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Research Article

Ultrasound-guided scalp block combined with dexmedetomidine for pain management in acute traumatic brain injury patients undergoing decompressive craniotomy: A randomized controlled trial

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Abstract

Background: Inadequate perioperative analgesia may lead to arterial hypertension, elevated Intracranial Pressure (ICP), and even secondary intracranial hemorrhage. Severe pain often necessitates high opioid doses, which can result in adverse events and delayed recovery. Significant hemodynamic improvement has been observed during neurosurgery when using either scalp nerve blocks or Dexmedetomidine (Dex). This study aimed to evaluate the synergistic effect of these combined interventions on opioid requirement reduction and pain management improvement in Traumatic Brain Injury (TBI) patients undergoing Decompressive Craniectomy (DC).

Methods: In this randomized controlled pilot trial, 126 TBI patients scheduled for DC under general anesthesia were enrolled. Patients were randomly assigned to one of three groups (n=42 each): ultrasound-guided scalp block with dexmedetomidine (US-G group), ultrasound-guided scalp block alone (US group), or no intervention (CG group). The primary outcome was intraoperative fentanyl consumption. The other outcomes included remifentanil and propofol requirements, RASS scores, Mean Arterial Pressure (MAP), Heart Rate (HR), stress response intensity.

Results: A total of 111 TBI patients were included in the final analysis. No complications associated with nerve blockade were observed. The US-G group exhibited the most significant reductions in intraoperative fentanyl, remifentanil, and propofol requirements among all study groups ($P<0.05$). Additionally, this group showed decreased incidence and severity of recovery agitation ($P<0.05$). Furthermore, the combination group showed significantly improved hemodynamic stability and more effective suppression of surgical stress responses during the surgery ($P<0.05$).

Conclusion: The combination of ultrasound-guided scalp block with Dex demonstrated significant reductions in both opioid and propofol requirements, while improving hemodynamic stability and attenuating surgical stress responses. Therefore, ultrasound-guided scalp block combined with Dex represents an effective strategy for perioperative pain management in TBI patients undergoing DC.

Keywords: Ultrasound-guided scalp block; Dexmedetomidine; Analgesia; Traumatic brain injury; Decompressive craniotomy.

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Background

Acute Traumatic Brain Injury (TBI) represents a critical neurological emergency characterized by acute subdural hematomas, cerebral edema, elevated Intracranial Pressure (ICP), and neurological deficits [1]. While Decompressive Craniotomy (DC) serves as a primary surgical intervention, it is inherently a traumatic and invasive procedure. Significant nociceptive stimuli originate from laryngoscopy, intubation, and traumatic injuries involving the scalp, soft tissue, pericranial muscles, and dura mater [2]. Inadequate analgesia may induce hypertension, tachycardia, and increased myocardial oxygen demand, which is particularly detrimental in patients with impaired cerebrovascular autoregulation [3]. It can increase ICP, risk of rebleeding and secondary surgery. While high-dose opioids serve as adjuvant analgesics, they may cause excessive sedation or respiratory depression in neurosurgery, and their overuse may impair postoperative neurological assessment [4].

A recent systematic review of 53 randomized controlled trials has established those regional analgesic techniques, particularly the scalp block, should be incorporated into craniotomy procedures [5]. Preoperative scalp block administration demonstrates significant attenuation of hemodynamic during skin incision and dural manipulation), along with superior perioperative analgesic efficacy [6]. However, most clinical studies have focused on elective brain tumor resections or awake craniotomies. Moreover, current evidence suggests many anesthesiologists still lack proficiency in ultrasound-guided scalp block techniques.

Alternatively, intravenous Dexmedetomidine (Dex) has been evaluated as a systemic analgesic adjunct for various surgical procedures. Moreover, it has been shown to attenuate the hemodynamic response to intubation while reducing the required doses of opioids and propofol [7]. Nevertheless, Dex may be more effective when combined with an ultrasound-guided scalp block for pain management in TBI patients undergoing DC. Therefore, we tested this hypothesis in our study.

Methods

Study design: This was a prospective, single-centre, randomized, parallel-group controlled trial designed in accordance with the CONSORT statement. All methods followed the principles of the Declaration of Helsinki and Good Clinical Practice guidelines. The trial was approved by the Medical Ethics Committee of Kunshan Hospital of Chinese Medicine on January 3, 2024 (Approval ID: KZY2024-012-01), and written informed consent was obtained from the dependants of patients to participation. Additionally, the study was registered in the Chinese Clinical Trials Registry (NO. ChiCTR2400087969) on January 3, 2024. From January 1, 2024, to January 1, 2025, all eligible patients were approached for enrolment.

Eligibility criteria

1. TBI patients scheduled for emergency DC under General Anesthesia (GA) were consecutively screened for eligibility based on the following cAge between 20 and 74 years (no gender restrictions);
2. Glasgow Coma Scale (GCS) score of 9 to 15;
3. Baseline Systolic Blood Pressure (SBP) between 90 and 180 mmHg;
4. Heart Rate (HR) between 60 to 100 beats per minute (bpm);
5. Complete medical records available.

The surgical procedure involved raising a bone flap followed by hematoma evacuation.

Ineligible criteria

Studies were considered ineligible if they met any of the following criteria

1. Patients with instable Blood Pressure (BP) and HR (severe hypertension or hypotension) and emergency endotracheal intubation, terminal cerebral herniation, or bilateral dilated pupils upon admission;
2. Patients with open skull defects or injuries to other vital organs or severe hypovolemia;
3. Patients with pre-existing craniocerebral system disorders;
4. Patients with a history of infection around the puncture site, allergies, or contraindications to local anesthetics;
5. Patients with uncontrolled hypertension, diabetes mellitus, cardiomyopathy, autoimmune diseases, or persistent arrhythmia.

Subject withdrawal criteria

Subjects may withdraw from the study under the following circumstances:

1. Patients are lost to follow-up in this trial;
2. Patients refuse to continue the intervention;
3. Patients undergo a second operation, or the planned craniotomy is not performed;
4. Patients experience adverse events, including severe hemodynamic instability, blood loss exceeding 1500 ml, or death within 3 days after surgery;
5. The operation time exceeds 6 hours.

Subjects who withdraw will be included in the final report of the REDUCE trial to ensure full transparency.

Randomization, allocation

In consultation with the neurosurgeon, eligible participants were randomized into three groups at a 1:1:1 ratio using a computer-generated allocation list in SPSS™ 22.0 (IBM, Chicago, IL, USA): Ultrasound-guided scalp block combined with dexmedetomidine (US-D group), Ultrasound-guided scalp block alone (US group), and Control Group (CG group). Patient management and data collection were assigned sequential numbers and overseen by a researcher not directly involved in the study.

Anesthesia

Preparation before anesthesia: After establishing central intravenous access, patients were routinely monitored for the fol-

lowing parameters during surgery: Electrocardiography (ECG), invasive arterial pressure, Pulse oximetry, and end-tidal Carbon Dioxide ($PetCO_2$). Crystalloids and colloids were administered as needed. Plasma and leukocyte-reduced blood products were transfused when necessary. Glucose- or lactate-containing solutions were avoided.

GA was induced with 3 to 5 μg/kg fentanyl, 1 to 2 mg/kg propofol, and 0.2 mg/kg atracurium. Endotracheal intubation was performed using video laryngoscopy 3 minutes later. Respiratory parameters were set as follows: volume-controlled ventilator; expiratory tidal volume, respiratory rate, and inhale: exhale ratio was adjusted when needed. Initial FiO_2 was set at 100%, with $PetCO_2$ maintained at 30 to 35 mmHg.

In the US-D group, patients received a Dex loading dose of 1 μg/kg over 10 minutes prior to anesthesia induction, followed by continuous infusion at 0.3 μg/kg/h until surgical conclusion.

Intraoperative management

Patients received 1 vol % sevoflurane, along with continuous infusions of remifentanil and propofol at titrated rates, with intermittent atracurium boluses as needed. If SBP or HR increased, 0.05 mg fentanyl was administered and repeated as required, with concurrent adjustment of remifentanil and propofol infusion rates. Conversely, if SBP or HR decreased, remifentanil and propofol doses were first reduced. If hemodynamics did not improve within 3 minutes, vasoactive agents were administered as rescue therapy to maintain SBP between 90 to180 mmHg, Mean Arterial Pressure (MAP) ≥65 mmHg, and HR between 60 to 100 bpm. All anesthetic agents (sevoflurane, propofol, and remifentanil) were discontinued upon procedure completion.

Ultrasonography

Due to the emergent nature of the surgery, the nerve blocks were performed by two neuroanesthesia-trained anesthesiologists, each with >50 prior scalp block procedures. All patients in the US-D and US group received ultrasound-guided scalp blocks after intubation, targeting five nerves [8]: supraorbital, supratrochlear, auriculotemporal, greater occipital, and lesser occipital nerves (Figure 1).

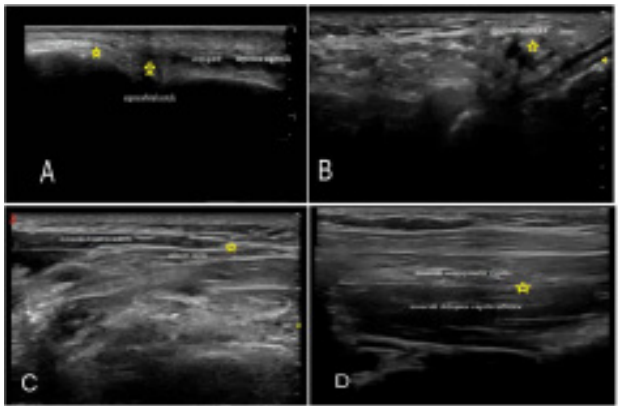

Figure 1: (A) Supraorbital nerve block, ropivacaine was injected at the medial aspect of the supraorbital notch. **Supratrochlear nerve block**, ropivacaine was injected between the nose and the eyebrow arch. **(B) Auriculotemporal nerve block**, ropivacaine was injected lateral to the superficial temporal artery. **(C) Lesser occipital nerve block**, ropivacaine was injected beneath the sternocleidomastoid muscle. **(D) Greater occipital nerve block**, ropivacaine was injected between the inferior oblique and the semipinalis capitis muscles. express the injection point.

Ultrasound scanning was performed using a GE Healthcare (LOGIQ e) linear array probe. Image optimization was achieved by adjusting depth, frequency range, and gain parameters. All blocks were performed with a 5.5# needle under sterile conditions: after skin preparation, ultrasound gel was applied to the transducer, which was then covered with a sterile plastic sleeve along with its cable.

The in-plane technique was uniformly employed. Correct needle position was confirmed prior to injecting 0.6% ropivacaine (2 to 5 mL per puncture site). Unilateral blockade required approximately 5 minutes to complete. Any adverse effects were documented in the patient's medical record.

Postoperative management

After surgery and postoperative CT examination, patients with tracheal catheters were transferred to the intensive care unit, where designated follow-up physicians conducted the relevant assessments.

Data collection and outcomes

Demographic dates, including age, sex, Body Mass Index (BMI), American Society of Anesthesiologists (ASA), and GCS score, were collected preoperatively. The duration of surgery and anesthesia, intraoperative blood lose, fluid infusion volume, lactate levels, Central Venous Pressure (CVP), and postoperative urine output were meticulously recorded by investigators.

The primary objective was to assess intraoperative fentanil consumption. The other outcomes included: cumulative intraoperative doses of propofol and remifentanil, Richmond Agitation-Sedation Scale (RASS) scores both pre-sedation and post-recovery.

Table 1: The RASS scoring criteria [9] are presented.

Score	Term	Description
4	Combative	Overtly combative or violent
3	Very Agitated	Pulls on or removes tube or catheter
2	Agitated	Frequent no purposeful movement
1	Restless	Anxious or apprehensive but movements not aggressive or vigorous
0	Alert and Calm	
-1	Drowsy	Not fully alert, but has sustained (more than 10 s) awakening with eye contact to voice
-2	Light Sedation	Briefly (less than 10 s) awakens with eye contact to voice
-3	Moderate Sedation	Any movement (but no eye contact) to voice
-4	Deep Sedation	No response to voice but any movement to physical stimulation
-5	Unarousable	No response to voice or physical stimulation

MAP and HR were recorded via an automated anesthesia recording system at the following time points: before anesthetic induction (T_0), during intubation (T_1), at scalp incision (T_2), during skull drilling (T_3), at scalp suture (T_4), immediately after surgery (T_5), and upon operating room transfer (T_6).

Blood samples were collected to assess stress response indicators, including blood Glucose (Glu) by blood gas analysis, Norepinephrine (NE) and epinephrine (AD) levels by Enzyme-Linked Immunoabsorbent Assay (ELISA) before surgery, 1.5 hours after surgical incision, and upon operating room transfer.

All relevant adverse effects associated with ultrasound-guided scalp block, including local anesthetic systemic toxicity, allergic reactions, nerve injury, arrhythmias, and immediate post-block hematoma formation, were meticulously documented in the Case Report Forms (CRFs).

Sample size calculation

According to the previous pre-experiment, the collected data conformed to the normal distribution, and it was concluded that the consumption of fentanil in the control group was 563.27±74.86 μg, the ultrasound-guided scalp block group was 375.69±54.86 μg, and the combination group was 332.41±52.93 μg using SPSS Version 22.0 software (SPSS Inc., Armonk, NY, USA). When the power was 0.90 and the signifcance level was 0.05, the required sample size was calculated as 35 patients per group. After considering 20% potential exclusions, we enrolled 42 patients in each study group.

Statistical analysis

The statistical analysis was performed using SPSS version 22.0 software. Normally distributed measurement data were presented as mean ± Standard Deviation (SD), and intergroup comparisons were conducted using independent samples *t*-tests. Categorical data were expressed as counts or percentages (%), and analyzed using *chi-square* tests. A *P*-value <0.05 was considered statistically significant.

Results

Experimental process

A total of 126 patients were screened, with 120 randomized into three equal groups (n=40 each). After excluding nine patients [three for hemodynamic instability, two for contralateral hematoma, one for prolonged surgery times (more than 6 hours), and three lost to follow-up], 111 patients completed the study (38 patients in group US-D, 37 patients in group US, and 36 patients in group CG, respectively). Figure 2 shows the CONSORT flow diagram.

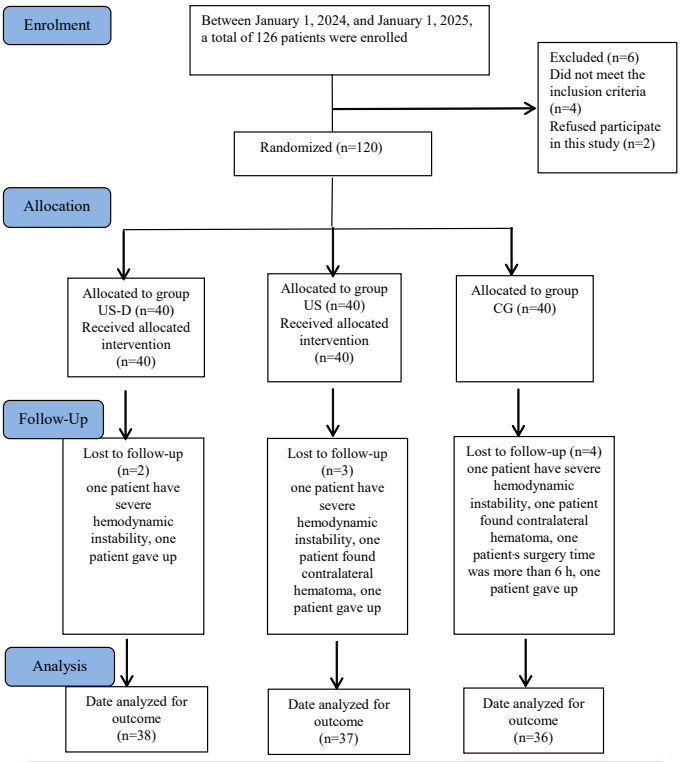

Figure 2: Flow diagram.

Demographic dates

The baseline data with respect to gender, age, BMI, ASA status, and preoperative GCS score were similar among the three groups ($P > 0.05$). The details are provided in Table 2.

Table 2: Demographic dates among the three groups.

Variables	group US-D (n=38)	group US (n=37)	Group CG (n=36)
Age (years)	52.18±6.74	51.63±6.25	53.04±7.12
Male/Female (n/n)	24/14	25/12	24/12
BMI (kg /m^2)	22.71±2.29	22.65±2.32	22.37±2.08
ASA status (n)			
I	13	12	12
II	21	19	20
III	4	6	4
Preoperative GCS score (score)	12.86±1.72	12.94±1.74	12.89±1.79
GCS score (n)			
13-15 score	19	19	18
9-12 score	19	18	18

Data are expressed as mean±SD or n.
BMI: Body Mass Index; ASA: American Society of Anesthesiologists; GCS: Glasgow Coma Scale.

Perioperative characteristics

The urine after surgery was increased in group US-D ($P<0.05$). The other surgical characteristics were similar among the three groups ($P>0.05$). The details are provided in Table 3.

Table 3: Perioperative characteristics among the three groups.

Variables	group US-D (n=38)	group US (n=37)	Group CG (n=36)
Duration of surgery (min)	208.43±28.64	202.62±27.29	212.54±25.03
Duration of surgery anesthesia (min)	219.05±30.27	215.17±32.48	223.64±33.62
Surgical site(right/left)	20/18	19/18	18/18
Blood lose (ml)	503.72±56.23	491.36±52.32	513.26± 59.27
Fluid infusion (ml)	2026.64±276.35	2009.35±254.47	2083.75±290.46
Lactate level	1.38±0.15	1.40±0.16	1.45±0.19
CVP (cmH_2O)	9.96±0.48	9.85±0.45	10.03±0.51
Urine after surgery (ml)	789.43±48.64^{*b}	564.29±36.05	558.53±33.05

Data are expressed as mean±SD.
CVP: central venous pressure.
$^{*}P<0.05$, versus CG group.
$^{b}P<0.05$, versus US group.

Opioids and propofol consumption and RASS score

Compared with group CG, both group US-D and US reduced intraoperative consumption of fentanil, remifentanil and propofol, with the lowest consumption observed in group US-D ($P<0.05$). The incidence of pre-sedation agitation (RASS≥1) was similar among the three groups ($P>0.05$). However, the incidence of recovery agitation (RASS≥1) was significantly lower in group US-D at 5.3%, compared to 37.8% in group US and 52.8% in group CG ($P<0.05$), as shown in Table 4.

Table 4: Opioids and propofol consumption and RASS score among the three groups.

Variables	group US-D (n=38)	group US (n=37)	Group CG (n=36)
Fentanil consumption (ug)	314.25±37.09*b	392.67±40.35*	592.36±45.27
Remifentanil consumption (ug)	453.09±58.04*b	604.12±65.37*	1184.52±70.29
Propofol consumption (mg)	465.18±60.04*b	632.75±71.29*	1468.42±84.35
RASS score			
Pre sedation agitation, RASS ≥ 1	25(65.8)	24(64.9)	26(72.2)
Recovery agitation, RASS ≥ 1	2(5.3)*b	14(37.8)	19(52.8)
1-Restless	2(5.3)*b	9(24.3)	13(36.1)
2-Agitation	0(0)*b	5(13.5)	6(16.7)
3-Very agitated	0(0)	0(0)	0(0)
4-Combative	0(0)	0(0)	0(0)
≤ 0-Alert and Calm	36(94.7)*b	23(62.2)	17(47.2)

RAAS: Richmond Agitation-Sedation Scale.
Data are expressed as mean±SD, or n (%).
*P<0.05, versus CG group.
bP<0.05, versus US group.

Hemodynamics parameters

Compared with T_0, both MAP and HR in group CG significant increased at T_1, T_2, T_3, T_4, T_5 and T_6 (P<0.05). In group US, MAP and HR were significantly increased at T_1, T_5 and T_6 (P<0.05). However, there were no significant differences in MAP and HR in group US-D from T_1 to T_6 (P>0.05), as shown in Figure 3.

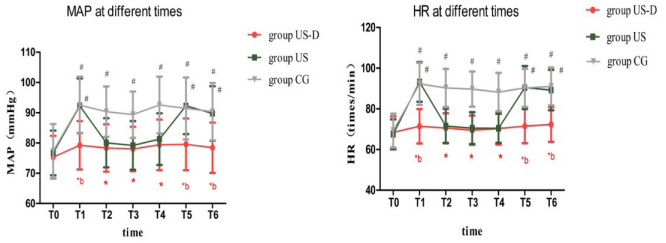

Figure 3: MAP and HR of three groups of patients at distinct junctures.
Data are expressed as mean±SD
*P<0.05, versus CG group.
#P<0.05, versus before surgery.
bP<0.05, versus US group.

Table 5: Effects on stress response.

Variables	group US-D (n=38)	group US (n=37)	Group CG (n=36)
Glu (mmol/L)			
before surgery	5.19±0.62	5.25±0.84	5.32 ± 0.93
1.5 hours after surgical incision	6.43±0.72#*	6.78±0.84#*	8.65 ± 1.57#
upon operating room transfer	7.18±0.93#*	7.54±1.17#*	10.85 ± 1.98#
NE (ng/mL)			
before surgery	19.62±2.67	20.04±2.83	20.15 ± 3.02
1.5 hours after surgical incision	23.62±2.93#*	25.03±3.05#*	35.42 ± 4.43#
upon operating room transfer	31.27±4.15#*	33.29 ± 4.85#*	52.14 ± 6.98#
AD (ng/mL)			
before surgery	10.32±1.37	10.47 ± 1.45	10.65 ± 1.39
1.5 hours after surgical incision	13.62±2.28#*	14.56 ± 2.76#*	17.15 ± 3.64#
upon operating room transfer	16.75±2.68#*	17.43 ± 3.42#*	27.05 ± 4.59#

Data are expressed as mean±SD.
Glu: blood glucose, NE: norepinephrine, AD: epinephrine.
*P<0.05, versus CG group.
#P < 0.05, versus before surgery.

Perioperative stress response indicators

All three groups showed significant intraoperative increases in Glu, NE, and AD levels compared to preoperative baseline values (P<0.05). However, when compared to group CG, the levels of these indicators at 1.5 hours after surgical incision and upon operating room transfer were significantly decreased, with the lowest values observed in group US-D (P<0.05). The data are shown in Table 5.

Discussion

This randomized controlled trial evaluated the efficacy of ultrasound-guided scalp block and Dex in pain management for acute TBI patients undergoing DC under GA. Our primary finding was that the combination therapy showed superior opioid and propofol sparing effects. Moreover, Dex significantly attenuated both the incidence and severity of recovery agitation. Scalp block provided superior control of hemodynamic responses during scalp incision, soft tissue manipulation, and pericranial muscle stimulation, while Dex more effectively suppressed hemodynamic fluctuations during intubation and recovery. Therefore, the combination group demonstrated optimal hemodynamic stability. The lower perioperative systemic stress response may be attributed to the well pain-controlled.

The pain-sensitive tissues of the head are highly complex and innervated by a multitude of nerve branches, including the trigeminal nerve and the second and third cervical nerves. The surgical area encompassed the frontal, parietal, and occipital regions. Anatomical view and clinical evidence indicate that targeted nerve blocks should encompass the auriculotemporal, supraorbital, supratrochlear, greater occipital, and lesser occipital nerves [10]. Unilateral blockade of these specific nerves effectively inhibits nociceptive signal transmission, consequently achieving analgesic outcomes [11]. In recent years, ultrasound-guided techniques can be performed safely and effectively. It reduces the incidence of procedure-related complications including nerve injury, hematoma formation, and transient facial nerve palsy [12].

In our study, ultrasound-guided scalp block was performed under GA. Based on our experience, unilateral nerve blockade was completed within five minutes. Ropivacaine was selected as the local anesthetic agent due to its prolonged analgesic duration, with 2 to 5 mL administered per injection site. Importantly, no procedure-related adverse events were documented during the study period. While ultrasound guidance significantly enhances both the precision and safety of nerve blocks, clinicians should remain cognizant of potential complications associated with these techniques.

As a highly selectiveα-2 adrenergic receptor agonist, Dex attenuates sympathetic export while exerting dual sedative and analgesic effects. Study has demonstrated Dex's efficacy in suppressing intubation-induced hemodynamic fluctuations and regulating ICP in patients undergoing DC [13]. Recent study has demonstrated that Dex significantly reduces neuroinflammation, stabilizes autonomic nervous system function in critically ill patients [14]. The recommended intravenous infusion regimen consists of a 0.5 to 1.0 μg/kg bolus before induction, followed by a maintenance infusion of 0.2 to 0.7 $\mu g \cdot kg^{-1} \cdot h^{-1}$ [15].

Consequently, we explored ultrasound-guided scalp block combined with Dex during general anesthesia as a novel anesthetic approach for TBI patients undergoing DC. In our study, patients receiving combination therapy required the lowest intraoperative doses of opioids and propofol. The Nerve block, serving as the basis of multimodal analgesia when supplemented with analgesic adjuncts, proved more effective in reducing perioperative pain.

The RASS score [16], a simple yet highly sensitive tool with excellent interrater reliability, was used to effectively evaluate sedation-related agitation in TBI patients. We defined RASS ≥+1 as an indicator of agitation based on previous researches [17]. Our study demonstrated that Dex significantly reduced both the incidence and severity of recovery agitation compared to scalp block alone or no intervention. This finding aligns with the results reported by Nanling Wu et al. [18]. The study demonstrated that scalp block reduced intraoperative anesthetic requirements, while Dex prevented choking and agitation events. Additionally, Dex offers a distinct advantage for procedural sedation due to its lack of respiratory depression [19].

Moreover, the analgesic effect can be quantified through hemodynamic parameters [20]. Our results demonstrated that MAP and HR were significantly lower in patients receiving ultrasound-guided scalp blocks during scalp and periosteal procedures. However, this approach did not eliminate stimil associated with tracheal intubation and resuscitation. Notably, the combined intervention group showed significant hemodynamic stability during surgery.

When the body experiences trauma, the hypothalamic-pituitary-adrenal axis becomes activated, secreting large amounts of glucocorticoids that progressively increase plasma cortisol and blood glucose levels [21]. Blood Glu, NE, and AD serve as sensitive stress biomarkers [22]. Our results demonstrated that invasive DC surgery induced varying degrees of stress response. However, patients receiving combined ultrasound-guided scalp block and Dex exhibited significantly lower levels of these biomarkers intraoperatively. These findings suggest that the combined approach effectively attenuates surgical pain, mitigates stress responses, and suppresses elevations in blood Glu, NE, and AD levels.

However, our study has several limitations. First, only patients with mild to moderate craniocerebral injury were selected in this study. Second, scalp nerves are challenging to distinguish under ultrasonography and require identification via anatomical landmarks (e.g., bones and blood vessels). Anatomical variations may further compromise block accuracy. Third, our cohort restricted postoperative analgesia assessment. The evidence regarding postoperative pain levels remains limited, and data on the transition from acute to chronic pain are particularly scarce. As patients were transferred to the intensive care unit, we could only evaluate short-term indicators. Future studies should optimize these clinical trial protocols.

Conclusion

The combination of ultrasound-guided scalp block with Dex demonstrated significant reductions in both opioid and propofol requirements, while improving hemodynamic stability and attenuating surgical stress responses. Therefore, ultrasound-guided scalp block combined with Dex represents an effective strategy for perioperative pain management in TBI patients undergoing DC.

Declarations

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Availability of data and materials: All data generated or analyzed during this study are included in this published article. The data used to support the findings of this study are available from the first author and corresponding author upon request.

Authors contributions: Ying Zhao and Peng Pan conducted the experiments. Peichun Lu performed data analysis. Shigang Qiao conceived and designed the study. Shigang Qiao and Shuquan Feng wrote the manuscript. Dailing Zhang provided essential reagents, materials, and analytical tools. All authors reviewed and approved the final manuscript.

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Ethics approval and consent to participate: This retrospective randomized study was reviewed and approved by the Medical Ethics Committee of the Kunshan Hospital of Traditional Chinese Medicine on January 3, 2024 (Approval ID: KZY2024-012-01), and written informed consent was obtained from each patient for participation in the study.

Competing interests: The authors declare that they have no competing interests.

Abbreviations: ICP: Intracranial Pressure; Dex: Dexmedetomidine; TBI: Traumatic Brain Injury; DC: Decompressive Craniotomy; MAP: Mean Arterial Pressure; HR: Heart Rate; GA: General Anesthesia; GCS: Glasgow Coma Scale; SBP: Systolic Blood Pressure; BP: Blood Pressure; PetCO2: Pulse Oxygen Saturation; BMI: Body Mass Index; ASA: American Society of Anesthesiologists; CVP: Central Venous Pressure; RASS: Richmond Agitation-Sedation Scale; Glu: Blood Glucose; NE: Norepinephrine; AD: Epinephrine; ELISA: Immunoabsorbent Assay.

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