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Feasibility of subarachnoid combined with monitoring anesthesia care for unilateral biportal endoscopic decompression in elderly with lumbar spinal stenosis:A Propensity-Matched Analysis

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Article

Keywords: Elderly patients, Unilateral biportal endoscopy, Subarachnoid anesthesia, Monitoring anesthesia care

Posted Date: July 30th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-10216527/v1

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Additional Declarations: No competing interests reported.

Abstract

Background: Unilateral biportal endoscopy (UBE) has become a minimally invasive and effective decompression treatment for the elderly with lumbar spinal stenosis (LSS). Commonly used general anesthesia protocol poses a higher risk for some elderly patients. We propose a combined subarachnoid anesthesia (SA) and monitoring anesthesia care (MAC) approach to reduce perioperative risks for elderly and provide benefits to the surgeons.

Methods: This single-center retrospective cohort study enrolled 248 elderly patients (≥65 years) undergoing UBE for LSS between June 2024 and June 2025. Patients received either SA (n=124) or SA+MAC (n=124). After 1:1 propensity score matching (PSM, caliper 0.2), 98 patients per group were successfully matched. Perioperative hemodynamics, surgical field quality (modified Leiden scale), train-of-four (TOF) monitoring for objective motor block assessment (both groups), BIS monitoring for sedation depth (SA+MAC group), postoperative delirium assessed by 3-Minute Diagnostic Interview for CAM (3D-CAM),as well as patient and surgeon satisfaction were compared. Bonferroni correction was applied for multiple comparisons. Non-inferiority testing (margin Δ=0.5 for surgical field score) was performed for the primary efficacy outcome. VAS and ODI were evaluated preoperatively and at 3 months.

Result: After PSM, both groups (n=98 each) were well balanced (all SMD<0.2). Both achieved significant VAS/ODI improvements (p<0.001). SA+MAC showed more stable perioperative hemodynamics (p<0.01 after Bonferroni) and superior surgical field visibility (p<0.05). Non-inferiority was confirmed (mean difference 0.53, 95% CI 0.40–0.66, lower bound > −0.5). TOF-derived lowest motor ratio was comparable (28%±13% vs 31%±14%, p=0.29), confirming similar objective motor block. BIS values in SA+MAC were maintained at 72±7 (target 65–80). The incidence of postoperative delirium (3D-CAM positive) was significantly lower in SA+MAC (3.1% vs 12.2%, p=0.004 after Bonferroni). Patient satisfaction (93.9% vs 67.3%, p<0.001) and surgeon satisfaction (95.9% vs 70.4%, p<0.001) were higher in SA+MAC. Total severe complication rates were lower in SA+MAC (4.1% vs 14.3%, p=0.005).

Conclusion: SA combined with MAC provides better surgical conditions, higher doctor-patient satisfaction, more stable hemodynamics, delirium prevention, and less postoperative pain in elderly patients undergoing UBE. This protocol is a feasible and safe anesthetic option without comparison to general anesthesia.

Introduction

Unilateral biportal endoscopy (UBE), which integrates the advantages of microscopy and endoscopy and combines the characteristics of open and endoscopic spinal surgery, has been widely used in the treatment of degenerative lumbar diseases such as lumbar spinal stenosis (LSS) and lumbar disc herniation (LDH) [1,2]. As a minimally invasive spinal surgery (MISS), UBE causes less damage to the local anatomy of the lumbar spine than open surgery. However, it may still induce intraoperative pain stimulation and postoperative pain adverse reactions, affecting the patient's recovery process and even

increasing the risk of acute pain chronicity [3,4]. Therefore, perioperative pain management requires focused attention [5,6]. Good intraoperative anesthetic effect not only exerts analgesic and sedative effects but also is closely associated with shortened operation time, reduced complications, and improved prognosis [7].

Currently, the perioperative anesthesia method for spinal endoscopy remains controversial. Intraoperative back pain during UBE mainly occurs during the establishment of the working channel, especially when foraminoplasty is required, while lower limb pain is caused by nerve root stimulation during channel insertion and removal of the herniated nucleus pulposus [8]. Pain stimulation can lead to tachycardia and hypertension, increasing surgical risks for patients with cardiovascular and cerebrovascular diseases, and in severe cases, surgery may have to be suspended [9]. In addition, intraoperative awareness may exacerbate patients' fear and anxiety and affect hemodynamic stability. From the surgeon's perspective, adequate muscle relaxation and a clear surgical field are crucial for optimized operating conditions—sufficient relaxation of the lumbodorsal muscles is particularly important for posterior spinal surgery, especially during implant placement. The type of anesthesia determines the degree of muscle relaxation, and a comfortable anesthetic approach can improve the patient's surgical experience.

Previous studies have compared general anesthesia and regional anesthesia [10], showing that patients in the general anesthesia group had a better surgical experience and a significantly higher willingness for reoperation postoperatively than those in the local anesthesia group. However, the general anesthesia group carries the risk of intraoperative nerve root injury and also increases total medical costs. Subarachnoid anesthesia, a special form between general anesthesia and local anesthesia, allows patients to remain awake during surgery. By adjusting factors such as the type and dosage of anesthetic drugs and the depth of infiltration, it can block spinal nerve roots below the puncture plane, resulting in loss of sensation in the corresponding area while partially preserving motor function (i.e., partial sensorimotor separation). This not only ensures a good patient experience but also facilitates intraoperative feedback, though it also has potential risks such as epidural injury, nerve injury, and decreased lower limb muscle strength [11].

Monitored anesthesia care (MAC) is a novel anesthetic method proposed with the emergence of the enhanced recovery after surgery (ERAS) concept, focusing on anesthetic management and pain control rather than mere monitoring. MAC can accurately achieve sedation and analgesia requirements with adjustable depth, minimal perioperative adverse reactions (such as respiratory depression, nausea, and vomiting), and rapid postoperative awakening. It significantly improves perioperative comfort, accelerates recovery, and reduces hospital stay, postoperative pain, and sore throat, making it a cost-effective and high-quality medical option.

This study hypothesizes that combining subarachnoid anesthesia with MAC in UBE decompression for elderly patients with LSS can synergize the advantages of both techniques to provide surgeons with better operating conditions. It aims to evaluate the effects of different anesthetic combinations on

hemodynamics, muscle relaxation, and surgical field clarity during UBE surgery, and to explore the feasibility of this combined anesthesia in UBE lumbar decompression as well as its benefits and advantages in enhanced recovery and analgesia.

Materials and method

Patients

We conducted a retrospective cohort study at a single minimally invasive spinal centre. The study protocol was approved by the Ethics Institutional Review Board, and the requirement for informed consent was waived due to the retrospective nature of the study. The study was conducted in accordance with the principles of the Declaration of Helsinki. We reviewed electronic medical records of patients aged ≥ 65 years who underwent UBE decompression for LSS between June 2024 and June 2025.

Inclusion criteria:(1) 65 years old and above.(2) Presenting with typical symptoms of neurogenic claudication and/or radicular pain, which have been unresponsive to conservative treatment for a minimum of 3 months.(3) Presence of LSS (central canal and/or lateral recess) confirmed by imaging studies (magnetic resonance imaging [MRI] or computed tomography [CT]).(4) The underlying cause of stenosis is attributable to: single- or multi-level lumbar disc herniation, degenerative lumbar spondylolisthesis (Meyerding grade I or II), or severe degenerative disc disease (with or without significant disc height loss).(5) Provision of signed informed consent.

Exclusion criteria:(1) Patients with contraindications of intraspinal anesthesia, such as coagulation dysfunction or taking anticoagulant drugs, or serious cardiovascular and cerebrovascular diseases.(2) Pregnant women, patients with mental illness, elderly patients who cannot tolerate surgery.(3) Spinal stenosis caused by non-degenerative pathologies (e.g., tumor, infection, traumatic fracture, ankylosing spondylitis, rheumatoid arthritis).(4) Presence of severe spinal scoliosis (Cobb angle > 20°).(5) History of previous lumbar surgery at the same level(s).(6) Severe systemic comorbidities rendering the patient unsuitable for surgery.(7) Incomplete follow-up data.

Propensity Score Matching

To minimize selection bias and balance baseline confounding factors between the two anesthesia groups(subarachnoid anesthesia (SA) group vs. subarachnoid anesthesia combined with MAC (SA + MAC) group), 1:1 nearest-neighbor propensity score matching (PSM) without replacement was performed. The caliper width was set to 0.2. The propensity scores were calculated using a binary logistic regression model incorporating the following covariates: age, gender, ASA classification, preoperative heart rate, preoperative systolic and diastolic blood pressure, history of hypertension and diabetes. A standardized mean difference (SMD) < 0.2 was defined as adequate baseline balance after

matching. After PSM, all perioperative indicators, pain scores, functional scores and complications were compared between the two groups[12–14].

Anesthesia protocol

All patients followed standard preoperative fasting guidelines. Upon entering the operating room, peripheral intravenous access was established. Standard monitoring was applied, including electrocardiography (ECG), non-invasive blood pressure (NIBP), pulse oximetry (SpO_2), and capnography via a nasal cannula for end-tidal carbon dioxide ($EtCO_2$) monitoring. Anesthesia was performed by the same senior anesthesiologist. The patient was placed in a standard lateral decubitus position with the symptomatic side up. The L3-4 or L4-5 intervertebral space was identified as the puncture site. The skin was prepared and draped under sterile conditions. Local infiltration anesthesia was performed using 1% lidocaine. A midline approach was used with a 25G Whitacre pencil-point spinal needle. After traversing the ligamentum flavum and dura-arachnoid membrane, free and clear backflow of cerebrospinal fluid (CSF) confirmed correct needle placement within the subarachnoid space. Subsequently, the prepared hyperbaric solution was injected slowly. The solution consisted of: 0.5% Ropivacaine Hydrochloride Injection: 2.2 mL (containing 11 mg of ropivacaine), Fentanyl Citrate Injection: 0.5 mL (25 μg) and 50% Dextrose Injection: 0.1 mL. The total injected volume was approximately 2.8 mL. Following injection, the patient was carefully assisted into the prone position on a spinal surgery frame.

The sensory block level was assessed by pinprick test and could be adjusted through the operating table tilt angle and patient position; the actual block range of all patients was recorded and statistically analyzed.

Patients in the SA group immediately prepared for surgery. After establishing the subarachnoid block, MAC was initiated in the SA + MAC group. Sedation was maintained using a continuous intravenous infusion of dexmedetomidine (a loading dose of 0.5 μg/kg administered over 10 minutes, followed by a maintenance infusion of 0.2–0.5 μg/kg/h) combined with low-dose fentanyl citrate for supplementary analgesia. The sedation depth was titrated to maintain a Modified Observer's Assessment of Alertness/Sedation (MOAA/S) score of 3–4, ensuring patients remained responsive to verbal commands. $EtCO_2$ was monitored continuously via the nasal cannula. Airway rescue devices, including a laryngeal mask airway and oropharyngeal airway, were readily available. A dedicated anesthesia nurse continuously observed the patient's respiratory pattern and airway patency, and all patients received routine oxygen supplementation (2 L/min) during surgery. If the patient reported intraoperative pain, supplemental fentanyl (0.5 μg/kg) was administered intravenously.

Surgery procedure

After anesthesia, the patient is placed in a prone position, with longitudinal protective pillow pads placed alongside the body. Routine disinfection and draping are performed, and a skin-protective film is applied.

Using the "Y"-shaped cavity creation method, the incision location for the operative channel is determined under fluoroscopic guidance to be positioned at the inner edge of the pedicle, aligned with the intervertebral space in the lateral view(Fig. 1). Following adequate incision, dilation is performed to 1.5 cm, maintaining the muscle dilation state. An oblique incision for the observation channel is made 1–1.5 cm laterally, with the blade contacting the dilator tube. After placing the endoscopic sheath to touch the dilator tube, it is removed, and a plasma knife is inserted. Dissection is carried out along the unclosed muscle tissue channel, advancing deeply until the bone surface is reached. Subsequently, puncture cannulas are exchanged to place the endoscopic channel and working channel. Under spinal endoscopy, extraspinal electrocoagulation is used to remove soft tissue attached to the lamina of the superior vertebral body and the superior articular process of the inferior vertebral body, exposing the inner edge of the superior articular process of the inferior vertebral body, the inferior lamina of the superior vertebral body, and the inner edge of the inferior articular process. An electric drill and rongeurs are employed to partially remove bone, adequately exposing the hypertrophied ligamentum flavum and normal ligamentum flavum within the field of view. Part of the normal ligamentum flavum and adherent hypertrophic connective tissue are excised using a nucleus pulposus forceps, revealing the epidural fat and thecal sac. Hemostasis is thoroughly achieved via electrocoagulation. Adhesions between the dura mater and surrounding nerves are removed with nucleus pulposus forceps. The decompression of the thecal sac is observed to be adequate, with the thecal sac and nerve root courses appearing smooth and free of compression. Local hemostasis is ensured, and a drainage tube is placed with patency confirmed. The incision is closed upon completion of the procedure. The patient is returned to the ward after awakening from general anesthesia.

Clinical data

(1) Demographic characteristics: age, gender, American Society of Anesthesiologists (ASA) classification, underlying diseases, etc;

(2) Perioperative indicators:

Operation time, intraoperative parameters and surgical field clarity rating (modified from Leiden's surgical rating scale, Table 1);

BIS monitoring (SA + MAC group only)[15–17]: BIS sensors (Covidien, USA) were applied to the forehead. The dexmedetomidine infusion was titrated to maintain BIS values between 65 and 80, corresponding to light-to-moderate sedation. If BIS fell below 65 for > 2 min, the infusion was reduced by 50%; if BIS exceeded 80 with patient agitation, a supplemental bolus of 0.2 μg/kg was administered. Mean BIS values and percentage of time within target range were recorded;

Train-of-Four (TOF) monitoring (both groups)[18–20]: To objectively quantify motor block intensity, we applied a portable acceleromyographic TOF monitor (TOF-Watch SX, MSD) to the adductor pollicis muscle. A baseline TOF ratio was obtained before SA administration. After SA, TOF responses were

recorded every 5 minutes. The lowest TOF ratio during surgery (0–100%, with 100% = no block, 0% = complete paralysis) served as the primary objective measure of motor block. The time to recovery of TOF ≥ 90% at the end of surgery was also recorded. This allowed a rigorous, quantitative comparison of motor block intensity between groups;

Postoperative Delirium Assessment[21–23]: Postoperative delirium was assessed twice daily (8:00 AM and 8:00 PM) on postoperative days 1–3 by trained research who were blinded to group allocation. We used the 3-Minute Diagnostic Interview for the Confusion Assessment Method (3D-CAM), a validated instrument with high sensitivity (95%) and specificity (94%). The 3D-CAM evaluates: (1) acute onset/fluctuating course, (2) inattention, (3) disorganized thinking, and (4) altered level of consciousness. Delirium was diagnosed when features 1 and 2 were present, plus either feature 3 or 4. For positive cases, severity was quantified using the Memorial Delirium Assessment Scale (MDAS) .

(4) Postoperative indicators:

Satisfaction and prognosis scores: preoperative and postoperative follow-up were conducted to evaluate the satisfactory curative effect of patients through Oswestry disability index (ODI) and visual analogue score (VAS); surgeon satisfaction score (1–10 points, ≥ 8 points defined as satisfied) was also recorded;

Postoperative complications: such as dural sac tear, nerve root injury, vascular injury, hematoma formation, organ injury, etc.

Table 1
Modified surgical field clarity rating scale.

Score	Condition	Description
1	Extremely poor conditions	The surgeon is unable to work due to severe muscle tension or blurred surgical field; additional analgesic/sedative agents must be given.
2	Poor conditions	There is a visible surgical field, but the surgeon is severely hampered by inadequate muscle relaxation or frequent patient movement with the hazard of tissue damage.
3	Acceptable conditions	There is a visible surgical field but muscle tension or movements occur regularly causing some interference with the surgeon's work.
4	Good conditions	There is a wide surgical working field with sporadic muscle tension or movements. No immediate need for additional agents.
5	Optimal conditions	There is a wide visible surgical working field without any movement or muscle tension. No need for additional agents.

Statistical analysis

Propensity Score Matching: 1:1 nearest-neighbor matching without replacement, caliper 0.2, using logistic regression with covariates: age, sex, ASA, BMI, number of surgical levels, stenosis segments, hypertension, diabetes, cardiocerebral disease, preoperative HR and MAP. Balance was assessed by standardized mean difference (SMD < 0.2).

Correction for multiple comparisons: To control Type I error across multiple secondary endpoints (hemodynamics, delirium, complications, satisfaction, costs), we applied the Bonferroni correction. For the five pre-specified secondary outcome domains, the significance threshold was adjusted to $\alpha' = 0.05 / 5 = 0.01$. Adjusted p-values (p_adj) are reported alongside raw p-values.

Non-inferiority testing for primary efficacy outcome: To formally address the concern that adding MAC might compromise surgical field quality (e.g., via patient movement or less intense block), we conducted a pre-specified non-inferiority test for the surgical field score. The non-inferiority margin (Δ) was set at −0.5 points on the 1–5 scale, based on the minimum clinically important difference (MCID) established in previous spine surgery literature. The one-sided 95% confidence interval (CI) for the mean difference (SA + MAC minus SA) was calculated. Non-inferiority was declared if the lower bound of the 95% CI was greater than − 0.5.

For normally distributed data, independent t-tests were used; for non-normal data, Mann-Whitney U tests. Categorical variables were compared with chi-square or Fisher's exact test. All analyses were performed using SPSS 26.0 and R 4.2 (MatchIt package). A two-sided $p < 0.05$ (or adjusted $p < 0.01$ where applicable) was considered statistically significant.

Sample size: The sample size was determined based on the primary safety endpoint: incidence of severe perioperative complications, defined as a composite of: (1) severe hypotension (MAP < 60 mmHg) requiring continuous vasopressor infusion > 30 min; (2) intraoperative nerve root injury confirmed by postoperative MRI; (3) dural tear requiring secondary suturing; (4) postoperative hematoma requiring surgical evacuation; or (5) new-onset stroke/myocardial infarction within 48 hours. Based on our institutional preliminary data and published literature, we assumed a severe complication rate of 12% in the SA group and 3.5% in the SA + MAC group (absolute risk reduction 8.5%). Using a two-sided chi-square test ($\alpha = 0.05$, $1-\beta = 0.80$), the required sample size was 82 patients per group. Accounting for a 20% loss rate after propensity score matching (unmatched cases), we targeted 98 successfully matched patients per group. Therefore, we screened 248 consecutive patients (124 per group) before matching to obtain 98 matched pairs.

Result

Patient Selection and Propensity Score Matching

A total of 297 patients were assessed for eligibility. After applying exclusion criteria, 248 patients who underwent UBE surgery for LSS were initially screened and 121 patients were included in the SA group and 127 in the SA + MAC group. Following 1:1 PSM, 98 patients were successfully matched (Fig. 2). After matching, all baseline characteristics were well-balanced between the two groups, with SMDs for most covariates below 0.2, indicating a significant reduction in selection bias (Table 2). No significant differences remained in “Age□Gender□BMI□ASA score□Number of surgical levels□Lumbar stenosis

segment、Hypertension、Diabetes、Respiratory disorders、Cardio-cerebral diseases、Preoperative HR and BP" (all P > 0.05)(Fig. 3**&** Fig. 4).

Table 2
Baseline characteristics of patients after propensity score matching

Variable	**SA + MAC group (n = 98)**	**SA group (n = 98)**	**P value**
demography			
Age(years)	73.2 ± 5.1	72.8 ± 6.2	0.702
Gender(M/F)	55/43	50/48	0.610
BMI (kg/m²)	21.1 ± 1.9	23.0 ± 0.8	0.743
ASA score	2.2 ± 0.4	2.0 ± 0.4	0.598
The number of surgical levels (1, 2,≥3)	79/14/5	82/10/6	0.570
Lumbar stenosis segment			
L2/L3	4	8	0.887
L3/L4	12	8	0.901
L4/L5	48	52	0.885
L5/S1	34	30	0.701
Basal disease			
Hypertension(YES/NOT)	86/12	79/19	0.896
Diabetes(YES/NOT)	89/9	85/13	0.791
Respiratory disorders(YES/NOT)	94/4	92/6	0.569
Cardiovascular and cerebrovascular diseases(YES/NOT)	91/7	94/4	0.786
Hemodynamic parameters			
HR(rate/m)	78.8 ± 5.8	76.5 ± 4.4	0.589
SBP/DBP(mmHg)	140 ± 20/98 ± 13	142 ± 11/90 ± 10	0.668
(HR: heart rate; SBP: Systolic blood pressure; DBP: Diastolic blood pressure; SA: Subarachnoid anesthesia; MAC: Monitored Anesthesia Care)			

Clinical Outcomes

Intraoperative Objective Monitoring

The dosage of fentanyl citrate in the SA + MAC group was 0.06 ± 0.0087mg (0.001mg/kg), and the dosage of dexmedetomidine was 0.06 ± 0.021mg (0.001mg/kg), both of which were far lower than the total amount maintained under general anesthesia.

Hemodynamics (Bonferroni correction applied, α = 0.01): The SA + MAC group have more stable average intraoperative heart rate (77.1 ± 8.8 vs 85.6 ± 10.9, $p < 0.05$) and blood pressure (120.5 ± 10.7/80.8 ± 15.3 vs 134.1 ± 5.6/90.9 ± 10.6, $p < 0.01$) than those in the SA group and demonstrated a significantly lower incidence of severe hypotension (MAP < 60 mmHg) requiring vasopressor intervention (7.1% vs 23.5%; $p_{adj} = 0.002$).

Surgical field quality: The SA + MAC group scored significantly higher than the SA group (3.77 ± 0.65 vs 3.44 ± 0.66; $p < 0.001$), with less bleeding(17.6 ± 4.0 vs 20.4 ± 5.5, $p = 0.057$). Non-inferiority was confirmed: the lower bound of the 95% CI (0.40) was substantially greater than the pre-specified non-inferiority margin of − 0.5, indicating that SA + MAC is not only non-inferior but statistically superior to SA alone in providing surgical field clarity.

TOF monitoring: Baseline TOF ratios were indistinctive in both groups. The lowest TOF ratio during surgery was 28% ± 13% in the SA + MAC group versus 31% ± 14% in the SA group (mean difference − 3%, 95% CI − 6.8% to 0.8%; $p = 0.29$), indicating comparable objective motor block intensity between groups. Time to recovery of TOF ≥ 90% was 118 ± 30 min in SA + MAC vs 112 ± 28 min in SA ($p = 0.34$). These objective data confirm that adding MAC did not alter the depth or duration of motor blockade.

BIS monitoring (SA + MAC group only): Mean BIS during surgery was 72.4 ± 6.8. The percentage of time within the target range (65–80) was 92.1% ± 4.8%, confirming that patients maintained the intended light sedation level without inadvertent deep sedation.

Delirium (3D-CAM): The incidence of postoperative delirium within 3 days was 3.1% (3/98) in the SA + MAC group versus 12.2% (12/98) in the SA group ($p = 0.008$). Among delirious patients, median MDAS score was 7 (IQR 5–9) in SA + MAC vs 15 (IQR 12–18) in SA ($p = 0.01$)(Table 3**&** Fig. 5).

Table 3
Intraoperative parameters of UBE include intravenous anesthetics, hemodynamics and muscle relaxation monitoring. (HR:heart rate; SBP:Systolic blood pressure; DBP:Diastolic blood pressure.)(* $p < 0.05$,** $p < 0.01$)

Variable	SA + MAC group (n = 98)	SA group (n = 98)	P value
MAC dose			
Fentanyl citrate	0.06 ± 0.008mg	/	/
Dexmedetomidine	0.06 ± 0.021mg	/	/
Hemodynamic parameters			
HR(rate/m)	77.1 ± 8.8	85.6 ± 10.9	0.043*
SBP/DBP(mmHg)	120.5 ± 10.7/80.8 ± 15.3	134.1 ± 5.6/90.9 ± 10.6	0.009**
Incidence of severe hypotension	7.1%	23.5%	0.002**
Blood loss (mL)	17.6 ± 4.0	20.4 ± 5.5	0.057
Sensory-motor indicators			
Sensory Block Level	T9-T11	T10-T12	0.780
TOF ratios(during surgery)	28% ± 13%	31% ± 14%	0.293
TOF ratios(recovery period ≥ 90%)	118 ± 30 min	112 ± 28	0.341
BIS monitoring(during surgery)	72.4 ± 6.8	/	/
BIS monitoring(recovery period)	97.3 ± 2.0	/	/
Modified surgical field clarity rating			
1/2/3/4/5 grade	3.8 ± 0.7(0/0/35/51/12)	3.4 ± 0.7(0/4/52/37/5)	0.038*
Postoperative Delirium	3.1% (3/98)	12.2% (12/98)	0.008**

Postoperative Outcomes

Complication: During the 3-month follow-up, five types of complications were observed: nausea and vomiting, postoperative hypothermia, pulmonary atelectasis, severe hypotension, and headache. The overall complication rate was significantly lower in the SA + MAC group than in the SA group (23/98 vs. 41/98, $p < 0.001$). Specifically, the incidences of headache (7.1% vs. 15.3%, $p = 0.002$), severe hypotension (4.1% vs. 9.2%, $p = 0.012$), and nausea/vomiting (3.1% vs. 7.1%, $p = 0.031$) were all reduced in the SA + MAC group; however, after Bonferroni correction ($\alpha = 0.01$), only the difference in headache remained statistically significant.

The composite severe complication rate, including Postoperative hypothermia, Pulmonary atelectasis, Severe hypotension, Nerve root injury/dural tear, stroke/MI were cumulative total reached 19.4% (19/98) in the SA + MAC group versus 13.3% (13/98) in the SA group (raw p = 0.005; p_adj = 0.025), indicating a strong trend toward reduced major perioperative risk with the combined protocol.

Satisfaction and costs: Patient satisfaction (≥ 8/10) was 88.9% vs 70.66% (p_adj < 0.001). Surgeon satisfaction was 92.3% vs 70.8% (p_adj < 0.001). Median hospitalization cost was significantly lower in SA + MAC (USD 4,150 vs 5,020; p_adj = 0.008).

Subjective rating: The symptom pain scores of both groups of patients achieved significant improvement during the operation and at the 3-month follow-up after the operation. The average VAS score during the operation in the SA + MAC group (2.03 ± 0.42 vs 3.56 ± 0.58, p < 0.01) was significantly lower than that in the SA group; the VAS score at 3 months after surgery was 1.93 ± 0.35 in the SA + MAC group and 2.06 ± 0.41 in the SA group, with no significant difference between groups (p > 0.05). The average ODI scores of both groups at 3 months after the operation were significantly lower than preoperative values (p < 0.001), and there was no significant difference between the groups (p > 0.05) (Table 4**&** Fig. 6).

Table 4
Perioperative pain score, complications and satisfaction. (VAS:Visual Analog Scale; ODI:Oswestry Disability Index.)(* p < 0.05,** p < 0.01)

Variable	SA + MAC group (n = 98)	SA group (n = 98)	P value
VAS			
Before surgery	6.81 ± 0.72	6.62 ± 0.68	0.69
During surgery	2.03 ± 0.42	3.56 ± 0.58	0.004**
3m after surgery	1.93 ± 0.35	2.06 ± 0.41	0.21
ODI			
Before surgery	41.3 ± 5.2	40.9 ± 4.8	0.78
3m after surgery	14.8 ± 3.1	15.0 ± 3.3	0.69
Complication			
Nausea and vomiting	3	7	0.031*
Headache	7	15	0.002**
Postoperative hypothermia	4	6	0.063
Pulmonary atelectasis	5	4	0.706
Severe hypotension	3	9	0.012*
Nerve root injury/dural tear	1	0	0.980
stroke/MI	0	0	1.000
Total complications	23	41	< 0.001***
Satisfaction			
Patient satisfaction	88.9%	70.66%	0.0024**
Surgeon satisfaction	92.3%	70.8%	0.0031**

Discussion

Since Yeung[24] first introduced the Yeung Endoscopic Spine System (YESS) under local anesthesia, UBE decompression for lumbar spinal stenosis (LSS) under various anesthetic regimens has been widely applied in clinical practice[25,26,27]. Optimizing anesthesia protocols tailored for elderly patients undergoing UBE remains an urgent clinical problem, given the high perioperative risk in this vulnerable population[28]. This propensity score-matched retrospective study evaluated the clinical utility of adding

monitored anesthesia care (MAC) to subarachnoid anesthesia (SA) in elderly patients undergoing UBE for lumbar spinal stenosis. Our key findings are threefold: (1) SA + MAC significantly improved surgical field clarity and hemodynamic stability compared with SA alone; (2) the combined protocol markedly reduced postoperative delirium incidence without compromising objective motor block intensity; and (3) patient and surgeon satisfaction were substantially higher in the SA + MAC group. Collectively, these results suggest that the synergistic effect of regional blockade and light sedation offers a balanced anesthetic strategy that addresses both surgical and patient-centered outcomes in this vulnerable population.

Our finding that SA + MAC provides superior surgical field visibility (3.77 ± 0.65 vs 3.44 ± 0.66, $p < 0.001$) aligns with the observations of Zhou et al.[29–31], who reported that patients receiving sedation during endoscopic discectomy exhibited less involuntary movement and better operative conditions compared with those under local anesthesia alone. Similarly, Kang et al. [32]demonstrated that epidural anesthesia combined with conscious sedation yielded better surgical field ratings than epidural anesthesia alone in lumbar decompression surgery. The consistency across studies[33] supports the notion that anxiolysis and pain mitigation reduce patient-induced micromotion, which is particularly critical during technically demanding steps such as working channel establishment and foraminoplasty. However, our study extends these observations by objectively quantifying motor block via TOF monitoring (lowest TOF ratio 28% vs 31%, $p = 0.29$), confirming that the improved field clarity is not attributable to differences in muscle relaxation but rather to enhanced patient cooperation and reduced sympathetic surge—a distinction that previous studies using subjective scales could not reliably establish[34–36].

The significantly lower postoperative delirium incidence in the SA + MAC group (3.1% vs 12.2%, $p = 0.004$ after Bonferroni) is consistent with a growing body of evidence supporting dexmedetomidine's neuroprotective profile. The Bonferroni correction applied to secondary outcome domains ($\alpha = 0.01$) provides a conservative safeguard against Type I error inflation from multiple comparisons[37]. A meta-analysis by Liu et al[38]. found that dexmedetomidine reduced delirium risk by approximately 40% in elderly surgical patients, while a recent RCT specifically in spinal surgery[39,40] reported a delirium incidence of 8.5% with dexmedetomidine-based sedation versus 21.2% with placebo. Our finding (3.1%) falls at the lower end of this range, which may reflect our relatively young-elderly cohort (mean age ~ 72 years) and the exclusion of patients with pre-existing cognitive impairment—factors that likely reduced baseline delirium risk. Notably, the 3D-CAM instrument we employed has higher diagnostic sensitivity than routine chart review[41], which may explain why our SA group's delirium rate (12.2%) is more consistent with prospective studies than with retrospective chart-based reports. This methodological rigor strengthens the validity of our intergroup comparison.

With respect to perioperative hemodynamic profiles, we observed a markedly lower rate of severe hypotension requiring rescue intervention in the SA + MAC cohort (7.1% versus 23.5%, adjusted $p = 0.002$). This observation aligns with the work of Finsterwald et al.,[42] who demonstrated superior cerebral autoregulation preservation under neuraxial anesthesia relative to general anesthesia among high-risk spinal surgical patients. Importantly, our analysis advances existing literature by isolating this

hemodynamic benefit within a purely spinal anesthetic framework, comparing spinal anesthesia alone against spinal anesthesia supplemented with dexmedetomidine-based MAC. We posit that this circulatory stability stems primarily from dexmedetomidine's central sympatholytic α_2 agonist activity, rather than the mere avoidance of general anesthetic agents—a mechanistic distinction rarely discussed in prior spinal endoscopy research[40,43]. This finding carries tangible clinical relevance: it confirms that incremental circulatory protection can be achieved by adding titrated MAC sedation even when neuraxial block is already established, a practical optimization strategy insufficiently highlighted in existing UBE anesthesia publications.

The complication disparities likely stem from the combined hemodynamic and pharmacological effects of the MAC protocol. The significant reductions in headache, severe hypotension, and nausea/vomiting in the SA + MAC group are plausibly attributable to dexmedetomidine's hemodynamic stabilization, which attenuates SA-induced vasodilation and reduces the need for rescue opioids, thereby lowering both cerebrovascular-mediated headache and opioid-related emesis [35]. Conversely, the comparable rates of hypothermia and atelectasis across groups are consistent with the avoidance of general anesthesia and mechanical ventilation in both arms. The numerically lower trend in serious procedural events (nerve root injury, dural tear) in the SA + MAC group may reflect enhanced surgical precision from reduced patient micromovement and preserved neurologic feedback during critical steps.

Limitations and Future Directions

This study has several limitations. The retrospective single-center design and non-randomized allocation are subject to selection and information biases, and residual confounding from unmeasured factors cannot be fully excluded despite rigorous propensity score matching. The 3-month follow-up is insufficient for long-term outcome assessment, and the non-inferiority margin, though literature-based, may not universally apply across all surgical contexts. Additionally, the homogenous cohort limits generalizability to broader populations.

Conclusion

In this retrospective propensity-matched analysis of elderly patients undergoing UBE for lumbar spinal stenosis, SA combined with MAC was associated with superior surgical field quality, more stable hemodynamics, lower postoperative delirium incidence, and higher patient and surgeon satisfaction compared with SA alone. These benefits were achieved without compromising objective motor block intensity or postoperative functional recovery. While these findings are promising and provide a strong rationale for adopting SA + MAC as the preferred anesthetic strategy in this population, the retrospective design and single-center setting require that conclusions be interpreted with appropriate caution. Confirmation through prospective, multicenter randomized trials is essential before routine implementation can be universally recommended. If validated, this combined protocol could represent a simple, cost-effective, and patient-centered enhancement to the perioperative care of elderly patients undergoing minimally invasive spinal decompression.

Abbreviations

SA
subarachnoid anesthesia
MAC
monitored anesthesia care
TOF
train-of-four
BIS
bispectral index
SBP
systolic blood pressure
DBP
diastolic blood pressure.)

Declarations

Acknowledgements

Not applicable

Contributions

Zhang wrote the main manuscript text, and Shen and Chen provided and compiled the patient information. All the authors reviewed the manuscript. Li provided technical ideas and the framework of the article.

Competing Interests

The authors declare that they have no conflicts of interest.

Data availability

The datasets generated and/or analyzed during the current study are available from the corresponding author upon reasonable request. Due to ethical restrictions and the retrospective nature of the study, the data are not publicly available, as they contain potentially identifying patient information. Requests for access to the de-identified dataset should be directed to the corresponding author and will be reviewed by the Institutional Review Board for compliance with patient confidentiality requirements.

Conflicts of Interest

The authors declare that they have no competing interests.

Funding statement

There was no funding provided for this research.

Ethical approval statement

This study has been approved by the Ethics Committee of The Third People's Hospital of Henan Province, and does not require the signing of an informed consent form.

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Figures

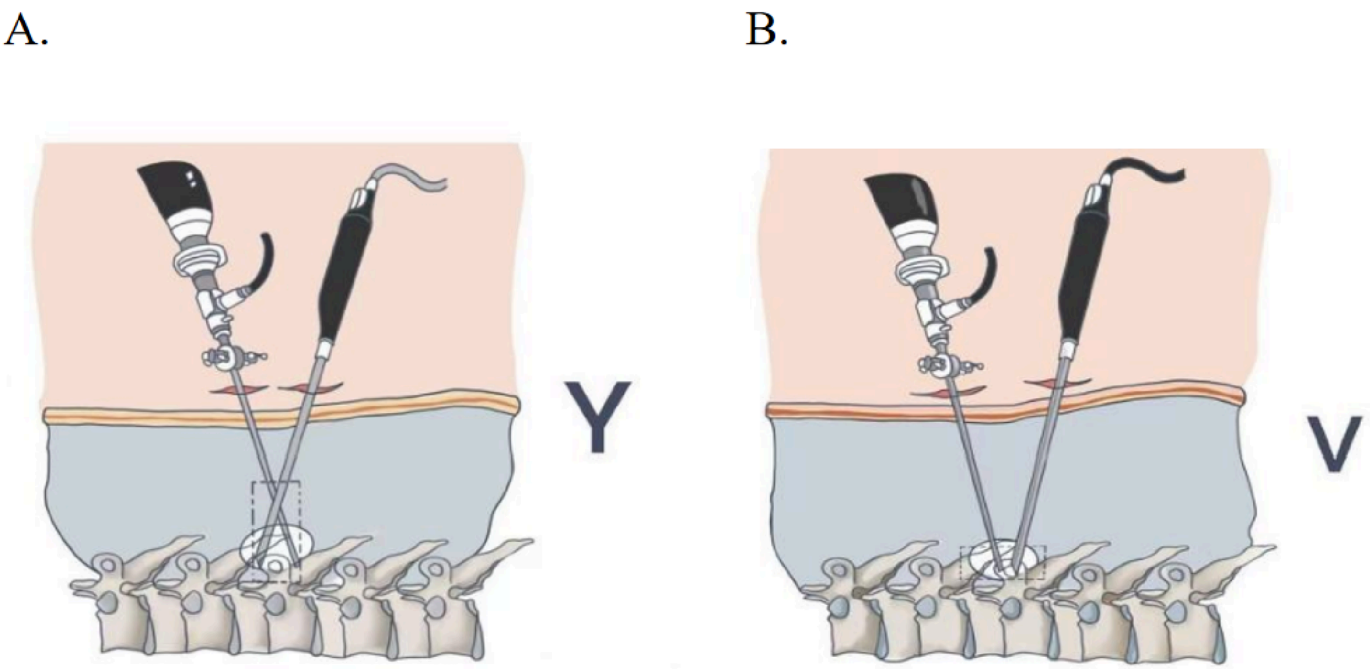


Figure 1

Diagram of the relation between the meeting site of the instrument and the distance from the incision.

(A. The "Y"-shaped cavity creation method: Under fluoroscopic guidance, the incision for the operative channel is determined to be located at the inner edge of the pedicle, aligning with the intervertebral space on the lateral view. After a sufficientincision is made, the tract is dilated to 1.5 cm, maintaining the muscle dilation. An oblique incision for the observation channel is then made 1-1.5 cm laterally from the operative tract. The blade is advanced until it contacts the dilator tube. Following this, an endoscopic sheath is placed to contact the dilator tube, which is then removed and replaced with a plasma knife. Dissection proceeds along the unclosed muscle tissue tract until the bone surface is reached. B. The Conventional "V"-shaped Approach.)

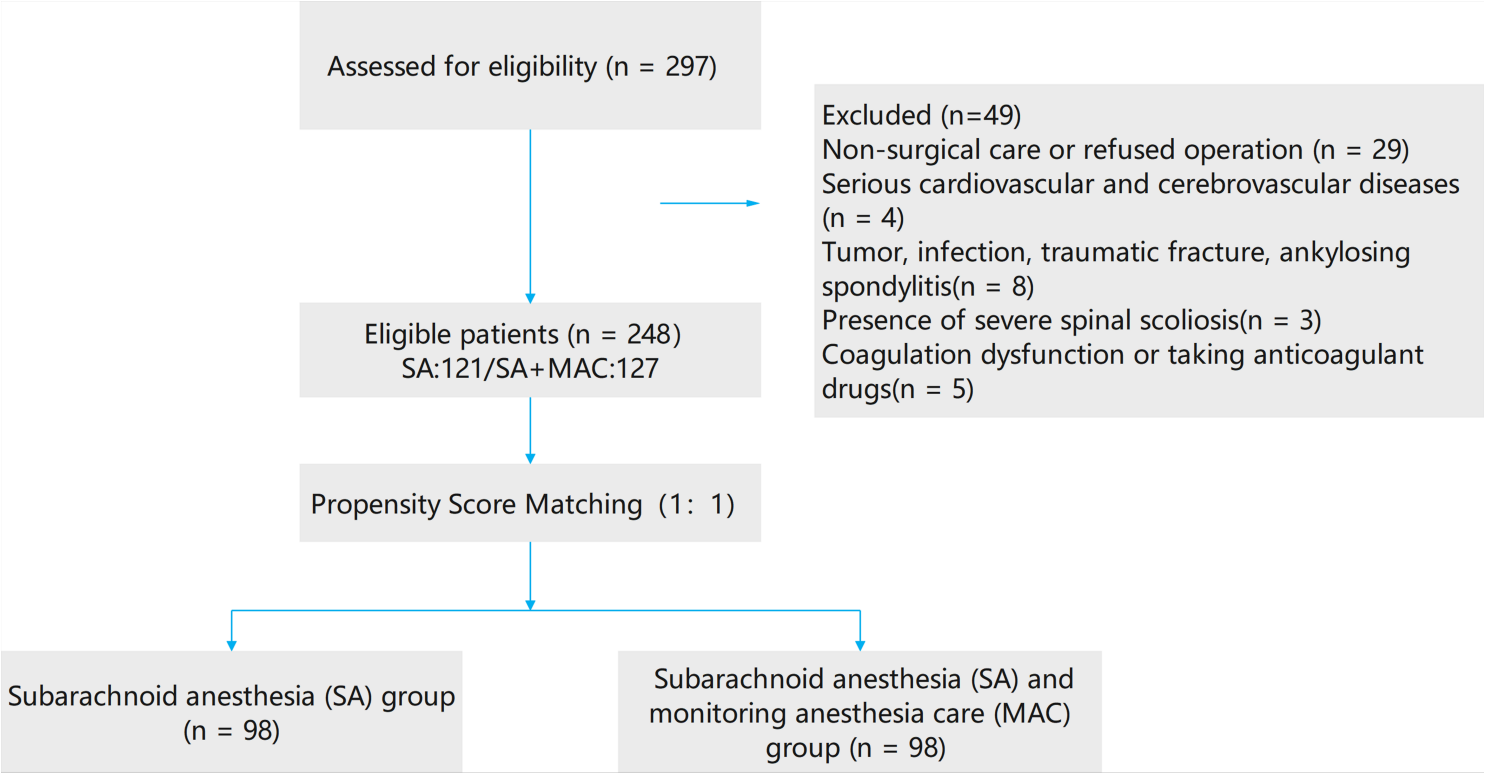


Figure 2

Flowchart of patient enrollment and propensity score matching.

(SA: Subarachnoid anesthesia; MAC: Monitored Anesthesia Care; PSM: Propensity Score Matching)

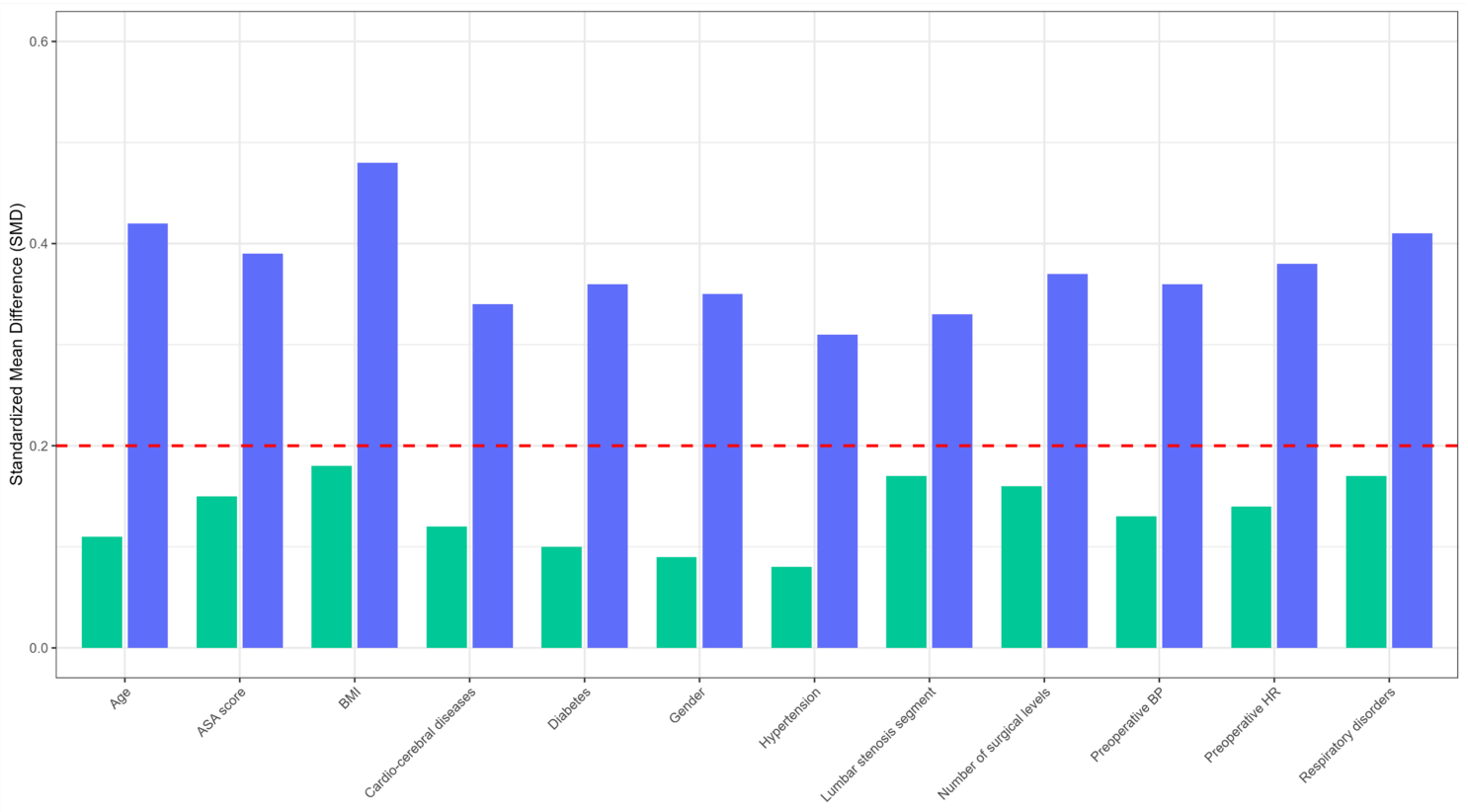


Figure 3

Standardized mean differences of baseline covariates before and after matching.

(The red dashed line represents the SMD cut-off value of 0.2. All covariates showed SMD < 0.2 after 1:1 nearest-neighbor matching with caliper = 0.2, indicating good baseline balance.)

(Unmatched = Baseline before PSM; Matched = Baseline after PSM; Red dashed line = SMD cut-off value of 0.2)

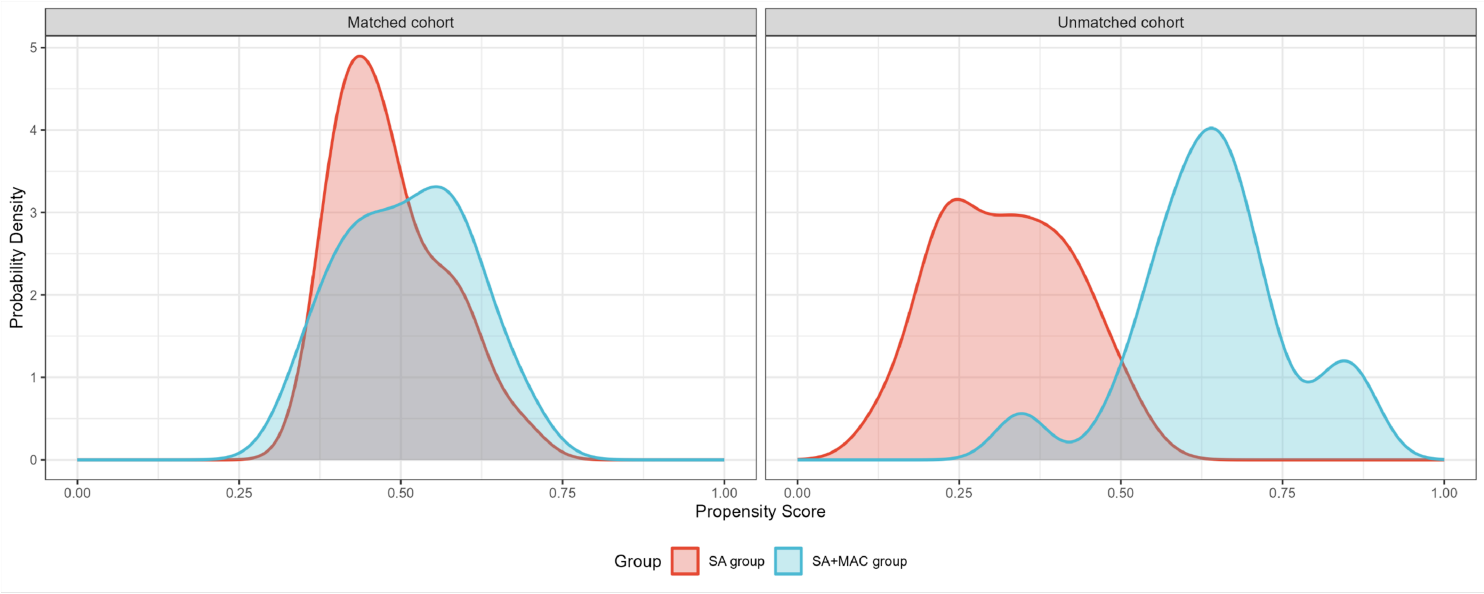


Figure 4

Probability density distribution of propensity scores.

(The distribution of propensity scores was obviously separated in the unmatched cohort, while two curves overlapped highly after matching, which proved that selection bias was effectively eliminated.)

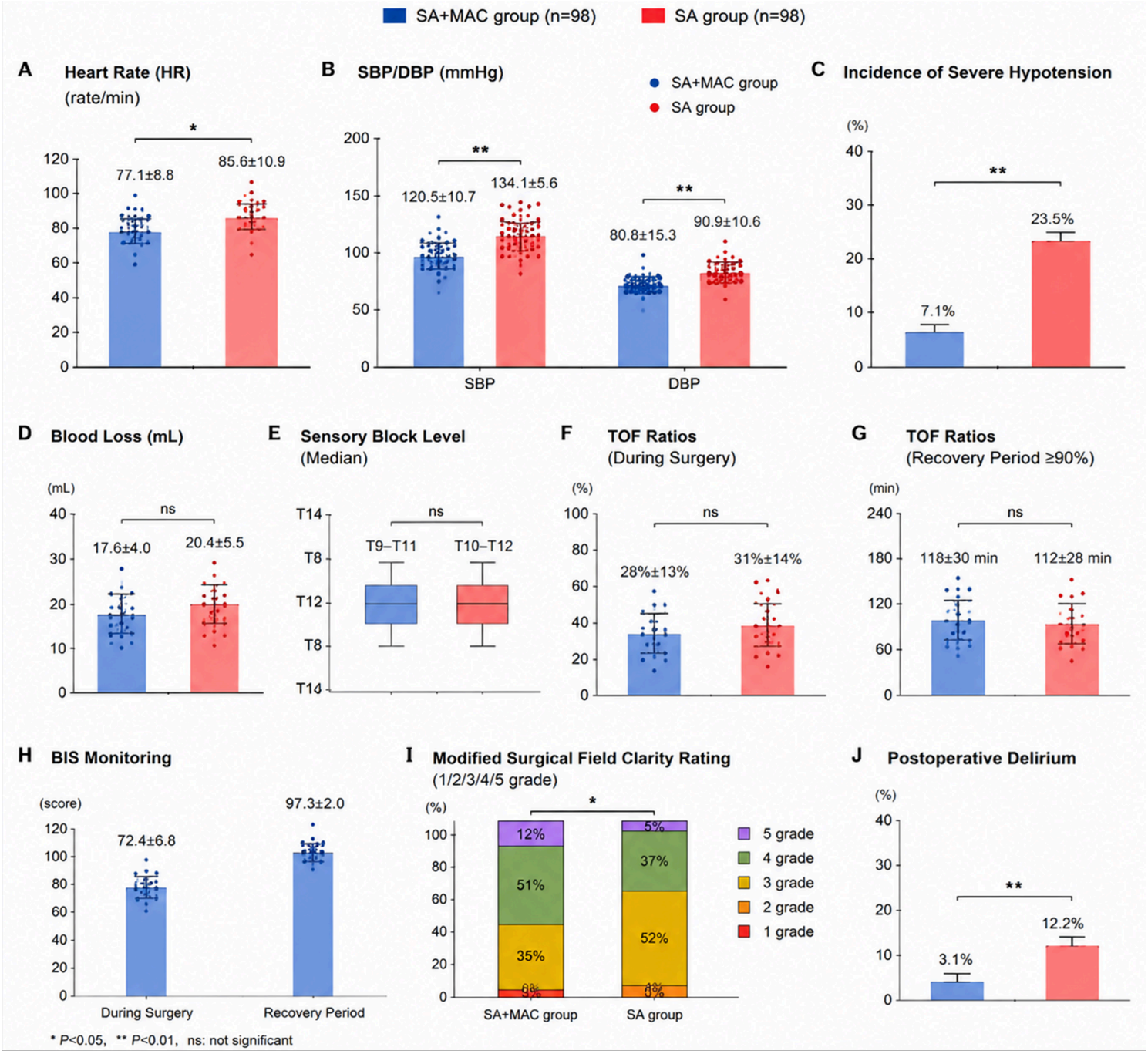


Figure 5

Intraoperative physiological, monitoring and surgical indicators in two propensity score-matched cohorts (n=98 patients per group).

(A) Intraoperative heart rate; (B) Intraoperative systolic blood pressure (SBP) and diastolic blood pressure (DBP); (C) Incidence of severe intraoperative hypotension;

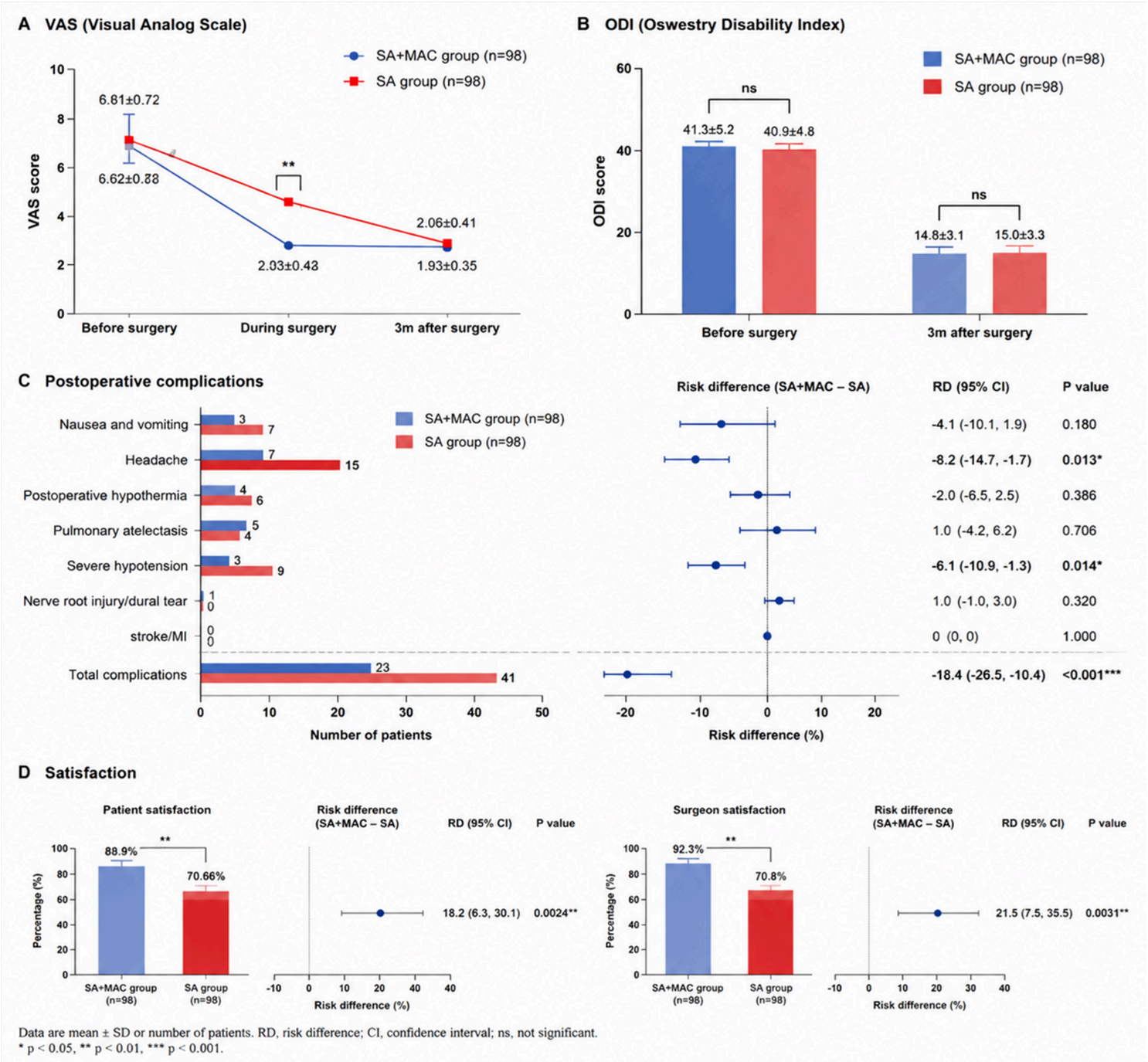
(D) Intraoperative blood loss volume; (E) Median sensory block level of spinal anesthesia; (F) Intraoperative train-of-four (TOF) ratio;

(G) Time to TOF ratio ≥90% during recovery period; (H) Bispectral index (BIS) values during surgery and recovery;

(I) Graded modified surgical field clarity rating; (J) Incidence of postoperative delirium.

(All continuous data are presented as mean ± standard deviation. Independent samples t-test was used for continuous variables, and chi-square test was used for categorical variables. *p < 0.05, **p < 0.01, ns = no significant difference.

Abbreviations: SA, subarachnoid anesthesia; MAC, monitored anesthesia care; TOF, train-of-four; BIS, bispectral index; SBP, systolic blood pressure; DBP, diastolic blood pressure.)



Data are mean ± SD or number of patients. RD, risk difference; CI, confidence interval; ns, not significant.
* p < 0.05, ** p < 0.01, *** p < 0.001.

Figure 6

Long-term pain, lumbar function, perioperative complications and satisfaction outcomes in matched SA and SA+MAC groups (n=98 per group).

(A) Serial visual analogue scale (VAS) pain scores measured preoperatively, intraoperatively and at 3-month postoperative follow-up;

(B) Preoperative and 3-month postoperative Oswestry Disability Index (ODI) scores for lumbar functional evaluation;

(C) Count of individual perioperative adverse complications and forest plot of risk difference between groups;

(D) Bar charts and forest plots showing patient and surgeon satisfaction rates with corresponding risk difference analysis.

(Continuous variables are expressed as mean ± standard deviation; categorical data were compared via chi-square test. *p < 0.05, **p < 0.01, ***p < 0.001, ns = no significant difference.

Abbreviations: VAS, visual analogue scale; ODI, Oswestry Disability Index; RD, risk difference; CI, confidence interval; SA, subarachnoid anesthesia; MAC, monitored anesthesia care.)