Sadauskas[23]	2024	United States	Prospective observational cohort study	38	SAPB	Standard care
7	Partyka[12]	2024	Australia	Multicenter, open-label, pragmatic randomized clinical trial	207	SAPB	Standard care

n: number of samples, SAPB: serratus anterior plane block, ESPB: erector spinae plane block, ICNB: intercostal nerve block, IV: intravenous, PCA: patient-controlled analgesia

Table 2. Characteristics of study participants

No	Author, year	Sample size (n)		Age, year*		Male, % (n)		Pain scale
		SAPB	Control	SAPB	Control	SAPB	Control	
1	El Malla et al.[20], 2022	25	25	34.4±12.35	35.8±11.56	68 (17)	80 (20)	NRS
2	Zengin et al.[14], 2025	30	30	53 [18]	44 [27.75]	70 (21)	66.67 (20)	VAS
3	Tekşen et al.[11], 2021	30	30	50.7±18.8	42.4±15.8	36.67 (11)	23.33 (7)	NRS
4	Abu-Elwafa et al.[21], 2021	20	20	NR	NR	NR	NR	VAS
5	Serra et al.[22], 2024	75	81	64 [55–74]	61 [51–74]	70.7 (53)	60.5 (49)	NRS
6	Sadauskas et al.[23], 2024	15	23	58±21	64±19	66 (10)	43 (10)	NRS
7	Partyka et al.[12], 2024	103	104	71 [54–85]	71 [58–82]	65 (67)	60 (62)	NRS

*Data are presented as mean ± SD or median (IQR)

**Partyka et al.[12] baseline characteristics are reported for the analyzed population (103 SAPB, 104 control); 210 patients were initially randomized

n: number of samples, SAPB: serratus anterior plane block, NRS: numeric rating scale, VAS: visual analog scale, SD: standard deviation, IQR: interquartile range

This total reflects the number of participants analyzed in each study, including 207 patients reported by Partyka et al.[12] (103 in the SAPB group and 104 in the comparator group), which is consistent with the baseline characteristics reported in that trial. The 210 patients initially randomized are reported in the study-characteristics table. The same total of 611 is reported consistently across the Abstract, Results section, and the GRADE evidence profile (Supplementary Table 1).

With respect to the local anesthetic used for the block, bupivacaine and ropivacaine were the agents employed across the included studies. Bupivacaine 0.25% was the most frequently used agent: Tekşen et al.[11] administered 30 mL (75 mg), Zengin et al.[14] used 20 mL (50 mg) for the superficial SAPB, and El Malla et al.[20] used a 30 mL mixture of bupivacaine 0.25% (15 mL, 37.5 mg) and lignocaine 1% (15 mL, 150 mg) with added dexamethasone. Abu-Elwafa et al.[21] administered a weight-based volume of bupivacaine 0.25% (0.5 mL/kg). Ropivacaine was used in the remaining studies: Serra et al.[22] administered 30 mL of 0.23–0.33% ropivacaine (median dose 80 mg; range 70–100 mg); Partyka et al.[12] used a high-volume, low-concentration ropivacaine solution as a single-shot block, with a median volume of 40 mL and a median dose of 150 mg; Sadauskas et al.[23] did not report the agent, concentration, or volume in sufficient detail (Supplementary Table 2). The number and anatomical location of fractured ribs (anterior/lateral/posterior; unilateral/bilateral) were inconsistently reported across studies and, therefore, could not be pooled. These gaps were acknowledged as limitations.

Clinical Outcomes

All included studies reported pain intensity as the primary outcome, assessed both at rest and during coughing at various time points within the first 24 hours after the intervention. The timing of assessments varied across studies, with the initial evaluation performed immediately after the procedure (T0; hour 0), followed by serial measurements at T0.5 (30 minutes), T1 (1 hour), T2 (2 hours), T4 (4 hours), T6 (6 hours), T8 (8 hours), T10 (10 hours), T12 (12 hours), T16 (16 hours), T18 (18 hours), T20 (20 hours), and T24 (24 hours) post-procedure. Overall, the SAPB intervention group consistently demonstrated lower pain scores compared with the control group, both at rest and during coughing. This analgesic benefit was most pronounced during the early postoperative period (up to the first 12 hours) and remained evident up to 24 hours.

In addition to pain outcomes, several studies evaluated length of hospital stay and postoperative opioid requirements. Serra et al.[22] reported a median hospital stay of 4 (3–6) days in the SAPB group compared with 5 (4–6) days in the control group. Partyka et al.[12] reported similar findings, with a median LOS of 4.2 (2.2–

7.7) days in the SAPB group versus 5 (3–7.3) days in the control group. Postoperative opioid consumption was also consistently lower in the SAPB group. Tekşen et al.[11] reported a total 24-hour tramadol consumption of 98.33±74.13 mg in the SAPB group, compared with 148.30±87.68 mg in the control group. Consistent results were also reported by Sadauskas et al.[23] and Partyka et al.[12], with lower morphine milligram equivalent (MME) values observed in the SAPB group compared with controls.

Meta-analysis

A total of nine pooled analyses were performed across two primary outcomes: pain score and opioid consumption. Baseline pain scores were comparable between groups (SMD: 0.18, 95% CI −0.13 to 0.49; $P = 0.25$; $I^2 = 77\%$). SAPB significantly reduced pain scores at 3 hours post-intervention (T3; SMD: −0.40, 95% CI: −0.79 to −0.02; $P = 0.04$; $I^2 = 67\%$), whereas no significant differences were observed at 6, 12, or 24 hours (all $P > 0.05$), with substantial heterogeneity across analyses ($I^2 = 88$–96%). A prespecified opioid subgroup analysis at T12 demonstrated a significant benefit favoring SAPB (SMD: −0.44, 95% CI: −0.72 to −0.16; $P = 0.002$; $I^2 = 46\%$); this effect remained unchanged in sensitivity analysis. Exclusion of an outlier study at T24 reduced heterogeneity but did not alter the non-significant result.

Regarding opioid consumption, SAPB was associated with significantly lower opioid requirements compared with the control group (SMD: −0.35, 95% CI: −0.67 to −0.02; $P = 0.04$; $I^2 = 61\%$) (Table 3).

Pain Intensity at Baseline

The forest plot at baseline showed no significant difference in pain intensity between SAPB and comparators overall (SMD: 0.18; 95% CI: –0.13 to 0.49; $P = 0.25$; $I^2 = 77\%$). In the subgroup analysis, no significant baseline difference was found in either subgroup: the opioid-comparator subgroup (SMD: 0.23; 95% CI: –0.19 to 0.64; $P = 0.28$) or the other-regional-block subgroup (SMD: 0.10; 95% CI: –0.37 to 0.57; $P = 0.68$). These findings indicate that the SAPB and comparator groups were broadly comparable at baseline, with no statistically significant imbalance detected (Figure 2).

Pain Intensity at 3 Hours

The forest plot at 3 hours showed that SAPB was associated with significantly lower pain intensity than opioids (SMD: –0.40; 95% CI: –0.79 to –0.02; $P = 0.04$; $I^2 = 67\%$). At this time point, No studies have compared SAPB with other regional block techniques. This result is consistent with an early analgesic effect of SAPB relative to systemic opioid analgesia, although the substantial heterogeneity and the very low certainty of the evidence warrant cautious interpretation (Figure 3).

Pain Intensity at 6 Hours

At 6 hours, the forest plot demonstrated marked heterogeneity between subgroups. Compared with opioids, SAPB was associated with lower pain scores (SMD: –0.57; 95% CI: –0.89 to –0.25; $P = 0.0005$). Conversely, when compared with other regional block techniques, SAPB was associated with higher pain scores (SMD: 0.85; 95% CI: 0.27 to 1.43; $P = 0.004$). The overall pooled result was not statistically significant (SMD: –0.29; 95% CI: –0.85 to 0.27; $P = 0.31$; $I^2 = 94\%$), reflecting opposing effects across subgroups. These findings suggest that, at 6 hours post-intervention, SAPB was associated with greater pain reduction than opioids but with less pain reduction than other regional blocks; given the substantial heterogeneity and low certainty of evidence, this pattern should be interpreted with caution (Figure 4).

Pain Intensity at 12 Hours

At 12 hours, the pooled result was not statistically significant (SMD: –0.37; 95% CI: –0.92 to 0.18; $P = 0.18$; $I^2 = 88\%$). Subgroup analysis showed that SAPB remained associated with significantly lower pain scores than opioids (SMD: –0.44; 95% CI: –0.72 to –0.16; $P = 0.002$; $I^2 = 46\%$), whereas no significant difference was observed between SAPB and other regional blocks (SMD: –0.24; 95% CI: –2.46 to 1.98; $P = 0.83$; $I^2 = 97\%$). These findings suggest that the analgesic effect of

Table 3. Meta-analysis result

Outcome	Time point	Pooled SMD (95% CI)	*P* value	I^2	Interpretation
Pain score	Baseline	0.18 (−0.13 to 0.49)	0.25	77%	Non-significant; groups comparable
Pain score	T3 (3 h)	−0.40 (−0.79 to −0.02)	0.04	67%	Significant; favors SAPB (low certainty)
Pain score	T6 (6 h)	−0.29 (−0.85 to 0.27)	0.31	94%	Non-significant overall; subgroup divergence
Pain score	T12 (12 h)-Main	−0.37 (−0.92 to 0.18)	0.18	88%	Non-significant overall
Pain score	T12-Opioid subgroup	−0.44 (−0.72 to −0.16)	0.002	46%	Significant; favors SAPB (low certainty)
Pain score	T12-Sensitivity (excl. El Malla et al.[20])	−0.44 (−0.72 to −0.16)	0.002	46%	Robust; result confirmed
Pain score	T24 (24 h)-Main	−0.76 (−1.79 to 0.27)	0.15	96%	Non-significant; extreme outlier present
Pain score	T24-Sensitivity (excl. Tekşen et al.[11])	−0.44 (−0.99 to 0.11)	0.12	88%	Still non-significant; I^2 reduced
Opioid consumption	Total	−0.35 (−0.67 to −0.02)	0.04	61%	Significant; SAPB opioid-sparing

CI: confidence interval, SAPB: serratus anterior plane block

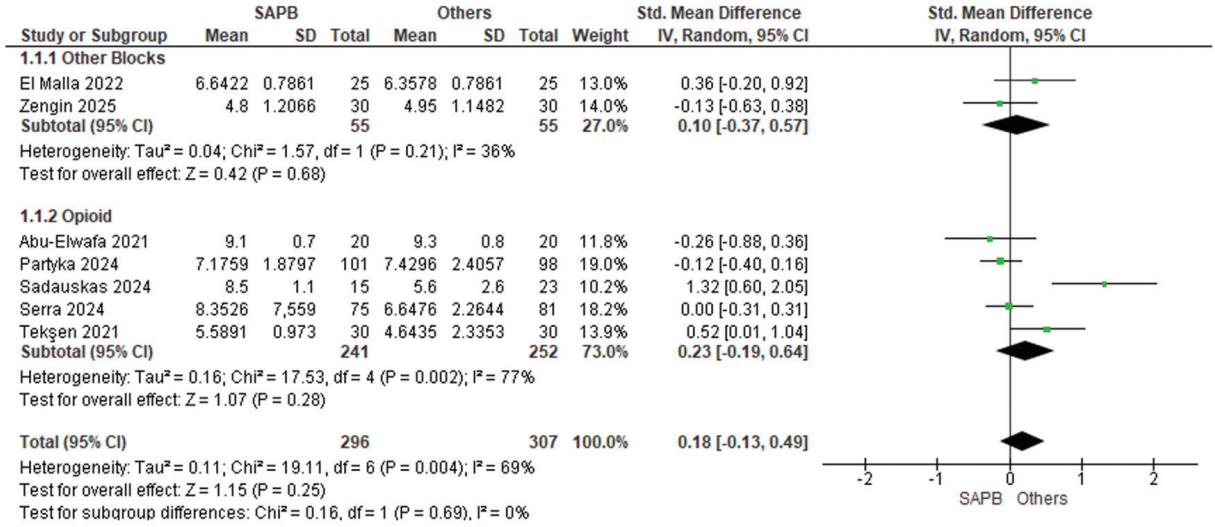


Figure 2. Mean pain intensity between SAPB and comparators at baseline

SAPB: serratus anterior plane block, SD: standard deviation, SMD: standardized mean difference, IV: inverse variance, CI: confidence interval, df: degrees of freedom

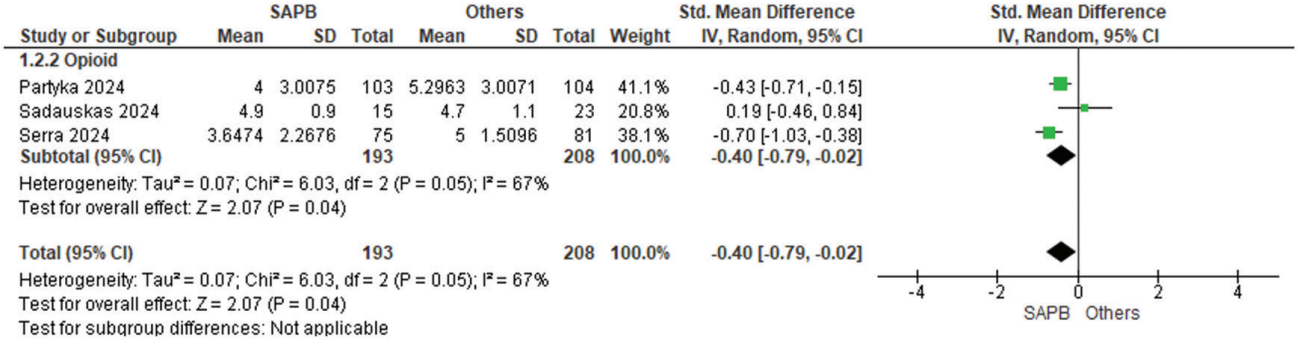


Figure 3. Mean pain intensity between SAPB and comparators at 3 hours

SAPB: serratus anterior plane block, SD: standard deviation, SMD: standardized mean difference, IV: inverse variance, CI: confidence interval, df: degrees of freedom

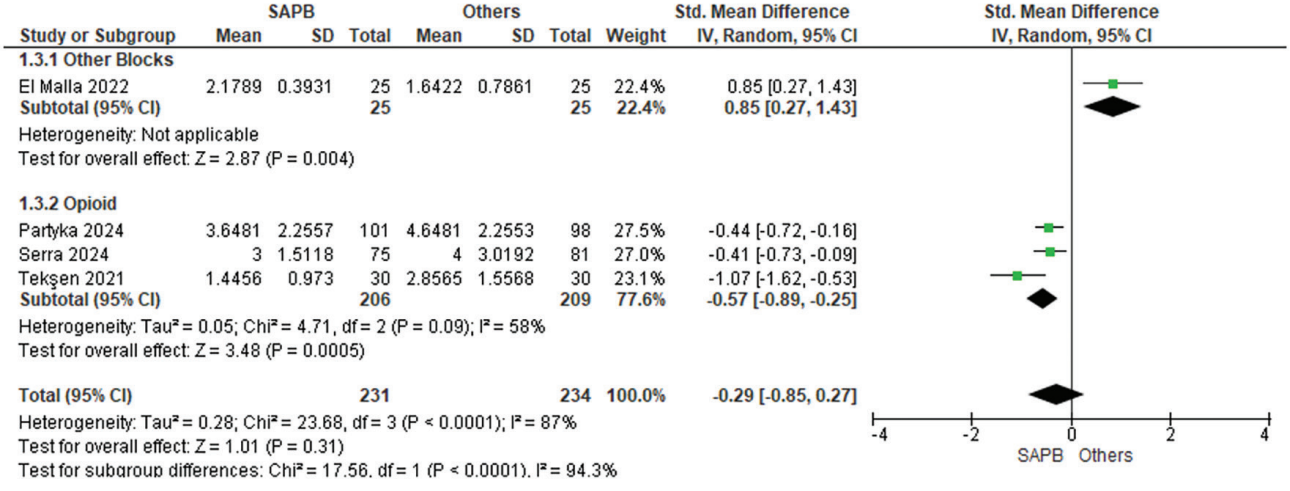


Figure 4. Mean pain intensity between SAPB and comparators at 6 hours

SAPB: serratus anterior plane block, SD: standard deviation, SMD: standardized mean difference, IV: inverse variance, CI: confidence interval, df: degrees of freedom

SAPB relative to opioids was sustained at 12 hours, whereas comparisons with other regional blocks were inconclusive and highly heterogeneous. Given the low certainty of evidence, these estimates should be interpreted with caution (Figure 5).

Pain Intensity at 24 Hours

At 24 hours, the overall pooled result was not statistically significant (SMD: –0.76; 95% CI: –1.79 to 0.27; $P = 0.15$; $I^2 = 96\%$), with very high heterogeneity. Subgroup analysis was likewise inconclusive: neither the comparison with opioids (SMD: –0.97; 95% CI: –2.28 to 0.35; $P = 0.15$; $I^2 = 97\%$) nor the comparison with other regional blocks (SMD: –0.43; 95% CI: –2.85 to 1.99; $P = 0.73$; $I^2 = 97\%$) reached statistical significance. Although the point estimates favored SAPB, the wide CIs and extreme heterogeneity—largely driven by a single small outlier study[11]—mean that no reliable conclusion about the 24-hour effect can be drawn; a sensitivity analysis excluding this outlier is presented in the Supplementary Figures 1-3 (Figure 6).

Total Opioid Consumption

Total opioid consumption within the first 24 hours was reported by four studies comprising 453 patients. Because the included studies expressed opioid use in different units (24-hour tramadol consumption in milligrams in Tekşen et al.[11] and MME in Sadauskas et al.[23], Partyka et al.[12], and MMEs in Serra et al.[22]), the outcome was pooled using the SMD to allow combination across heterogeneous measurement scales. Compared with

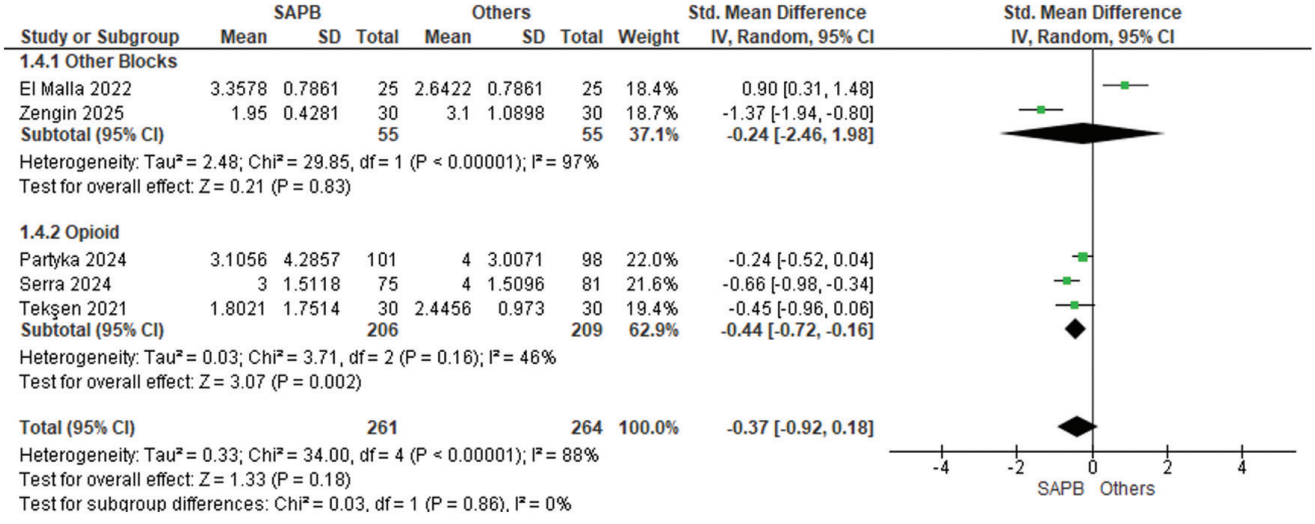


Figure 5. Mean pain intensity between SAPB and comparators at 12 hours

SAPB: serratus anterior plane block, SD: standard deviation, SMD: standardized mean difference, IV: inverse variance, CI: confidence interval, df: degrees of freedom

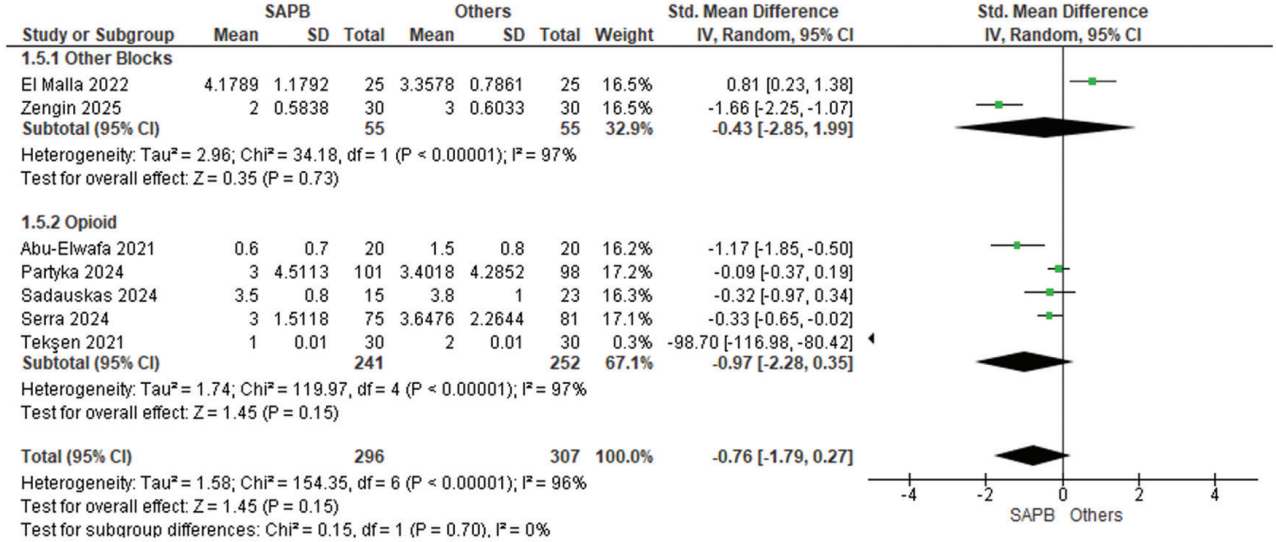


Figure 6. Mean pain intensity between SAPB and comparators at 24 hours

SAPB: serratus anterior plane block, SD: standard deviation, SMD: standardized mean difference, IV: inverse variance, CI: confidence interval, df: degrees of freedom

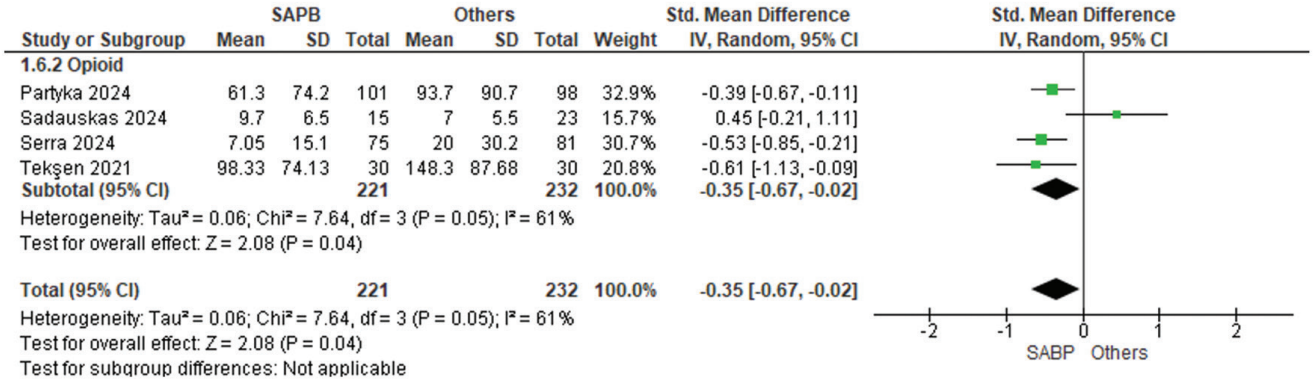


Figure 7. Total opioid consumption

SAPB: serratus anterior plane block, SD: standard deviation, SMD: standardized mean difference, IV: inverse variance, CI: confidence interval, df: degrees of freedom

controls, SAPB was associated with a significant reduction in opioid requirements (pooled SMD: –0.35; 95% CI –0.67 to –0.02; $P = 0.04$; $I^2 = 61\%$), which indicates a moderate opioid-sparing effect, although this substantial statistical heterogeneity and the small number of contributing studies warrant cautious interpretation (Figure 7).

Risk-of-Bias Assessment and Quality of Evidence

Risk-of-Bias Assessment in Randomized Studies

The risk of bias assessment of the randomized studies indicated that most domains were judged to be at low risk of bias. El Malla et al.[20] were assessed as having a low risk of bias across all domains, except for outcome measurement (D4), which was rated as having "some concerns." Zengin et al.[14] demonstrated a low risk of bias in most domains; however, concerns were identified in the domain of deviations from the intended interventions (D2). Similarly, Tekşen et al.[11] showed a low risk of bias in the domains of randomization, missing outcome data, and selection of the reported results, while concerns were noted in D2 and outcome measurement (D4). Partyka et al.[12] demonstrated a low risk of bias in D1 (randomization process), D3 (missing outcome data), and D5 (selection of the reported result), with some concerns in D2 and D4. Overall, the randomized studies included in this review were judged to have a low to moderate risk of bias, with particular concerns related to deviations from intended interventions and outcome measurement methods (Supplementary Figure 4).

Risk-of-Bias Assessment in Non-randomized Studies

The risk-of-bias assessment for non-randomized studies demonstrated greater variability than that for randomized studies. Serra et al.[22] exhibited a serious risk of bias, particularly in the domains of confounding (D1) and selection of the reported results (D7). Sadauskas et al.[23] showed a serious risk of bias related to confounding (D1) and a moderate risk of bias in participant selection (D2). Overall, non-randomized studies included in this review tended to have a higher risk of bias, primarily attributable to confounding, deviations from interventions, and outcome selection and measurement issues (Supplementary Figure 5).

Quality of Evidence

Using the GRADE framework, the certainty of evidence for pain-related outcomes ranged from very low to low. Evidence for baseline pain intensity was rated low certainty, primarily due to moderate risk of bias and substantial heterogeneity ($I^2 = 77\%$), despite the presence of direct comparisons and adequate precision. Evidence for pain intensity at 3 hours was of very low certainty, driven by a high risk of bias and considerable inconsistency ($I^2 = 67\%$). For pain outcomes at 6, 12, and 24 hours, the certainty of evidence was consistently low; the downgrading was mainly attributable to moderate risk of bias and high inconsistency (I^2 ranging from 88% to 96%). At these time points, the overall pooled estimates did not reach statistical significance, further limiting the strength of any conclusion. Indirectness, imprecision, and other factors were not considered serious concerns (Supplementary Table 1).

DISCUSSION

The SAPB has been increasingly utilized as an analgesic technique for patients with rib fractures. Multiple studies have demonstrated that SAPB provides rapid analgesia, is relatively easy to perform under ultrasound guidance, and has a favorable safety profile; no serious complications, such as pneumothorax or hematoma, have been reported.[8,11,24] In addition to pain control, SAPB has been shown to improve respiratory function, as evidenced by increased diaphragmatic excursion,[14] stabilization of the SpO_2/FiO_2 ratio,[24] and reduced supplemental oxygen requirements in several studies.[25] Collectively, these findings suggest that SAPB not only alleviates pain but also contributes to the preservation of pulmonary function, which is critical in preventing respiratory complications in patients with rib fractures.

Our findings suggest that SAPB may provide more consistent and sustained analgesia than other analgesic modalities. Baseline pain scores were broadly comparable between groups, with no statistically significant difference overall (baseline SMD: 0.18; $P = 0.25$) or within the opioid or other-block subgroups, indicating that the groups were reasonably balanced before intervention. An early analgesic effect of SAPB relative to opioids was evident at 3 hours (SMD: −0.40; $P = 0.04$). This rapid early effect may be explained by the mechanism of the

blockade: deposition of local anesthetic in the plane of the serratus anterior muscle produces relatively rapid blockade of the lateral cutaneous branches of the intercostal nerves (T2-T9), thereby providing analgesia to the anterolateral thoracic region.[26] In the opioid subgroup, this association remained statistically significant at 12 hours (SMD: −0.44; $P = 0.002$). However, the overall pooled estimates at 6, 12, and 24 hours did not reach statistical significance and were accompanied by wide CIs and very high between-study heterogeneity (I^2 up to 96%), leading to uncertainty about the persistence of analgesic efficacy beyond the early period.

One possible explanation for the transient attenuation of the observed effect is the limited duration of analgesia associated with single-injection SAPB. Variations among studies in local anesthetic type, concentration, volume, and delivery technique (single-shot and continuous catheter) may have influenced both the temporal pattern of analgesic efficacy and the substantial between-study heterogeneity observed (I^2 up to 96%). Direct evidence comparing single-shot and continuous SAPB remains limited. While the present meta-analysis examined only single-shot SAPB for rib fracture analgesia, continuous SAPB administered via a PCA device has also demonstrated effectiveness in managing acute pain and is frequently recommended when extended analgesic coverage is required.[27] A trial by Er et al.[28] evaluated single-shot SAPB, continuous SAPB, and PCA. The study found that continuous SAPB was associated with better recovery outcomes and fewer postoperative complications compared with the single-shot approach. However, patients receiving continuous SAPB reported higher pain scores during activity. Additional well-designed studies are needed to establish the comparative advantages of single-shot versus continuous SAPB.[28]

One possible explanation for the 6-hour dip followed by recovery is the pharmacokinetic profile of a single-shot block: as the initial local anesthetic bolus is redistributed and metabolized, analgesia may wane before the next scheduled assessment, whereas continuous catheter infusion or the use of larger volumes and higher concentrations of longer-acting agents such as bupivacaine or ropivacaine, would be expected to provide more sustained coverage. Differences between studies in the choice, concentration, and volume of local anesthetic, and in single-shot versus catheter techniques, are therefore plausible contributors both to the time-dependent pattern of effect and to the high between-study heterogeneity (I^2 up to 96%).

Compared with other regional analgesic techniques, SAPB demonstrated time-dependent effectiveness. In the early phase (≤6 hours), some studies reported that traditional regional blocks, such as thoracic epidural or PVBs, provided superior analgesia.[9] Beyond the early hours, the comparison between SAPB and other regional blocks was inconclusive: the pooled estimates at 12 and 24 hours did not reach statistical significance and were accompanied by very high heterogeneity; therefore, no firm conclusion about relative efficacy at later time points can be drawn. Nonetheless, the potential advantages of SAPB include its technical simplicity, a favorable safety profile in patients with coagulopathy, and its potential for continuous administration via catheter placement, making it a viable alternative when conventional techniques are contraindicated or technically challenging.[29] Overall, the available data do not allow a firm conclusion about the relative duration of the effect of SAPB versus that of other regional techniques within the first 24 hours.

At 6 hours, SAPB was associated with higher pain scores than other regional blocks, whereas comparisons at 12 and 24 hours were not statistically significant. These differing point estimates may reflect differences in the onset and duration profiles of the comparator techniques rather than a true reversal of effect; however, because the comparator group pooled several diverse techniques (TEA, PVB, ICNB, and ESPB) with distinct pharmacodynamics, and because the later estimates were imprecise and highly heterogeneous, any time-dependent pattern should be regarded as hypothesis-generating rather than definitive.

Compared with systemic opioid analgesia, SAPB was associated with lower pain scores in the pooled subgroup analyses. This association reached statistical significance at 3 hours and, within the opioid subgroup, at 12 hours, although the wide CIs, substantial heterogeneity, and non-significant overall estimates at later time points warrant caution.[11] This finding is clinically relevant given the well-recognized limitations of opioid therapy, including the risks of respiratory depression, sedation, constipation, and delirium, particularly in elderly patients.[21] Therefore, SAPB may provide more effective analgesia than systemic opioids while also reducing patient exposure to opioid-related adverse effects. The opioid-sparing effect observed in the pooled analysis (SMD: −0.35; $P = 0.04$) is clinically meaningful because lowering cumulative opioid exposure is expected to reduce the incidence of respiratory depression, nausea and vomiting, ileus, and delirium in the predominantly elderly rib-fracture population. By providing targeted regional analgesia, SAPB can serve as the regional component of a multimodal strategy, allowing opioids to be reserved for breakthrough pain rather than serving as the mainstay analgesic.

The opioid-sparing effect of SAPB further reinforces its role within multimodal analgesia strategies. Evidence indicates that patients receiving SAPB require significantly less supplemental opioid analgesia, which in turn reduces the incidence of opioid-associated nausea and vomiting.[11] Abu-Elwafa et al.[21] similarly reported that SAPB was comparable to intravenous morphine infusion in reducing pain scores, while avoiding the risk of respiratory compromise. These findings are consistent with case series demonstrating that SAPB can serve as an effective strategy to reduce opioid dependence in patients with multiple rib fractures.[8,10]

Despite the demonstrated benefits of SAPB for analgesia and respiratory function, evidence regarding its impact on hospital LOS remains heterogeneous. Serra et al.[22] reported a shorter duration of hospitalization in the SAPB group compared with controls [median 4 (3–6) vs. 5 (4–6) days]. Similar results were observed by Partyka et al.[12] with a median LOS of 4.2 (2.2–7.7) days in the SAPB group versus 5 (3–7.3) days in the control group. In contrast, Sadauskas et al.[23] found no significant difference in LOS between SAPB and non-SAPB cohorts. These discrepancies suggest that although SAPB may shorten hospitalization through optimized analgesia and improved

respiratory mechanics, its effect on LOS is not consistently observed across patient populations, underscoring the need for large-scale RCTs to clarify this association.

These findings must be interpreted in light of the risk of bias and GRADE assessments. Under the GRADE framework, the certainty of evidence for the pain outcomes was low to very low at all time points, downgraded primarily for serious inconsistency (I^2, ranging from approximately 67% to 96%) and for risk of bias. The risk-of-bias evaluation identified recurring concerns in the randomized trials regarding deviations from intended interventions (D2) and outcome measurement (D4), which is especially relevant because pain is a subjective outcome and several studies were not blinded, thereby raising the possibility of outcome-measurement bias. In the non-randomized studies, confounding (D1) was judged to be serious in more than one study. Taken together, the low certainty of the evidence and these specific bias domains mean that the pooled estimates should be regarded as preliminary, and any clinical recommendation derived from them must be interpreted with caution.

Study Limitations

This study has several important limitations. First, the included studies were heterogeneous in design, combining RCTs with prospective and retrospective observational studies. Pooling randomized and non-randomized data increases the risk of bias and statistical heterogeneity; the heterogeneity was substantial across nearly all time points (I^2 approximately 67–96%). To mitigate this, we used a random-effects model, conducted subgroup analyses (opioid comparators and other regional blocks), and performed sensitivity analyses, but these steps could not fully overcome the underlying design heterogeneity. The number of studies included was small, and several pooled estimates rested on as few as three studies, limiting statistical power and making the estimates sensitive to the influence of any single study. The risk of bias was serious in several studies, with concerns regarding outcome measurement (a subjective pain outcome assessed largely without blinding) and confounding in the non-randomized studies. The included studies used different pain scales (NRS 0–10 and VAS 0–100). Although this was addressed by pooling SMDs, combining instruments introduces additional uncertainty. Although baseline pain scores did not differ significantly between groups in the pooled analysis, small sample sizes limited the precision of this comparison. Furthermore, the number and anatomical location of fractured ribs and the type, concentration, and volume of local anesthetic were inconsistently reported and could not be pooled, despite their potential influence on block efficacy. Finally, the certainty of evidence was low to very low; long-term outcomes and mortality data were largely unavailable; and the potential for publication and language bias cannot be excluded. These limitations should be weighed when interpreting the findings, and should underscore the need for adequately powered, well-designed RCTs.

CONCLUSION

Although the certainty of evidence remains low, SAPB may provide effective early analgesia and an opioid-sparing effect in patients with rib fractures; however, its comparative efficacy against other regional techniques remains uncertain and does not reach statistical significance in pooled analyses beyond the early hours. Given its favorable safety profile, technical simplicity, and potential opioid-sparing effects, SAPB may be a useful component of multimodal analgesia. Because the available studies were few, heterogeneous, and at substantial risk of bias, these findings should be interpreted with caution and confirmed in high-quality, well-designed RCTs before clinical recommendations can be made.

Ethics

Ethics Committee Approval: Not applicable.

Informed Consent: Not applicable.

Footnotes

Authorship Contributions

Concept: C.A., S.F.S., S.A.'A., P.P.M.E., Design: C.A., S.F.S., S.A.'A., P.P.M.E., Data Collection or Processing: C.A., S.F.S., S.A.'A., Analysis or Interpretation: C.A., S.F.S., S.A.'A., P.P.M.E., Literature Search: C.A., S.F.S., Writing: C.A., S.F.S., S.A.'A., P.P.M.E.

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Supplementary Figures Link: https://d2v96fxpocvxx.cloudfront.net/beb8919b-f013-4ea1-b1c8-40332e840fe1/content-images/93968981-2e75-44ad-9bcc-337e6fb1147b.pdf

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