

Ultrasonic bone curette in thoracic spinal decompression: a comprehensive systematic review and meta-analysis

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Abstract. – OBJECTIVE: The aim of this study was to compare the efficacy and safety of ultrasonic bone curette (UBC) and conventional surgical instruments in thoracic laminectomy decompression (TLD) for the treatment of thoracic spinal stenosis (TSS) by meta-analysis.

MATERIALS AND METHODS: Two authors independently searched Medline *via* PubMed, Embase, Cochrane Library, Web of Science, Wanfang Database, and China National Knowledge Infrastructure for the period from the establishment of the database until January 2023 to identify the studies on the safety and efficacy of UBC *vs.* conventional instruments for TSS. Data extraction and quality assessment were performed by two researchers independently. We used RevMan 5.4 software (Review Manager Web, The Cochrane Collaboration, Copenhagen, Denmark) to analyze the data.

RESULTS: Eight retrospective studies were included in the present work. This meta-analysis revealed that no significant differences in the preoperative JOA scores, the JOA scores at the last follow-up, the improvement rate of JOA scores, and the incidence of cerebrospinal fluid leakage/dura injury were detected between the two groups ($p>0.05$). However, there were significant differences in the operative time and intraoperative blood loss during single-level TLD [operative time: MD=-1.47, 95% CI (-1.86, -1.09), $p<0.001$; intraoperative blood loss: MD=-46.62, 95% CI (-53.83, -39.40), $p<0.001$], total operative time [MD=-56.88, 95% CI (-69.66, -44.10), $p<0.001$], total intraoperative blood loss [MD=-143.52, 95% CI (-212.49, -74.54), $p<0.001$], the incidence of neurological deterioration/nerve root injury [RR= 0.29, 95% CI (0.09, 0.91), $p=0.03$] between the groups.

CONCLUSIONS: The application of UBC in TLD to treat TSS is safe and effective. UBC can

significantly shorten operation time and reduce intraoperative blood loss compared to traditional surgical instruments. Moreover, it has the advantage of reducing perioperative nerve injury.

Key Words:

Ultrasonic bone curette, Thoracic spinal decompression, Thoracic spinal stenosis, Systematic review and meta-analysis.

Introduction

Thoracic spinal stenosis (TSS) is a spectrum of neuro-related syndromes resulting from a combination of factors, including reduced volume of the thoracic spinal canal and compression of the thoracic medulla¹⁻³. Among them, ossification of the posterior longitudinal ligament (OPLL) in the thoracic spine, thoracic ossified ligamentum flavum (TOLF), and thoracic disc herniation (TDH) are the three primary diseases causing acquired TSS⁴. TSS can lead to muscle weakness and varying degrees of trunk/limb numbness, sensory disturbances in the lower limbs, and walking difficulties, which in severe cases can lead to complete paralysis^{5,6}. The physiological kyphosis of the thoracic spine results in minimal space for the thoracic medullary buffering. Therefore, surgery is often the only intervention when conservative treatment is ineffective^{7,8}. Thoracic laminectomy decompression (TLD) is the most common procedure for treating TSS. Its therapeutic goals are to remove the compacts, increase the adequate volume of the spinal canal, and maintain thoracic stability⁹. High-speed drills, rongeurs, or

osteotomes are among the most common tools for this procedure. Using rongeurs or osteotomes during decompression of thoracic laminectomy is labor-intensive and takes a long time to decompress. Moreover, it is highly susceptible to re-injure the already severely compressed spinal cord¹⁰. High-speed drills have improved surgical efficiency but often require a high technical level among surgeons. Otherwise, complications such as geothermal damage, peripheral tissue injury, and dural injury may occur¹¹.

An ultrasonic bone curette (UBC) is a device developed specifically for bone cutting, generating cutting force based on the principle of the ultrasonic cavitation effect. This device selectively cuts bony tissues by adjusting different ultrasound frequencies. Furthermore, it effectively maintains the integrity of soft tissue structures such as the dura mater and nerves intact intraoperatively¹². Theoretically, it has the advantages of a short operation time, less intraoperative bleeding, and less tissue damage. Moreover, this device highlights performing surgery near the dura mater and other neural tissues without causing excessive mechanical and thermal damage^{11,12}.

Currently, there are several studies^{11,12} on the safety and efficacy of TLD using UBC to treat TSS. However, these studies all have the drawbacks of small sample size and weak strength of evidence. Meta-analysis is a quantitative method to pool the data from studies on the same topic, thereby expanding sample size and obtaining high-quality evidence. To our best knowledge, meta-analyses on the safety and efficacy of UBC for treating TSS still need to be improved. Therefore, the purpose of this study was to compare the safety and efficacy of UBC with conventional surgical instruments in TSS to obtain a large sample and high-strength evidence to guide clinical practice.

Materials and Methods

We strictly followed the guidance provided by the Cochrane Handbook to conduct the current study. We reported the study results based on the recommendations of the PRISMA (Preferred Reporting Items for Systematic Review and Meta-analysis) working group on preferred reporting items for systematic reviews and meta-analyses¹³. The present work is primarily a secondary analysis of published studies reporting the safety and

efficacy of UBC compared with conventional decompression devices for the treatment of TSS. It does not involve human or animal studies, and ethical approval can be waived.

Inclusion and Exclusion Criteria

We adopted the PICO (population, interventions, comparison, outcomes, and study design) framework to develop the inclusion criteria for this study:

- 1) Population: clinical and radiographic findings consistent with primary or secondary TSS, including but not limited to OPLL, TOLF, and TDH. The surgical thoracic level is not limited, but the indication for TSS is required. Age, gender, ethnicity, and nationality were not restricted.
- 2) Intervention and Comparison: UBC was used for TSS in the intervention group, whereas the control group adopted conventional tools, including high-speed drills, rongeurs, or osteotomes.
- 3) Outcomes: at least one of the following outcomes was included: operative time, intraoperative bleeding, Japanese Orthopedic Association score (JOA), visual analogue scale (VAS), the Oswestry disability index (ODI), the incidence of cerebrospinal fluid leakage or dura defect, the incidence of neurological deterioration or nerve root injury, and infectious complications (wound infection, pneumonia, urinary tract infection, intracranial infection, etc.).
- 4) Study design: the randomized controlled studies (RCTs) were prioritized, but the prospective or retrospective studies were included if there were no relevant RCTs or the sample size was too small.

The language of the literature was unlimited. Only those with the most extended follow-up and complete results were included in continuous studies from the same research team. Moreover, studies reported in the form of reviews, conference abstracts, commentaries, animal studies, etc., were also excluded.

Search Strategy

The two authors developed a literature search strategy based on being fully aware of the study protocol. Then, they independently electronically searched the following database: Medline *via* PubMed, Embase, Cochrane Li-

brary, Web of Science, Wanfang Database, and China National Knowledge Infrastructure (CNKI). The studies on the safety and efficacy of UBC *vs.* conventional instruments for TSS published from the establishment of the database until January 2023 were identified. The literature search was conducted using a combination of Subject Heading and text-word. We adopted the following search terms: “bone curette”, “bone cutter”, “bone scalpel”, “bone shaver”, “osteotome”, “piezosurgery” “ultrasonic aspirator”, and the search formula is following: ((((((Bone Curette) OR (Bone Cutter)) OR (Bone Scalpel)) OR (bone shaver)) OR (osteotome)) OR (ultrasonic aspirator)) OR (piezosurgery)) AND (((Thoracic) OR (Spinal)) OR (Decompression)). Moreover, we conducted a manual search of the included studies and relevant references to identify potential studies that were not included in the initial search.

Literature Screening and Data Extraction

According to the given search strategy, potential studies initially retrieved will be imported into the literature management tool EndNote (Thomson Corporation, Stanford, CT, USA). Duplicate records from multiple databases in the EndNote will be identified and retained only once. Two authors independently labeled each study as “include”, “exclude”, or “uncertain” by browsing titles and abstracts. Both authors’ records marked as “exclude” will be directly deleted. The decision to be included in this study will be made by reading the full text.

Two authors independently extracted the data from each literature included in this study. The data were then populated into a pre-made summary table. Disagreements between the authors will be resolved by consultation with a third author. The following data from each study were extracted:

- 1) Study characteristics: first author, location of the study, study period, and study design.
- 2) Patients’ characteristics: age, gender, inclusion criteria, intraoperative decompression devices, and commodities.
- 3) Surgery-related indicators: operative time, intraoperative blood loss, clinical evaluation, and complications.

Quality Assessment

We adopted the Newcastle-Ottawa Quality Assessment Scale (NOQAS) to evaluate the

methodological quality of the included observational studies^{14,15}. The evaluation criteria included eight entries under three broad categories of study population selection, comparability between groups, and evaluation of outcome measures, with a total of 9 points; an asterisk marks each entry. Studies were considered high quality if marked with asterisks greater than or equal to 6; otherwise marked as low quality¹⁶. Intraoperatively dural and nerve root injuries usually have corresponding clinical manifestations in a short period. Therefore, the studies with a follow-up time of more than 12 months have an adequate follow-up for the observation of outcome measures. We considered studies with a loss rate of less than 25% as having maintained the continuity of follow-up. Two authors independently evaluated the quality of each study included in this study. Disagreements were resolved by discussion between the authors or by consultation with a third author with more than 3 years of experience in literature’s quality assessment.

Statistical Analysis

This study used RevMan 5.4 software (Review Manager Web, The Cochrane Collaboration, Copenhagen, Denmark) to analyze the data. Mean difference (MD) and 95% confidence intervals (95% CI) were used as the effective indicators for continuous data with the same unit of measurement; otherwise, we adopted the standardized mean difference (SMD). Moreover, we used relative risks (RR) and 95% CI as the effective indicators for dichotomous data. A statistical difference was considered if the *p*-value was lower than or equal to 0.05.

We used quantitative I^2 to detect the heterogeneity among the included studies. The I^2 value of more than 75% indicated high heterogeneity, 50%-75% as moderate heterogeneity, and less than 50% as low heterogeneity¹⁷. If the heterogeneity among studies was high, a random-effects model was used for statistical analysis. Moreover, the subgroup analysis or meta-regression analysis was performed to explore the sources of heterogeneity. The fixed-effects model was used to pool the data for low heterogeneity among studies. We performed sensitivity analyses by removing studies individually to verify that the pooled statistical effect was robust. We used the funnel plots to detect potential publication bias.

Results

Literature Search

Based on the established search strategies, we searched electronic databases and initially screened 1,075 articles that potentially met inclusion criteria. The literature management tool eliminated one hundred fifty-eight duplicate publications from multiple databases. Reading the titles and abstracts eight hundred ninety-eight studies that did not meet the inclusion criteria were excluded. The full text of the remaining 19 articles was obtained, and eleven studies¹⁸⁻²⁸ were finally included after careful review. The literature search process is shown in Figure 1.

Literature Characteristics and Quality Assessment

The eleven included studies were all retrospective studies¹⁸⁻²⁸, and three were single-arm uncontrolled studies²⁶⁻²⁸. The included studies were published from 2017 to 2021, and the study's sample size ranged between 15 and 100 cases. The experimental groups included in the study used a UBC for TLD, and the control group used a high-speed drill for TLD in all but one of the studies¹⁹. One of the studies¹⁷ did not describe relevant outcome measures using means \pm standard deviations (SD), where authors could not be contacted to request raw data. Therefore, we used the method proposed by McGrath et al²⁹⁻³²

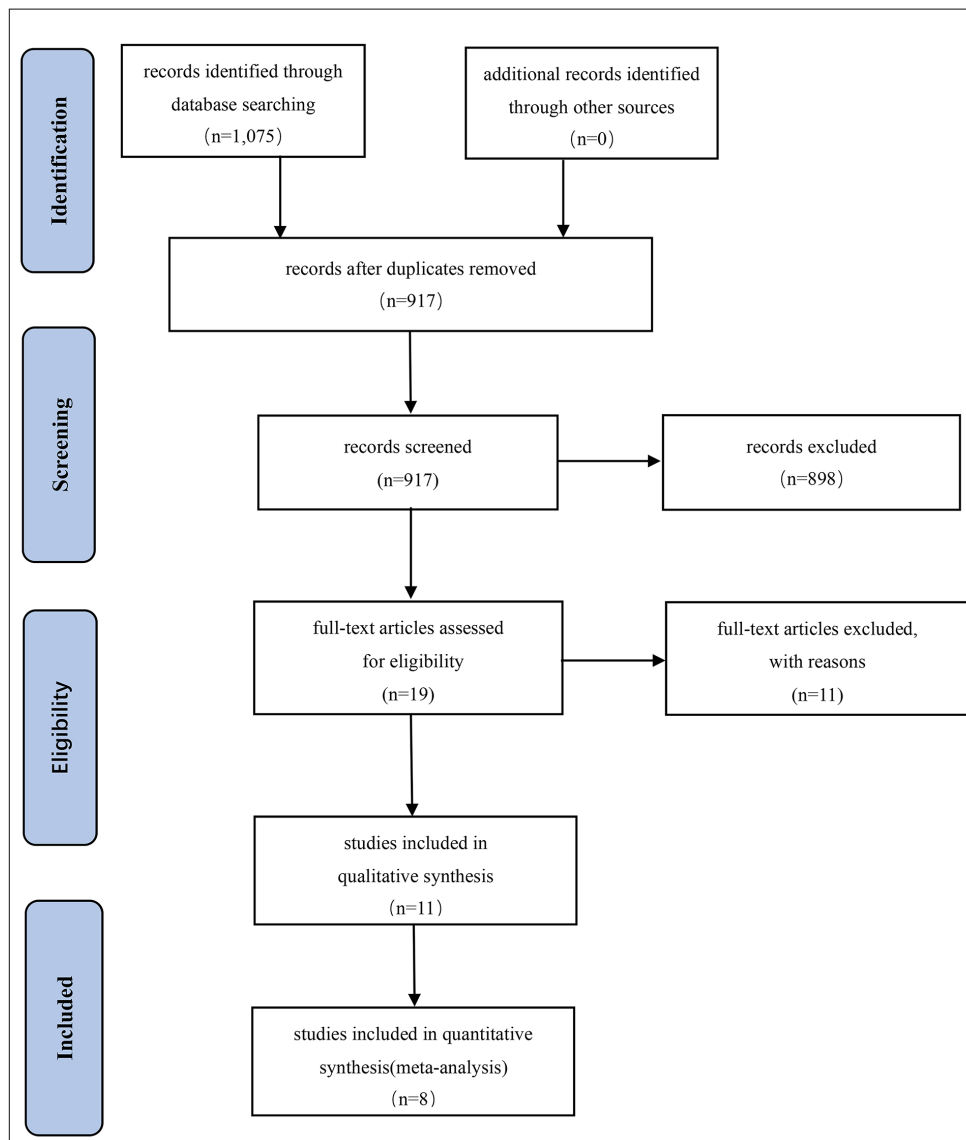


Figure 1. Flow diagram of study selection.

to calculate the approximate means \pm SD. The General characteristics of the included studies are summarized in Table I.

According to the criteria of the NOS score, the quality scores of eight included studies¹⁸⁻²⁵ ranged from 6 to 8, all considered high-quality studies. The quality assessment of the included studies is shown in Table II.

The Results of Operative Time and Intraoperative Blood Loss During Single Level TLD

Four studies^{18,22,23,25} reported the operative time for single-level TLD in both groups, with statistically significant heterogeneity between studies ($p < 0.001$, $I^2 = 91\%$), which was pooled using a random-effects model. A total of 5 studies^{18,19,22,23,25} reported the volumes of intraoperative blood loss during single-level TLD, with no statistically significant heterogeneity among studies ($p < 0.001$, $I^2 = 91\%$), which was pooled using a fixed-effects model. The results of this meta-analysis showed statistically significant differences in operative time and intraoperative blood loss between UBC and conventional instrumentation in single-level TLD [operative time: MD = -1.47, 95% CI (-1.86, -1.09), $p < 0.001$, Figure 2; intraoperative blood loss: MD = -46.62, 95% CI (-53.83, -39.40), $p < 0.001$, Figure 3]. In addition, a single-arm study by Sun et al²⁸ reported a mean operative time of (3.0 \pm 1.4) min and intraoperative blood loss of (108.3 \pm 47.3) ml for single-level TLD with UBC.

Results of Total Operative Time and Intraoperative Blood Loss

Four studies^{19-21,24} reported total operative time and intraoperative blood loss, with no statistically significant heterogeneity among studies (total operative time: $p = 0.01$, $I^2 = 73\%$; total intraoperative blood loss: $p < 0.001$, $I^2 = 83\%$), which was pooled using a random-effects model. The results of this meta-analysis showed statistically significant differences in total operative time and intraoperative blood loss between the two groups [Total operative time: MD = -56.88, 95% CI (-69.66, -44.10), $p < 0.001$, Figure 4; total intraoperative blood loss: MD = -143.52, 95% CI (-212.49, -74.54), $p < 0.001$, Figure 5]. In single-arm uncontrolled studies, Li et al²⁶ and Yang et al²⁷ reported that the mean total operative time during TLD with UBC was 112.7 min (range 45 to 180) and (83.7 \pm 12.3) min, respectively, and the intraoperative total blood loss was 24.9 (range 15 to 48) ml and (513.8 \pm 217.0) ml.

The Pooled Results of Perioperative JOA Score

There were eight studies¹⁸⁻²⁵, seven studies^{18,19,21-25}, and three studies^{20,21,23} that reported preoperative JOA scores, last follow-up JOA scores, and improvement rate of JOA scores (%), respectively. The results of this meta-analysis showed no statistically significant differences in preoperative JOA score, last follow-up JOA score, and improvement rate of JOA score (%) between the two groups [Preoperative JOA score: MD = 0.17, 95% CI (-0.46, 0.12), $p = 0.25$; last follow-up JOA score: MD = 0.43, 95% CI (-0.44, 0.13), $p = 0.33$; improvement rate of JOA score (%): MD = 5.0, 95% CI (-2.53, 12.54), $p = 0.19$, Figure 6].

The results from three single-arm studies²⁶⁻²⁸ demonstrated significant improvement in JOA scores at the last follow-up for TLD with UBC compared to that of preoperative JOA scores (Li et al²⁶: 5.87 \pm 1.41 vs. 9.87 \pm 1.06; Yang et al²⁷: 6.2 \pm 0.8 vs. 8.9 \pm 1.0; Sun et al²⁸: 4.7 \pm 0.9 vs. 10.1 \pm 0.6). The postoperative improvement rate of JOA score (%) in these three studies was: 78.3%²⁶, 58.8%²⁷, and 85.8%²⁸, respectively.

The Pooled Results of Intraoperative and Postoperative Complications

The eight included studies¹⁸⁻²⁵ reported the incidence of intraoperative and postoperative complications. Statistical analysis of the incidence of cerebrospinal fluid (CSF) leakage/dura injury and neurological deterioration/nerve root injury showed no statistically significant heterogeneity among studies (CSF leakage/dura injury: $p = 0.84$, $I^2 = 0\%$; neurological deterioration/nerve root injury: $p = 0.90$, $I^2 = 0\%$), which was pooled using a fixed-effects model. Meta-analysis revealed no statistically significant difference in CSF leakage/dural injury incidence during TLD [RR = 0.68, 95% CI (0.41, 1.13), $p = 0.14$, Figure 7]. However, a statistically significant difference in the incidence of neurological deterioration/nerve root injury was detected between the two groups [RR = 0.29, 95% CI (0.09, 0.91), $p = 0.03$, Figure 7]. The incidence of CSF leakage/dura injury and neurological deterioration/nerve root injury was 14.80% (31/210) and 1.90% (4/210), respectively.

Three single-arm studies²⁶⁻²⁸ have also reported the incidence of these complications, with Sun et al²⁸ reporting the incidence of CSF leakage and neurological deterioration of 21.4%

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Table I. General characteristics of the included literature.

Author	Country	Sex (male/female)		Age (years)		Diagnostic	Preoperative JOA score		Observation indicators
		Experimental	Control	Experimental	Control		Experimental	Control	
Lu et al ¹⁸	China	13/5	5/7	58.3 (45-73)	55 (45-67)	TSS	9.0 ± 1.1	8.9 ± 1.2	①③⑤⑦⑧
Krishnan et al ¹⁹	India	26/19	24/31	56.33 ± 11.63	53.51 ± 12.24	TSS	4.97 ± 1.57	4.98 ± 1.56	②③④⑤⑦⑧
Rajdeep et al ²⁰	India	23/9	31/14	58.6 ± 12.6	57.6 ± 7.2	TOLF	4.25 ± 1.9	4.27 ± 1.7	②④⑥⑦⑧
Liu et al ²¹	China	14/4	16/7	60.2 ± 9.5	57.7 ± 12.3	TOLF	5.7 ± 2.0	5.6 ± 1.8	②④⑤⑥⑦⑧
Pan et al ²²	China	17/9	15/11	52.3 ± 6.5	53.4 ± 6.8	TOLF	4.7 ± 1.2	4.9 ± 1.6	①③⑤⑦⑧
Li et al ²³	China	10/11	21/32	56.38 ± 8.32	59.00 ± 7.47	TOLF	5.67 ± 1.71	6.09 ± 1.94	①③⑤⑥⑦⑧
Peng et al ²⁴	China	8/13	6/11	54.4 ± 7.5	52.7 ± 7.3	TOLF	3.52 ± 1.08	3.59 ± 0.94	②④⑤⑦⑧
Hui et al ²⁵	China	19/10	18/12	57.1 ± 8.3	54.6 ± 7.2	TOLF	4.67 ± 1.42	4.53 ± 1.37	①③⑤⑦⑧
Li et al ²⁶	China	11/4	NC	56.3 (44-78)	NC	TOLF	9.87 ± 1.06	NC	②④⑤⑥⑦⑧
Yang et al ²⁷	China	16/11	NC	54.7 ± 8.5	NC	TOLF	6.2 ± 0.8	NC	②⑤⑥⑦⑧
Sun et al ²⁸	China	12/16	NC	49.7 ± 8.5	NC	TSS	4.7 ± 0.9	NC	①③④⑤⑥⑦⑧

TSS, Thoracic spinal stenosis; TOLF, Thoracic ossified ligamentum flavum; NC, No clear; ① Single-level laminectomy time; ② Operation time; ③ Single-level laminectomy bleeding volume; ④ Total intraoperative blood loss; ⑤ Last follow-up JOA score; ⑥ Improvement rate of JOA score (%); ⑦ Incidence of cerebrospinal fluid leakage or dura injury; ⑧ Incidence of neurological deterioration or nerve root injury.

Table II. Quality assessment of the included clinical controlled trials.

Study	Selection	Comparability	Exposure	NOS score)
Lu et al ¹⁸	★★★	★★	★★	7
Krishnan et al ¹⁹	★★★	★★	★★	7
Rajdeep et al ²⁰	★★★	★★	★★★	8
Liu et al ²¹	★★	★★	★★	6
Pan et al ²²	★★★	★★	★★	7
Li et al ²³	★★★	★★	★★	7
Peng et al ²⁴	★★★	★★	★★	7
Hui et al ²⁵	★★	★★	★★	6

A star (★) marks each entry of Newcastle-Ottawa Quality Assessment Scale (NOQAS), and studies were considered high quality if marked with asterisks greater than or equal to 6.

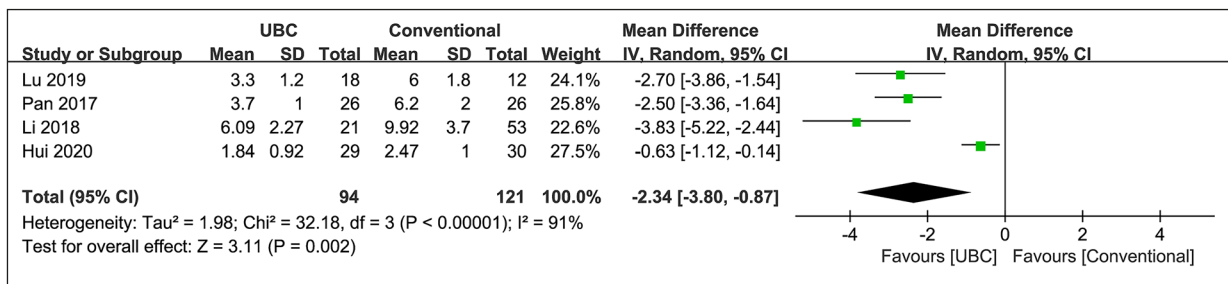


Figure 2. Forest plot of the meta-analytic estimate for operative time during single-level thoracic laminectomy decompression.

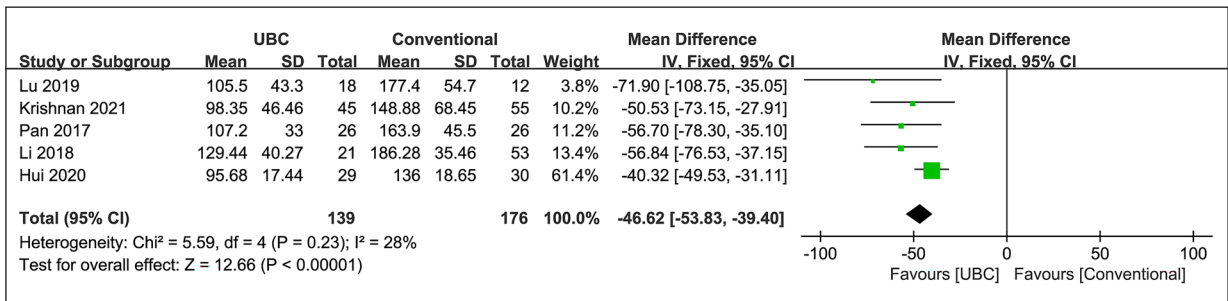


Figure 3. Forest plot of the meta-analytic estimate for intraoperative blood loss during single-level thoracic laminectomy decompression.

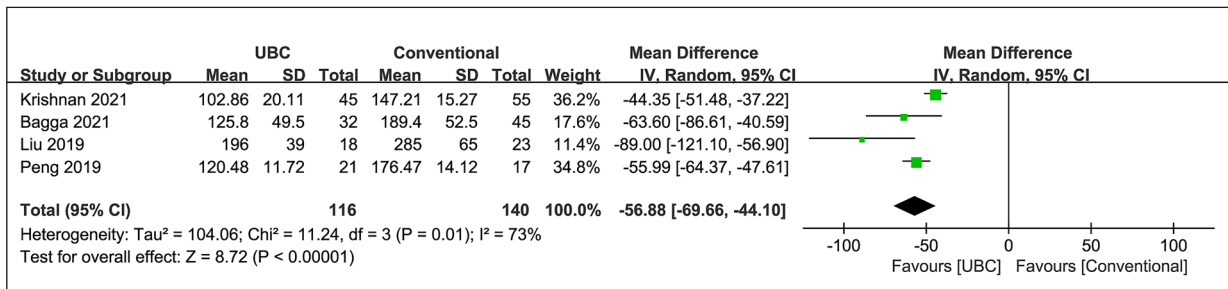


Figure 4. Forest plot of the meta-analytic estimate for total operative time.

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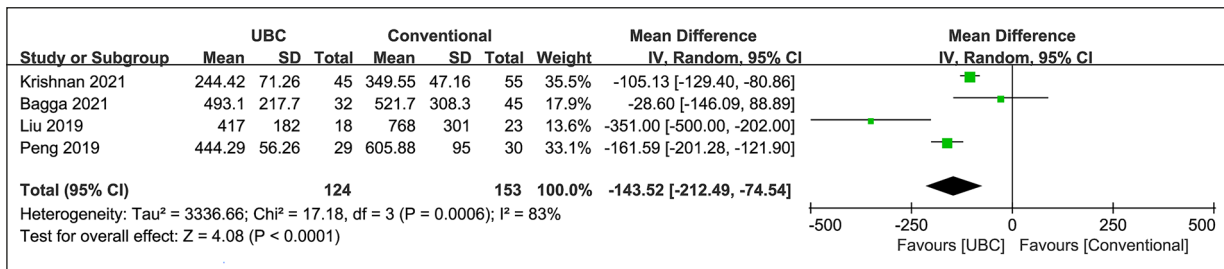


Figure 5. Forest plots of the meta-analytic estimate for total intraoperative blood loss.

(6/28) and 7.1% (2/28). However, CSF leakage and neurological deterioration did not appear in the studies of Li et al²⁶ and Yang et al²⁷.

Sensitivity Analysis and Publication Bias

Sensitivity analysis effectively verified the robustness of the outcome measures after pooling. We performed sensitivity analyses by removing studies individually for the outcome measures

with more than five included studies. The results showed that there were no statistical differences in operative time and intraoperative blood loss during single-level TLD, total operating time and intraoperative blood loss, JOA scores at the last follow-up, the improvement rate of JOA score, and the incidence of CSF leakage/dura defect, indicating that the above outcome measures were better robust, and the strength of evidence was

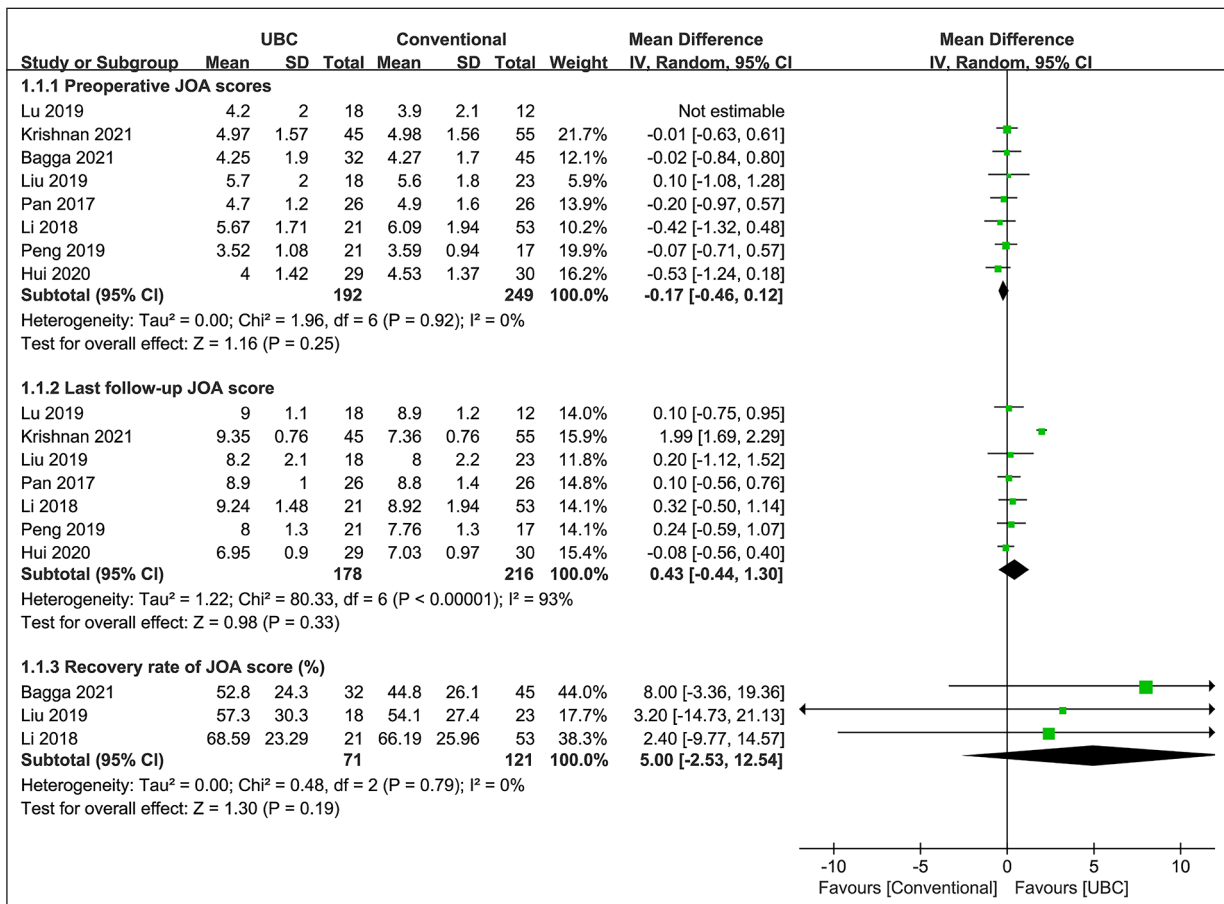


Figure 6. Forest plots of the meta-analytic estimate for perioperative JOA scores.

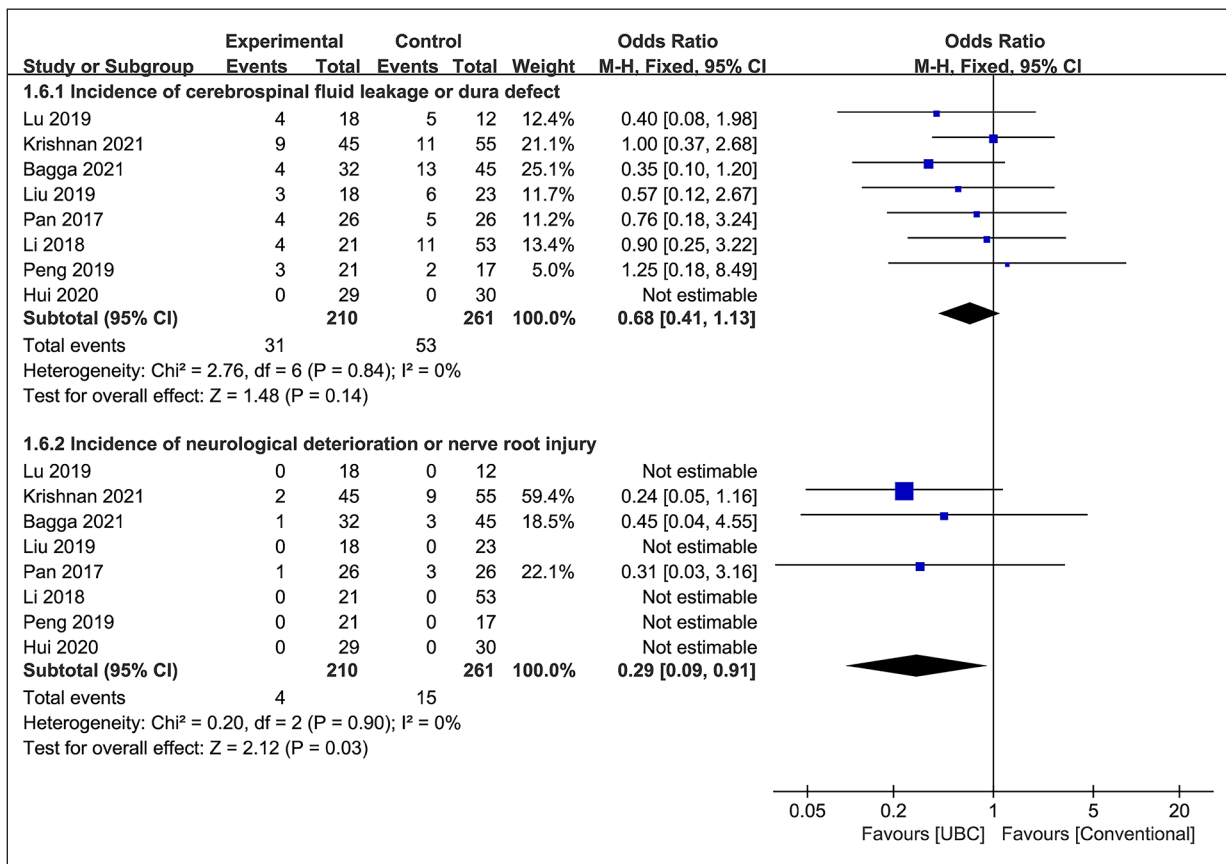


Figure 7. Forest plots of the meta-analytic estimate for intraoperative and postoperative complications.

higher after consolidation. However, there was no statistical difference in the incidence of neurological deterioration/nerve root injury in TLD after excluding the study by Krishnan et al¹⁹, [RR=0.39, 95% CI (0.08, 1.87), *p*=0.24], indicating that the statistical results of this indicator were affected more by a single study, and the pooled results were less reliable. The detection of publication bias is less significant when the number of included studies is less than 10¹⁷. Therefore, potential publication bias can be exempted from detection in the current study.

Discussion

Since it was reported in 1952, UBC had become a standard tool in dental osteotomy because of its ability to finely cut hard tissue and separate soft tissue, effectively reduce surgical trauma and provide precise control intraoperatively^{33,34}. Compared to high-speed drills, the bone tissue cut by UBC has better activity. It is more conducive

to bone repair and remodeling, with decreased inflammatory cells and increased osteogenesis in the periphery after bone grafting^{35,36}.

Given its convenience, flexibility, and high precision, it has also been widely used in spinal surgery^{11,37}. However, the evidence for its application in TLD still needs to be improved. To the best of our knowledge, this is the first meta-analysis to report the safety and efficacy of UBC in TLD for treating TSS. The results of this meta-analysis indicate that: (1) The application of UBC and traditional surgical instruments in TLD for the patients with TSS resulted in significant improvement in postoperative symptoms. (2) Compared with conventional surgical instruments, using UBC for TLD is more efficient, with shorter operative time, less bleeding, less nerve irritation, and a lower incidence of postoperative neurological deterioration. However, it does not offer significant advantages in reducing the incidence of dura injury.

Intraoperative blood loss is a critical indicator for evaluating the operation's safety. After pool-

ing the data from multiple studies, the results of the present work found that UBC has a significant advantage in reducing intraoperative blood loss. This may be related to the fact that the UBC works with imperceptible oscillations of the tip, which results in better flexibility and satisfactory precision. In addition, UBC only requires less operating space during surgery, can effectively avoid damage to surrounding tissues, and allows the operator to perform a laminectomy with greater convenience and speed¹¹. The ultrasonic cavitation effect is selective, and colloid-rich tissues such as blood vessels and nerves are more challenging to fragment. The resulting high temperature can also play an excellent hemostatic effect. The ultrasonic cavitation and thermal effects endow UBC with better hemostatic effects than high-speed drills³⁸. Suzuki et al³⁹ also showed that UBC generated more heat than high-speed drills, with attention to continuous water cooling, thus avoiding damage to surrounding tissues.

It has been shown^{40,41} that the efficacy of UBC applied in spine surgery is similar to that of conventional surgical instruments. The results of our study support this notion. The results indicated that the choice of surgical instruments had no influence on the efficacy of TLD for the patients with TSS, and UBC or traditional surgical instruments could all provide a good decompression. The recovery of neurological function after surgery is mainly related to the operator's decompression level. However, good surgical instruments might play an auxiliary role.

UBC has the effect of selectively cutting hard tissues, which can avoid iatrogenic injury to blood vessels, and dura mater during spine surgery, reduce the incidence of complications, and theoretically have a higher safety^{11,34}. However, the results of this meta-analysis revealed no significant difference in the incidence of cerebrospinal fluid (CSF) leakage or dura injury between the two groups. These results were consistent with the findings of Bydon et al⁴⁰ and Moon et al⁴¹. CSF leakage or dura injury due to UBC may be related to oscillation transmission to essential tissues such as the dura, spinal cord, blood vessels, and nerves. Therefore, some scholars have proposed that cotton cushions can be placed between UBC and vital tissues for protection^{37,42}, which is prohibited in high-speed drills. A porcine myelotomy study by Ota et al⁴³ demonstrated that UBC is a safe surgical tool with a low risk of dural perforation as long as it is not in vigorous contact with the dura mater. Therefore, the oscil-

lating tip should be avoided to stay in the same position for a long time intraoperatively, and attention should be paid to controlling UBC energy output and satisfactory intraoperative operation for patients with dural ossification.

As with other studies^{17,44}, the current study also suffered several limitations: (1) The number of the included studies was small, and all were retrospective studies. Therefore, the need for more high-quality RCTs may affect the level of evidence. (2) Due to the limitation of the number of included studies, the stratified analysis by follow-up time and surgical thoracic segments could not be performed, which may affect the reliability of the conclusions. (3) There was a lack of more exhaustive information on studies such as proficiency of operator in using UBC, brands and models of surgical instruments. (4) The language of the included studies was limited to Chinese and English, which may be subject to language bias.

Conclusions

It is safe and effective to use UBC for TLD for the treatment of TSS. Compared with conventional surgical instruments, UBC can significantly shorten the operation time and intraoperative blood loss and has advantages in reducing perioperative nerve injury. Given the limitations of this study, large sample, high-quality, multicenter RCTs are still needed to validate the current study's findings.

Conflict of Interest

The Authors declare that they have no conflict of interests.

Acknowledgements

Not applicable.

Informed Consent

Not applicable.

Ethics Approval

Not applicable.

Availability of Data and Materials

The datasets analyzed during the present study are available from the corresponding author on reasonable request.

Authors' Contribution

Xiaoping Mu and Jianxun Wei conceived and designed the study. Fuyu Chen, Xiaodong Wei, and Xueping Yang performed the experiments. Fuyu Chen, Xiaodong Wei, and Shengquan Huang interpreted the data. Xiaodong Wei, Chenqiang Yu, Jinxian Ou, and Shengquan Huang contributed reagents, materials, analysis tools. Fuyu Chen and Xiaoping Mu wrote the first draft of the manuscript.

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