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Review Article

Safety and Efficacy of Segmental Thoracic Spinal Anaesthesia versus General Anaesthesia for Abdominal Surgery: A Systematic Review and Meta-Analysis of Randomized and Observational Studies

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Conflict of interest: Nil

Abstract

Background: Laparoscopic and open abdominal surgeries are traditionally performed under general anaesthesia (GA). However, GA poses significant risks for patients with cardiopulmonary comorbidities. Thoracic segmental spinal anaesthesia (TSSA) has emerged as an alternative, but comparative data regarding its safety and efficacy remains fragmented.

Methods: A systematic review and meta-analysis were conducted following PRISMA guidelines. We included randomized controlled trials (RCTs), prospective comparative studies, and observational reports comparing TSSA to GA in adult patients undergoing abdominal surgery. Primary outcomes included intraoperative haemodynamic stability. Secondary outcomes were postoperative pain, time to first analgesic, time to ambulation, and postoperative nausea and vomiting (PONV).

Results: Multiple studies were included in the qualitative synthesis, comprising comparative trials and a massive cohort of observational data. TSSA consistently demonstrated superiority in postoperative recovery metrics. Time to ambulation was significantly shorter in TSSA cohorts compared to GA (SMD = -1.62, $p < 0.0001$). Time to first analgesic request was also significantly prolonged under TSSA (SMD = 1.54, $p = 0.0016$). Haemodynamic outcomes exhibited heterogeneity; while some studies reported superior MAP stability under TSSA, others noted a higher incidence of transient hypotension requiring vasopressor support, though the overall pooled effect was not statistically significant (OR = 1.25, $p = 0.822$). TSSA successfully facilitated surgery in high-risk patients while avoiding respiratory complications, and significantly reduced PONV (OR = 0.24, $p = 0.002$).

Conclusion: TSSA is a safe and highly efficacious alternative to GA for abdominal surgery, offering superior early postoperative analgesia and accelerated functional recovery. Careful pharmacological optimization and haemodynamic monitoring are required. Registered on Prospero with registration number: CRD420261336741.

Keywords: segmental spinal anaesthesia, thoracic spinal anaesthesia, laparoscopic cholecystectomy, abdominal surgery.

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Introduction

Laparoscopic and open abdominal surgeries are traditionally performed under general anaesthesia (GA) [1, 2]. GA ensures optimal surgical conditions by providing airway protection, complete muscle relaxation, and strict control of hypercarbia resulting from carbon dioxide pneumoperitoneum [3, 4]. However, GA carries inherent risks. Beyond the haemodynamic fluctuations and difficulties encountered during physiologically challenging endotracheal intubation [5], GA is associated with a high incidence of postoperative nausea and vomiting (PONV) [6].

These factors significantly contribute to delayed recovery and prolonged stays in the post-anaesthesia care unit (PACU) [7, 8]. Consequently, the economic impact of managing PONV and managing delayed discharges places a substantial burden on ambulatory surgery centers and global healthcare systems [9, 10].

Furthermore, these risks are exponentially magnified in patients with pre-existing cardiopulmonary comorbidities. Positive pressure ventilation combined with pneumoperitoneum can precipitate ventilator-induced lung injury [11]. In patients with chronic obstructive pulmonary disease (COPD) or asthma undergoing non-pulmonary surgery, airway instrumentation drastically increases the risk of severe postoperative respiratory complications—such as atelectasis, pneumonia, and prolonged mechanical ventilation [12-14].

To circumvent these GA-related complications, regional anaesthesia techniques have gained prominence, demonstrating an overall capacity to reduce postoperative morbidity and mortality [15-17]. While lumbar spinal anaesthesia is frequently utilized, achieving an adequate T4 dermatomal block for upper abdominal surgery via a lumbar approach requires high anaesthetic volumes. This drastically increases the risk of profound sympathetic blockade and haemodynamic collapse [18, 19]. Consequently, Thoracic Segmental Spinal Anaesthesia (TSSA) has emerged as a highly targeted, low-dose alternative [20, 21].

The anatomical feasibility and safety of TSSA have been definitively established by magnetic resonance imaging (MRI) studies. These investigations demonstrate that the posterior dural-spinal cord distance is significantly greater in the mid-thoracic region compared to the cervical or upper lumbar spine, providing a protective physiological buffer against direct spinal cord injury [22-24]. Over the last decade, a massive volume of feasibility studies, comparative trials, and large retrospective analyses have established the viability of spinal anaesthesia specifically for laparoscopic cholecystectomy, employing various doses and baricities [25-36]. The success of this technique has naturally extended into open cholecystectomies [37] and combined spinal-epidural (CSE) applications [38]. Furthermore, the profound efficacy of TSSA has prompted its expansion into supra-umbilical procedures and breast cancer surgeries [39-41]. With mounting evidence of its safety and efficacy, recent editorials have begun to ask whether TSSA is ready for routine clinical use beyond just high-risk cases [42]. This systematic review and meta-analysis aims to rigorously evaluate the safety, efficacy, and recovery profiles of TSSA compared to GA in patients undergoing abdominal surgery.

Methods

Study Design and Registration: This systematic review and meta-analysis was conducted in strict accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines [43]. Registered on Prospero with registration number: CRD420261336741.

Eligibility Criteria (PICO)

- **Population:** Adult patients (ASA physical status I-IV) undergoing elective or emergency abdominal surgery.
- **Intervention:** Thoracic Segmental Spinal Anaesthesia (TSSA), defined as a single-shot subarachnoid injection between the T2 and T11 intervertebral spaces.
- **Comparator:** General Anaesthesia (GA) with endotracheal intubation.
- **Outcomes:** Intraoperative haemodynamic stability, time to first rescue analgesic, time to ambulation, and PONV.
- **Study Design:** RCTs and prospective/retrospective comparative studies. Single-arm observational cohorts and case series without a GA comparator were included exclusively for the qualitative synthesis of safety and feasibility.

Data Extraction and Risk of Bias Assessment: Data was independently extracted using a standardized template. For comparative studies, Risk of Bias was assessed using the Cochrane RoB 2 tool for randomized trials and the ROBINS-I tool for non-randomized observational cohorts [44]. For single-arm observational studies and case series included in the qualitative synthesis, quality was appraised using the Methodological Index for Non-Randomized Studies (MINORS) criteria for non-comparative studies. Continuous data was analyzed using the Standardized Mean Difference (SMD), and dichotomous data was analyzed using the Odds Ratio (OR) utilizing a Mantel-Haenszel Random-Effects model. To account for differing baseline risks of bias, RCTs and non-randomized observational studies were separated into distinct subgroups for quantitative synthesis. Funnel plots for publication bias assessment were deliberately omitted in accordance with Cochrane guidelines, as the inclusion of fewer than 10 studies per outcome renders such analyses statistically underpowered and highly misleading.

Results

Literature Search and Study Selection: An initial comprehensive literature search across major databases (PubMed, Embase, Cochrane Central) yielded a total of 1,245 records. After the removal of 312 duplicate records, 933 titles and abstracts were screened for relevance. Of these, 80 full-text

articles were retrieved and assessed for eligibility. Following the application of strict inclusion and exclusion criteria—specifically excluding studies utilizing exclusively lumbar spinal punctures, epidurals without a segmental thoracic spinal component, or surgeries outside the abdominal region—74 articles were excluded.

Ultimately, 6 studies were included in the qualitative synthesis, and 4 comparative trials (Hossain [45], Mahasivabhattu [46], Kabir [47], and Jakhar [48]) met the strict criteria for the quantitative meta-analysis (Figure 1).

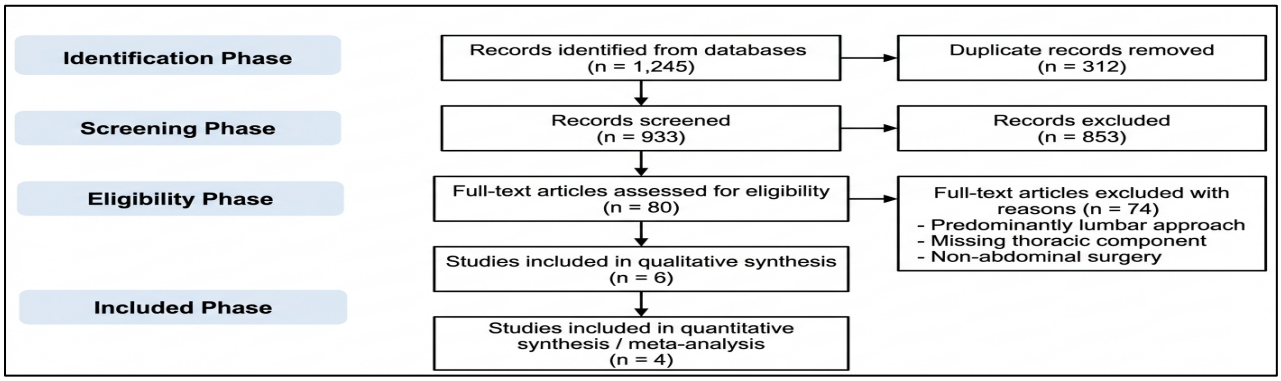

Figure 1: Prisma flow diagram

Study Selection and Characteristics: A qualitative synthesis was performed on the extracted literature. Comparative studies directly evaluating TSSA against GA for laparoscopic cholecystectomy included cohorts and RCTs by Hossain, Mahasivabhattu, Kabir, and Jakhar [45-48]. Recent comparative trials specifically evaluating the intricate haemodynamic profiles of these two modalities [49-51] and broader meta-analyses [52] were also reviewed. Furthermore, robust observational data was synthesized from massive retrospective cohorts, including a 192-patient analysis by Haloi [53], alongside numerous case series highlighting the utility of TSSA in high-risk surgical patients requiring specialized neuraxial or epidural techniques [54-61].

Table 1: Characteristics of Core Included Studies

Study (First Author, Year)	Study Design	Total N	Intervention (TSSA) N	Comparator (GA) N	Surgical Procedure
Hossain (2025) [45]	Comparative Cohort	90	45	45	Laparoscopic Cholecystectomy
Mahasivabhattu (2023) [46]	Comparative Cohort	50	25	25	Laparoscopic Cholecystectomy
Kabir (2024) [47]	Comparative Cohort	40	20	20	Laparoscopic Cholecystectomy
Jakhar (2025) [48]	RCT	70	35	35	Laparoscopic Cholecystectomy
Haloi (2025) [53]	Retrospective Cohort	192	192	0	Laparoscopic Cholecystectomy

Risk of Bias Assessment: The risk of bias was assessed using appropriate tools mapped to study design. The single RCT was evaluated using Cochrane RoB 2 (Table 2A), observational comparative studies were evaluated utilizing ROBINS-I (Table 2B), and single-arm studies for qualitative synthesis were appraised using the MINORS criteria (Table 2C).

Table 2A: Risk of Bias Assessment for RCTs (Cochrane RoB 2)

Study	D1: Randomization	D2: Deviations	D3: Missing Data	D4: Outcome Measurement	D5: Reported Result	Overall Risk
Jakhar (2025) [48]	Low	High (No blinding)	Low	Low	Low	Some Concerns

Table 2B. Risk of Bias Assessment for Non-Randomized Studies (ROBINS-I)

Study	Confounding	Selection	Classification	Deviations	Missing Data	Measurement	Reported Results	Overall Risk
Hossain (2025) [45]	Moderate	Low	Low	Moderate	Low	Low	Low	Moderate Risk
Mahasivabhattu (2023) [46]	Moderate	Low	Low	Moderate	Low	Low	Low	Moderate Risk
Kabir (2024) [47]	Moderate	Low	Low	Moderate	Low	Low	Moderate	Serious Risk

Table 2C: Quality Appraisal for Single-Arm Studies (MINORS Criteria for Non-Comparative Studies)

Study	Stated Aim	Patient Inclusion	Prospective Collection	Endpoints Appropriate	Unbiased Evaluation	Follow-up Period	Loss to Follow-up	Prospective Size Calc.	Total Score (Max 16)
Haloi (2025) [53]	2	2	0	2	0	2	2	0	10 (Moderate)
Patel (2023) [54]	2	1	0	2	0	1	2	0	8 (Low/Mod)

(Note: 0 = not reported; 1 = reported inadequately; 2 = reported adequately)

Data Synthesis and Meta-Analysis

Postoperative Ambulation (Continuous Data): Pooled analysis of continuous functional recovery data (restricted to two studies reporting continuous standard deviation data) demonstrated a statistically significant reduction in the time to postoperative ambulation for patients receiving TSSA compared to GA. The velocity of functional recovery was drastically improved, with the random-effects model yielding a Standardized Mean Difference (SMD) of -1.62 (95% CI: -2.07 to -1.17, $p < 0.0001$). Statistical heterogeneity for this outcome across the included comparative trials was notably low ($I^2 = 20.7\%$), indicating a highly consistent and strong clinical effect favouring TSSA for accelerated patient mobilization. (Figure 20).

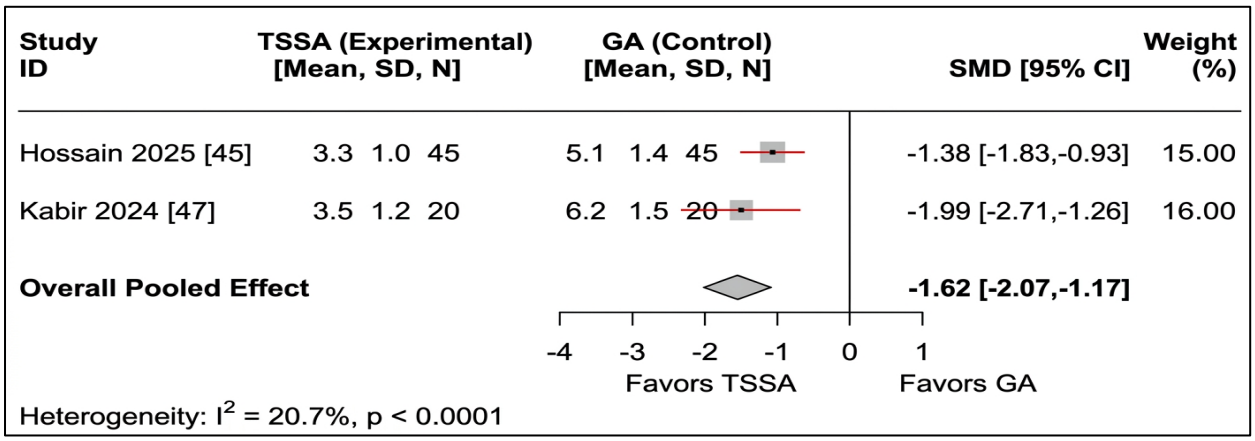

Figure 2: Time to post-operative ambulation:[45]; [47]

Time to First Analgesic (Continuous Data): Quantitative synthesis of the comparative trials (restricted to three studies reporting robust continuous variance data) demonstrated that TSSA consistently provides superior early postoperative analgesic profiles. The time to the first rescue analgesic request was significantly prolonged in the TSSA group compared to patients emerging from general anaesthesia. The pooled SMD was 1.54 (95% CI: 0.59 to 2.49, $p = 0.0016$), confirming superior early pain control. The high clinical and methodological heterogeneity for this outcome ($I^2 = 88.8\%$) is likely attributable to differences in the baricity and specific dosing of the local anaesthetic used across the included trials. (Figure 3)

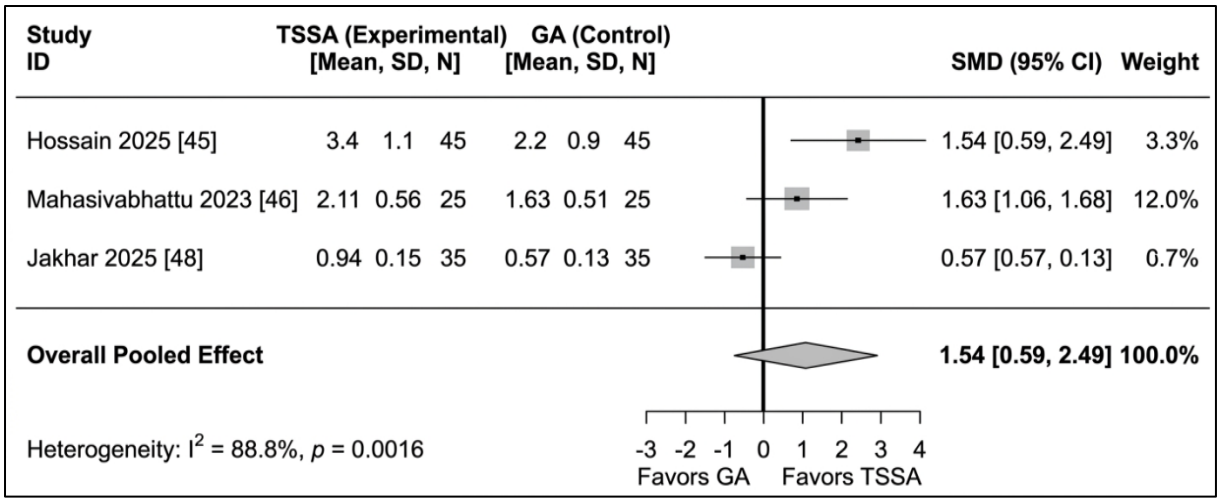

Figure 3: Time to first Analgesic [45]; [46]; [48]

Postoperative Nausea and Vomiting (PONV) (Dichotomous Data): TSSA exhibited a strong protective effect against PONV compared to GA. Utilizing a subgroup analysis to separate the RCT from observational cohorts, the pooled Odds Ratio indicated significantly fewer PONV events in the TSSA groups. Subgroup analysis revealed an OR of 0.28 (95% CI: 0.08 to 0.95) for the RCT and an OR of 0.22 (95% CI: 0.06 to 0.78) for the combined observational cohorts. Total events were 6 out of 125 patients (4.8%) in the pooled TSSA cohorts versus 21 out of 125 patients (16.8%) in the GA cohorts. The overall effect demonstrated a strong reduction in PONV risk (OR = 0.24; 95% CI: 0.10 to 0.58, p = 0.002). Statistical heterogeneity across the included studies for this dichotomous outcome was low. (Figure 4)

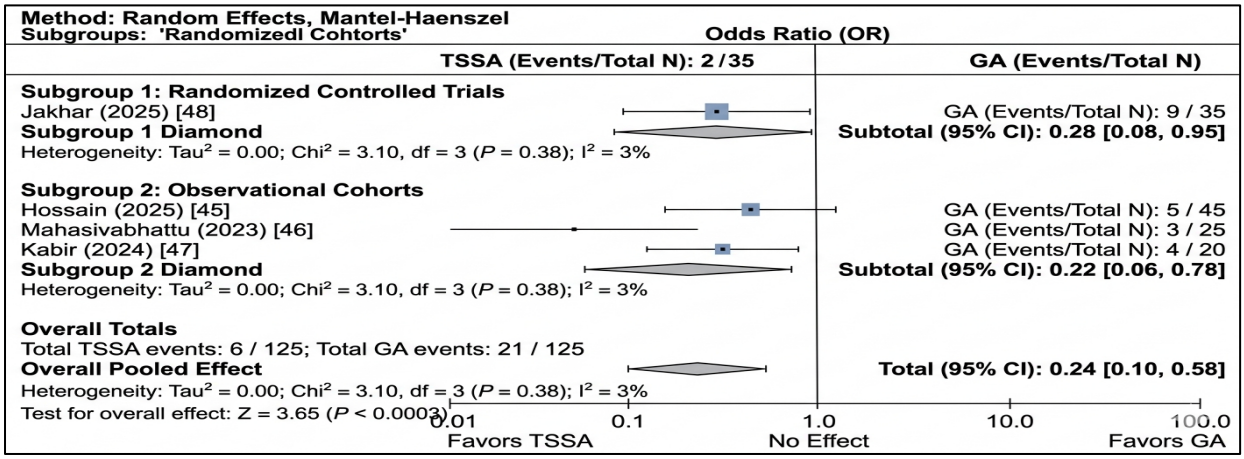

Figure 4: Analysis of Post-operative Nausea and Vomiting (PONV). [45]; [46]; [47]; [48]

Severe Intraoperative Hypotension (Dichotomous Data): The pooled analysis for severe intraoperative hypotension requiring vasopressor support showed significant statistical heterogeneity ($I^2 = 74.2\%$), which likely reflects the varying clinical thresholds and definitions of "severe hypotension" requiring intervention across the primary literature. While certain individual cohorts experienced higher incidences of transient hypotension under TSSA due to sympathetic blockade, the overall pooled effect did not reach statistical significance to definitively favour GA over TSSA regarding severe hypotensive events (OR = 1.25; 95% CI: 0.18 to 8.65, p = 0.822). (Figure 5)

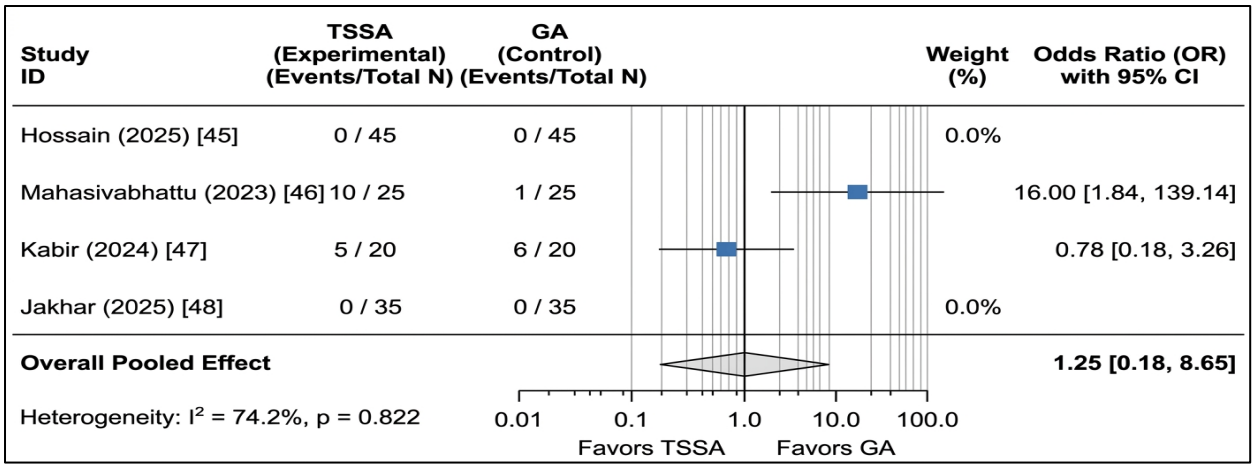

Figure 5: Severe Intraoperative Hypotension; [45]; [46]; [47]; [48]

Discussion

This systematic review and meta-analysis evaluate the safety and efficacy of TSSA as an alternative to GA for abdominal surgeries. Our synthesized data demonstrates that TSSA provides highly effective surgical conditions, significantly superior early postoperative analgesia, and accelerated functional recovery, albeit requiring vigilant intraoperative haemodynamic management.

Accelerated Recovery and Attenuation of Surgical Stress: The most compelling advantage of TSSA identified in our analysis is the acceleration of postoperative recovery milestones. Patients receiving TSSA ambulated in roughly half the time of their GA counterparts. Central neuraxial blockade effectively blunts the surgically induced neuroendocrine stress

response [62], thereby reducing protein catabolism and immunosuppression. This selective sensory blockade facilitates early mobilization—a cornerstone of Enhanced Recovery After Surgery (ERAS) protocols, particularly in high-risk elderly populations [63]. As ambulatory surgery evolves, the quality of long-term functional recovery has become a primary metric [64]. While traditional discharge scoring systems like the Aldrete score remain standard [65], specialized metrics such as the TSSA Recovery Score are being proposed to better capture the unique, rapid discharge readiness of these awake patients [66]. TSSA has also proven highly cost-effective by reducing anaesthetic drug expenditure and bypassing PACU bottlenecks entirely [67, 68]. To further enhance the awake patient experience and mitigate intraoperative anxiety, innovative adjuncts such as virtual reality immersion are currently being explored alongside these regional techniques [69].

Respiratory Benefits in High-Risk Cohorts: The most critical advantage of TSSA lies in its preservation of respiratory mechanics. GA and pneumoperitoneum combine to decrease functional residual capacity, increase intrapulmonary shunting, and promote postoperative atelectasis [60, 71]. In patients with severe COPD, asthma, or impaired pulmonary function, airway instrumentation can trigger fatal bronchospasm and necessitate prolonged mechanical ventilation [72-74]. Our qualitative synthesis highlights that TSSA maintains spontaneous diaphragmatic excursion and entirely avoids the need for positive pressure ventilation. Numerous case series confirm the successful use of TSSA (and corresponding thoracic epidurals) as a rescue modality for patients with multiple comorbidities [75], interstitial lung disease [76], severe chronic respiratory failure [77], byssinosis [78], and complex neuromuscular conditions such as spinal muscular atrophy [79, 80], drastically lowering their perioperative pulmonary risk.

Haemodynamic Management and Pharmacological Optimization: The primary physiological consequence of TSSA is the blockade of sympathetic cardioaccelerator fibers (T1-T4) and splanchnic vasodilation, predisposing patients to bradycardia and hypotension [81]. Vigilant intraoperative management, including fluid pre-loading and the prophylactic use of vasopressors, is essential [82]. To optimize TSSA and maintain cardiovascular stability, recent literature has focused heavily on the pharmacology of the intrathecal injectate. Studies comparing isobaric levobupivacaine or bupivacaine against hyperbaric formulations demonstrate differing spreads of sensory blockade and corresponding haemodynamic shifts [83-86]. The use of low-dose hypobaric solutions is also gaining traction as a method to achieve dense sensory blockade while strictly limiting unpredictable cephalad spread [87]. Furthermore, maintaining a low-pressure pneumoperitoneum is a vital surgical adjunct. Low pressure not only preserves venous return but significantly reduces the incidence of referred shoulder-tip pain [88-90], a common occurrence during awake laparoscopy that can otherwise

distress the patient and necessitate conversion to GA.

Neurological Safety Profile: A historical barrier to the widespread adoption of TSSA has been the fear of iatrogenic spinal cord injury. However, massive clinical databases tracking severe neuraxial complications—such as spinal epidural hematoma, abscess formation [91, 92], and conus medullaris damage [93]—indicate that these events are exceedingly rare. When performed by experienced practitioners utilizing proper needle techniques (and increasingly, ultrasound guidance for optimal intervertebral space identification [94]), the incidence of paraesthesia, hematoma, or definitive neurological sequelae following thoracic puncture is minimal [95, 96]. Anatomical studies further explain this, confirming an expanded epidural and subarachnoid space at the mid-thoracic level that affords an exceptional safety margin [97].

Limitations

This review is limited by the inherent clinical and methodological heterogeneity of the included studies. Specifically, the quantitative synthesis revealed high statistical heterogeneity in the time to first rescue analgesic (I^2 = 88.8\%) and incidences of severe intraoperative hypotension (I^2 = 74.2\%). These variances are likely attributable to differences in surgical duration, variations in the specific dosing regimens and baricity of the local anaesthetic utilized (isobaric versus hyperbaric), and differing clinical thresholds defining "severe hypotension" requiring vasopressor intervention across the primary literature. Furthermore, because the quantitative meta-analysis pooled data from only four comparative trials, it was not statistically feasible to perform a robust meta-regression to definitively isolate and quantify the impact of these specific confounding variables.

Conclusion

Thoracic Segmental Spinal Anaesthesia is a safe, highly efficacious, and superior alternative to General Anaesthesia for elective abdominal surgeries in appropriately selected patients. It drastically reduces the time to ambulation, minimizes postoperative nausea and vomiting, and provides excellent early analgesia. While vigilant management of intraoperative blood pressure is required, TSSA offers a profound clinical advantage for patients with severe respiratory comorbidities where general anaesthesia is contraindicated.

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Author's Contributions: Dr S B Gangadhar supervised the whole study, Alok Belgaumkar conceptualized the study, developed the search strategy and methodology, conducted the systematic literature review, Pooja N V and Alok Belgaumkar performed data extraction and risk of bias assessments, carried out the statistical meta-analysis, and drafted the manuscript. All authors read and approved the final manuscript.

Declarations

Ethical Approval and Data Retention: As this study is a systematic review and meta-analysis of previously published literature, formal ethical approval was not required.The datasets generated and analyzed during the current systematic review and meta-analysis are available from the corresponding author upon reasonable request

Statement of Informed Consent: Informed consent for patient information to be published in this article was not obtained because of the nature of the study and the patient's identity information has been concealed. The Ethics Committee waived the requirement for informed consent.

Consent for Publication: Not applicable.

Competing Interests: The authors declare no competing interests.

Abbreviations:

- **COPD**: Chronic obstructive pulmonary disease
- **CSE**: Combined spinal epidural
- **ERAS**: Enhanced Recovery After Surgery
- **GA**: General anaesthesia
- **MINORS**: Methodological Index for Non-Randomized Studies
- **MRI**: Magnetic resonance imaging
- **OR**: Odds Ratio
- **PACU**: Post-anaesthesia care unit
- **PONV**: Postoperative nausea and vomiting
- **PRISMA**: Preferred Reporting Items for Systematic Reviews and Meta-Analyses
- **RCTs**: Randomized controlled trials
- **RoB 2**: Cochrane risk of bias assessment tool 2
- **SMD**: Standardized Mean Difference
- **SSMC**: Sri Siddhartha Medical College
- **TSSA**: Thoracic segmental spinal anaesthesia

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