Meta-Analysis of Complications in Minimally Invasive Spine Surgery (2013–2024)

Lumbar Spine—Biportal Endoscopic Spine Surgery A proportional Meta-Analysis

Sean Inzerillo, BS,[a] Eesha Gurav, BS,[b] Chibuikem A. Ikwuegbuenyi, MD,[c] Noah Willett, BS,[c] Mousa Hamad, MD,[c] Ibrahim Hussain, MD,[c] Alan Hernández-Hernández, MD,[d] Galal Elsayed, MD,[c] Roger Härtl, MD,[c] and Osama Kashlan, MD, MPH[c]

Study Design. Systematic review and proportional meta-analysis.

Objective. To assess total and specific complication rates associated with lumbar biportal endoscopic spine surgery (BESS).

Summary of Background Data. In recent years, BESS has emerged as an effective minimally invasive technique for treating lumbar spine conditions, offering benefits such as reduced tissue damage and improved outcomes. However, the safety of BESS across lumbar pathologies is underexplored, with complication rates reported up to 50%.

Methods. We registered on PROSPERO (CRD42024570377) and systematically searched PubMed, Medline, Embase, and Cochrane Library (Jan 2013–Mar 2024) per PRISMA guidelines. Studies were included if they focused on lumbar BESS in cohorts of at least 10 adult patients and provided extractable complication data. We excluded conference abstracts, reviews, meta-analyses, non-English studies, and those using microendoscopic, lateral, or oblique approaches. A random-effects model was used to pool complication rates, and study quality was assessed using the Cochrane Risk of Bias Tool and Newcastle-Ottawa Scale. Analyses were performed in R Studio.

Results. Seventy-five studies with 4404 patients (sample sizes 10–797) were included. Most studies were retrospective and geographically concentrated in China and Korea. Patients ranged from 27.6 to 80 years old, with 51.8% being male, and follow-up durations spanned from 3 to 27.5 months. The overall pooled complication rate for lumbar BESS was 7.75% (95% CI: 5.97%, 10.01%). Specific complication rates included dural tears (2.64%), nerve palsies (1.33%), postoperative hematomas (1.80%), surgical site infections (0.20%), and surgical revisions (1.68%). Total complication rates showed significant heterogeneity ($I^2 = 82.0\%$, $P < 0.01$), while specific complications exhibited low to moderate heterogeneity.

Conclusions. Lumbar BESS has a low overall complication rate of 7.75%, with dural tears and nerve palsies being the most common. Results should be interpreted with caution due to significant heterogeneity. Future research should explore risk factors of specific complication types and compare long-term outcomes with traditional methods.

Key Words: biportal, endoscopy, lumbar spine, surgical complications

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Minimally invasive spine surgery (MISS) has transformed the field of spinal surgery, offering reduced tissue disruption, faster recovery, and shorter hospital stays compared with traditional open approaches.[1] Endoscopic spine surgery represents an advancement in minimally invasive techniques, using an endoscope through tiny ports rather than traditional tubular retractors to access the spine.[2–4] To address the challenges encountered in the 1990s with maintaining surgical visualization and instrument manipulation through a single port, biportal endoscopic spine surgery (BESS) was developed, incorporating two separate working portals to

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From the [a]College of Medicine, SUNY Downstate Health Sciences University, New York, NY; [b]School of Medicine, University of South Carolina, Columbia, SC; [c]Department of Neurological Surgery, Och spine at New York Presbyterian Hosptial, Weill Cornell Medicine, New York, NY; and [d]Neurosurgery Department, Instituto Nacional de Neurología y Neurocirugía Manuel Velasco Suárez, Mexico City, Mexico.

S. I., E. G., these authors contributed equally.

IRB approval was not required for this study, as it is a systematic review and meta-analysis of previously published data.

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Address correspondence and reprint requests to Osama Kashlan, MD, MPH, Department of Neurological Surgery, Weill Cornell Medical College, New York Presbyterian Hospital, 525 East 68th Street, Box 99, New York, NY 10021; E-mail: kashlao@ccf.org

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enhance efficiency and precision.[5] BESS application started with treatment of lumbar disc herniation (LHD) with progression to lumbar spinal stenosis (LSS) and fusions.[5] In comparison to other MISS techniques, studies have shown that lumbar BESS reduces blood loss, decreases postoperative pain, and shortens hospital length of stay (LOS), with comparable treatment outcomes.[6,7]

Despite its easier learning curve and improved visualization compared with lumbar uniportal endoscopic spine surgery (UESS), complications can still arise during and after lumbar BESS.[8,9] Among these, dural tears are the most frequently reported, with incidence rates varying significantly across studies.[10–12] In addition, complications like nerve palsies, postoperative hematomas, surgical site infections (SSIs), and surgical revisions have been observed at lower frequencies with similar variability the literature.[10,11,13,14] While earlier analyses have attempted to pool complication rates for lumbar BESS, the literature focuses on LSS and excludes studies reporting no complications. This limits the assessment of the technique's overall safety and highlights the need for a comprehensive study to determine both total and individual incidence rates of these events.[10,11,13]

This systematic review and proportional meta-analysis, aims to define the safety profile of lumbar BESS by providing a detailed evaluation of its complication rates. Drawing on data from studies published over the past decade, the analysis examines overall complication rates and specific events, including dural tears, nerve palsies, postoperative hematomas, surgical site infections (SSIs), and surgical revisions. By clarifying the risks associated with BESS, this study seeks to inform clinical decision-making and support its integration into the evolving field of MISS.

MATERIALS AND METHODS

Literature Search

This systematic review and meta-analysis followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, and the study protocol was prospectively registered in PROSPERO (CRD42024570377).[15] PubMed, Medline, Embase via OVID, and the Cochrane Library were systematically searched to identify relevant publications from January 2013 to March 2024. To ensure comprehensive coverage of lumbar BESS and its associated complications, both Medical Subject Headings and relevant keywords were utilized. The search terms encompassed "Minimally invasive," "MISS," "Minimally Invasive Surgical Procedures," "tubular," "biportal," "uniportal," "spine," "surgery," "complications," "lumbosacral region," "cervical," "thoracic," "lumbar," "postoperative complications," and "intraoperative complications." The expanded search terms allowed for a thorough examination of complications across various MISS techniques (biportal, tubular, and uniportal) and spinal regions (cervical, thoracic, and lumbar), ensuring standardized screening while distinctly identifying lumbar BESS studies in this review. To supplement the database search, Google Scholar was also queried to identify additional studies that may have been overlooked. Detailed search strategies for each database are provided in Supplemental Digital Content 1, http://links.lww.com/BRS/C846.

Inclusion and Exclusion Criteria

Studies were considered for inclusion if they reported on lumbar BESS done on the lumbar spine and involved at least 10 adult patients. To be eligible, studies needed to provide extractable data on complications, either by detailing specific complication rates or explicitly noting the absence of complications. Conference abstracts, systematic reviews, meta-analyses, and studies without full-text availability in English were excluded. Research involving microendoscopic techniques or oblique/lateral surgical approaches was not considered. When multiple studies analyzed the same patient population, priority was given to the study with the largest cohort to minimize data redundancy.

Study Selection and Data Extraction

All articles identified through the literature search were imported into Rayyan (Cambridge, MA), a professional research tool designed to streamline study selection. After removing duplicate records, two independent reviewers (S.I. and E.G.) then evaluated titles and abstracts based on the predefined inclusion and exclusion criteria. Full texts of potentially relevant studies were retrieved and assessed using the same criteria. For data extraction, a standardized form was used to collect details on study characteristics, patient demographics, complication rates, and risk of bias. To ensure accuracy, extraction was performed independently by two reviewers (S.I. and E.G.). Any disagreements were resolved through discussion, with a third reviewer (C.I.) consulted when necessary.

Quality Assessment

The methodological quality of the included studies was evaluated using tools appropriate for their study design. Randomized controlled trials (RCTs) were assessed with the Cochrane Risk of Bias Tool, while non-randomized studies, including cohort and case-control studies, were evaluated using the Newcastle-Ottawa Scale (NOS).[16,17] An NOS score of 6 or higher was deemed indicative of good study quality, consistent with previous meta-analyses on complications in BESS used to treat LSS.[11] Two researchers (S.I. and E.G.) independently assessed study quality, resolving any discrepancies through discussion. If agreement could not be reached, a third reviewer (C.I.) was consulted to ensure consistency in the evaluations.

Data Management and Analysis

Our primary outcome was the lumbar BESS overall complication rate. Secondary outcomes included the rate of specific complications like dural tears, nerve palsies, postoperative hematomas, surgical site infections (SSIs), and surgical revisions. Statistical analysis was performed using R software (version 4.4.1; R Project for Statistical Computing, Vienna, Austria). These outcomes were selected based on their clinical significance and the frequency with which they were reported across the included studies.

Study heterogeneity was assessed using the I^2 statistic, though its interpretation required caution, as elevated I^2 values are often observed in proportional meta-analyses and may not be indicative of true variability.[18] A random-effects model was used throughout the analysis to account for expected variations in complication rates across different study settings.[18,19] In addition, a generalized linear mixed model with a logit transformation was used to handle the relatively low observed event rates.[18,20] Sensitivity analyses were performed by excluding studies with a moderate to high risk of bias and comparing results using a fixed-effect model. Publication bias was assessed qualitatively using funnel plots, which are reported in Supplemental Digital Content 2 to 7, http://links.lww.com/BRS/C847, http://links.lww.com/BRS/C848, http://links.lww.com/BRS/C849, http://links.lww.com/BRS/C850, http://links.lww.com/BRS/C851, http://links.lww.com/BRS/C852. However, their application in proportional meta-analyses remains unvalidated.[18] Our proportional meta-analysis was conducted using the *metaprop* function from the *meta* package.[21] All statistical analyses and visualizations were performed using R version 4.4.1 (R Project for Statistical Computing, Vienna, Austria).

RESULTS

Characteristics of Included Studies and Quality Assessment

The initial database search yielded 880 publications, leaving 799 distinct studies after removing 81 duplicates. Ninety-three studies were selected for full-text review to assess lumbar BESS complication rates, and 75 studies met the inclusion criteria. Figure 1 outlines the PRISMA flow diagram detailing study selection. The included studies encompassed 4404 patients, with sample sizes ranging from 10 to 797 patients. Summative data on study characteristics and complications are detailed in Table 1. The average age of participants ranged from 27.6 to 80.0 years, with males accounting for 51.8% of all patients. Follow-up durations ranged from 3.0 to 27.5 months in 73

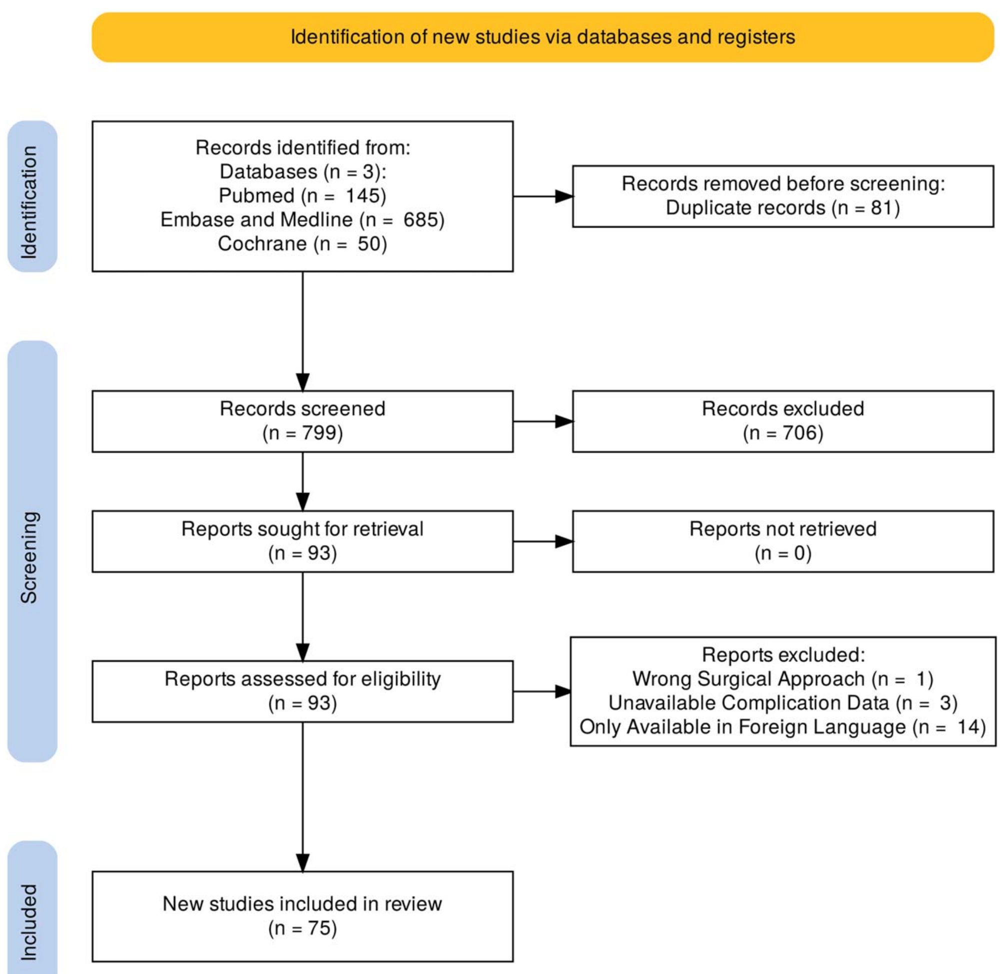

Figure 1. PRISMA Flow Diagram for study selection.

TABLE 1. Summary of Complications Across Studies in Lumbar Biportal Endoscopic Spine Surgery

Study	Sample Size	Total Complications	Dural Tears	Nerve Palsies	Postoperative Hematomas	Surgical Site Infections	Surgical Revisions
Lee *et al*[22]	47	6	2	0	0	0	3
Wang *et al*[23]	73	17	2	12	3	0	0
Kim *et al*[24]	30	1	–	–	–	0	–
Wu *et al*[25]	31	4	0	4	–	0	0
Park *et al*[13]	84	22	–	17	2	–	0
Wang *et al*[26]	13	1	–	–	–	1	–
Perez *et al*[3]	163	12	2	–	–	1	–
Pao[27]	89	7	1	–	2	–	2
Park *et al*[28]	34	4	2	0	1	0	1
Yuan *et al*[29]	22	8	–	–	–	0	–
Min *et al*[30]	54	3	2	–	1	–	–
Kim *et al*[31]	55	5	2	1	1	–	1
Park *et al*[32]	71	5	3	0	1	0	–
Hao *et al*[33]	20	2	–	0	–	–	–
Ito *et al*[34]	42	2	2	0	0	–	0
Guo *et al*[35]	26	3	2	–	–	–	–
Hu *et al*[36]	50	2	2	0	–	0	–
Liu *et al*[37]	27	1	1	0	0	0	–
Heo *et al*[38]	23	8	1	–	2	1	0
Heo *et al*[39]	37	2	1	0	1	–	–
He *et al*[40]	33	1	0	1	–	0	–
Wang *et al*[41]	51	3	1	1	–	–	–
Wu *et al*[42]	31	1	1	0	–	–	–
Ozer *et al*[43]	54	2	1	0	–	–	0
Kang *et al*[44]	81	6	3	0	2	0	–
Huang *et al*[45]	38	2	2	0	–	–	0
Xie *et al*[46]	30	2	–	2	–	–	–
Cheng *et al*[47]	32	1	0	1	–	–	0
Tan *et al*[48]	50	1	1	–	–	0	–
Yu *et al*[49]	29	0	0	0	0	0	–
Choi *et al*[50]	35	3	2	1	0	0	2
Heo *et al*[51]	14	2	0	0	-	0	–
Guo *et al*[52]	184	11	3	1	2	0	–
Ahn *et al*[53]	21	1	1	0	-	0	–
Kim *et al*[54]	57	5	–	1	1	–	2
Xu *et al*[55]	197	12	4	3	2	0	3
Choi *et al*[8]	68	7	2	1	0	0	–
Park *et al*[56]	60	6	3	0	1	0	2
Kang *et al*[57]	47	5	1	0	1	1	–
Hwa Eum *et al*[58]	58	8	2	2	1	–	–
Jiang[59]	57	5	2	0	3	–	–
Kim *et al*[60]	797	127	18	–	18	1	35
Xu *et al*[61]	65	2	–	1	–	1	–
Chen *et al*[62]	97	6	2	–	–	-	2
Wu *et al*[63]	17	1	1	0	–	-	0
Yang *et al*[64]	42	4	–	2	–	-	1
Kim *et al*[65]	105	3	2	1	1	0	1
Pao *et al*[66]	81	7	4	1	1	0	–
Jiang *et al*[67]	24	1	1	–	–	–	–
Huang *et al*[68]	44	2	1	1	0	–	–
Choi *et al*[69]	30	15	1	–	6	0	8
Kim *et al*[70]	32	3	0	1	1	0	1
Zhang *et al*[71]	70	2	1	1	0	0	-
Tsai *et al*[72]	20	1	0	1	0	0	0
Chien *et al*[73]	14	0	–	–	–	–	–
Librianto *et al*[7]	54	0	–	0	–	–	0
Wu *et al*[74]	32	0	0	0	–	0	0
Cao *et al*[12]	62	10	3	2	–	–	–
Heo *et al*[75]	32	2	0	1	1	0	–
You *et al*[76]	12	1	1	–	0	0	–
Park *et al*[77]	10	2	0	1	1	0	–
Song *et al*[78]	25	1	–	1	0	0	–
Chang *et al*[79]	42	6	1	4	0	0	0
Wang *et al*[80]	70	0	0	0	0	–	–
Park *et al*[81]	32	20	0	1	7	0	1
Gao *et al*[82]	44	2	2	0	0	0	–
Hua *et al*[83]	36	2	2	0	–	0	–

TABLE 1. (*continued*)

Study	Sample Size	Total Complications	Dural Tears	Nerve Palsies	Postoperative Hematomas	Surgical Site Infections	Surgical Revisions
Park *et al*[84]	115	95	–	–	15	0	5
Kang *et al*[85]	18	4	2	–	2	–	0
Czigleczki *et al*[86]	21	3	2	–	–	–	–
Kim *et al*[87]	58	8	2	–	–	–	2
Heo *et al*[88]	46	2	1	–	1	0	–
Segawa *et al*[89]	15	0	0	0	–	–	–
Heo *et al*[90]	11	2	0	2	0	–	–
Kang *et al*[91]	13	0	–	–	–	–	–

The value "0" indicates that the complication was explicitly noted to not have occurred. A "-" indicates that the complication was not explicitly mentioned in the study.

studies where follow-up time was reported. Geographically, most studies were conducted in China (31) and Korea (30), with a significant portion investigating lumbar spinal stenosis (41 studies) and disc herniation (30 studies). Notably, 69 out of the 75 included studies were retrospective in design. The studies were comprised of 68 cohort studies, five case-control studies, and two RCTs.

The included studies demonstrated good quality overall. Most cohort studies and all case-control studies scored at least 6/9 on the NOS (a score range of 6–9 indicated good quality). Only three cohort studies had a moderate risk of bias, scoring 5/9. Both RCTs were determined to have a low risk of bias using the Cochrane Risk of Bias Tool. The results of the quality assessments are listed in Tables 2 and 3.

Meta-Analysis Results

Overall Complications

The meta-analysis included 75 studies with 4404 patients undergoing lumbar BESS, with 533 documented complication events. The pooled incidence of overall complications was 7.75% (95% CI: 5.97%, 10.01%) based on the random-effects model. Significant heterogeneity was observed among the included studies ($I^2 = 82.0\%$, $P < 0.01$) (Figure 2). Sensitivity testing was not necessary.

Dural Tears

Sixty-one studies, representing 3820 patients, reported a total of 101 dural tears. The pooled incidence of dural tears was 2.64% (95% CI: 2.18%, 3.20%) based on the random-effects model. Negligible heterogeneity was observed across the studies ($I^2 = 0.0\%$, $P > 0.99$) (Figure 3).

Nerve Palsies

Among 54 studies with 2689 patients, 69 nerve injuries or palsies were identified. The pooled incidence of nerve injuries was 1.33% (95% CI: 0.78%, 2.26%) using the random-effects model. Moderate heterogeneity was observed among the included studies ($I^2 = 31.3\%$, $P = 0.017$) (Figure 4).

Postoperative Hematomas

Out of 43 studies with 3145 patients, 81 postoperative hematomas were identified. The pooled incidence of postoperative hematomas was 1.80% (95% CI: 1.13%, 2.88%) according to the random-effects model. Moderate heterogeneity was detected across the studies ($I^2 = 50.0\%$, $P < 0.01$) (Figure 5).

Surgical Site Infections (SSIs)

From 43 studies with 3029 patients, 6 events of SSI were reported. The pooled incidence of SSIs was 0.20% (95% CI: 0.09%, 0.44%) based on the random-effects model, with negligible heterogeneity ($I^2 = 0.0\%$, $P > 0.99$) (Figure 6).

Surgical Revisions

Among 31 studies with 2442 patients, 72 surgical revisions following lumbar BESS were noted. The pooled incidence of revisions was 1.68% (95% CI: 0.94%, 2.98%) according to the random-effects model. Low heterogeneity was observed across the studies ($I^2 = 15.9\%$, $P = 0.22$) (Figure 7).

Figure 8 Illustration depicting hematoma, dural tear and CSF leak and potential nerve injury mechanisms during endoscopic minimally invasive lumbar spine surgery.

DISCUSSION

Our study demonstrated a pooled overall complication rate of 7.75% based on 4404 patients across 75 studies, and the most frequently observed complications were dural tears (2.64%) and nerve palsies (1.33%). The persistent heterogeneity likely reflects genuine differences in complication rates attributable to variations in patient selection, surgical technique, surgeon experience, and other clinical factors rather than study quality limitations. This effect was most evident for overall complications, where inconsistent definitions and reporting contributed to greater variability, whereas specific complications such as dural tears and SSIs were reported more consistently, resulting in lower heterogeneity. Previous meta-analyses for BESS treatment of LSS report rates of complications between 5% and 8.1%.[10,11,14] He *et al*[92] noted that BESS yielded a higher rate of "postoperative excellence" than UESS, with similar symptom improvement with both approaches in terms of VAS and ODI pain scores.

TABLE 2. Study Evaluation Using the Newcastle-Ottawa Scale for Nonrandomized Studies.*

Study	Design	Selection	Comparability	Exposure	Total Score
Lee *et al*[22]	Retrospective cohort	4	2	3	9
Wang *et al*[23]	Retrospective cohort	3	0	3	6
Kim *et al*[24]	Retrospective cohort	4	2	3	9
Wu *et al*[25]	Retrospective cohort	3	0	3	6
Park *et al*[13]	Retrospective cohort	3	0	3	6
Wang *et al*[26]	Retrospective cohort	3	0	3	6
Perez *et al*[3]	Retrospective cohort	3	0	3	6
Pao[27]	Retrospective cohort	3	0	3	6
Yuan *et al*[29]	Retrospective cohort	4	2	3	9
Min *et al*[30]	Retrospective cohort	4	2	3	9
Kim *et al*[31]	Retrospective cohort	3	0	3	6
Park *et al*[32]	Retrospective cohort	3	0	3	6
Hao *et al*[33]	Retrospective cohort	4	2	3	9
Ito *et al*[34]	Retrospective cohort	4	2	3	9
Guo *et al*[35]	Retrospective cohort	4	2	3	9
Hu *et al*[36]	Retrospective cohort	3	0	3	6
Liu *et al*[37]	Prospective case control	3	2	3	8
Heo *et al*[38]	Retrospective cohort	4	2	3	9
Heo *et al*[39]	Retrospective cohort	4	2	3	9
He *et al*[40]	Retrospective case control	3	2	3	8
Wang *et al*[41]	Retrospective cohort	4	2	3	9
Wu *et al*[42]	Retrospective cohort	4	2	3	9
Ozer *et al*[43]	Retrospective cohort	4	2	3	9
Kang *et al*[44]	Retrospective cohort	3	0	3	6
Huang *et al*[45]	Retrospective cohort	4	2	3	9
Xie *et al*[46]	Retrospective cohort	4	2	3	9
Cheng *et al*[47]	Retrospective cohort	3	0	3	6
Tan *et al*[48]	Retrospective cohort	4	2	3	9
Yu *et al*[49]	Retrospective cohort	4	2	3	9
Choi *et al*[50]	Retrospective cohort	4	2	3	9
Heo *et al*[51]	Retrospective cohort	3	0	3	6
Guo *et al*[52]	Retrospective cohort	3	0	3	6
Ahn *et al*[53]	Retrospective cohort	3	0	3	6
Kim *et al*[54]	Retrospective cohort	3	0	3	6
Xu *et al*[55]	Retrospective cohort	3	0	3	6
Choi *et al*[8]	Retrospective cohort	3	0	2	5
Park *et al*[56]	Retrospective cohort	3	0	2	5
Kang *et al*[57]	Retrospective cohort	4	2	3	9
Hwa Eum *et al*[58]	Retrospective cohort	3	0	3	6
Jiang[59]	Retrospective cohort	4	2	3	9
Kim *et al*[60]	Retrospective cohort	3	0	3	6
Xu *et al*[61]	Retrospective cohort	4	2	3	9
Chen *et al*[62]	Retrospective cohort	3	0	3	6
Wu *et al*[63]	Retrospective cohort	3	0	3	6
Yang *et al*[64]	Retrospective cohort	3	0	3	6
Kim *et al*[65]	Retrospective cohort	3	0	3	6
Pao *et al*[66]	Retrospective cohort	3	0	3	6
Jiang *et al*[67]	Retrospective cohort	4	2	3	9
Huang *et al*[68]	Retrospective cohort	3	0	3	6
Choi *et al*[69]	Retrospective cohort	4	2	3	9
Kim *et al*[70]	Retrospective cohort	4	2	3	9
Zhang *et al*[71]	Retrospective cohort	4	2	3	9
Tsai *et al*[72]	Prospective cohort	3	0	3	6
Chien *et al*[73]	Retrospective cohort	3	0	3	6
Librianto *et al*[7]	Retrospective cohort	4	2	3	9
Wu *et al*[74]	Prospective cohort	3	0	3	6
Cao *et al*[12]	Retrospective cohort	4	2	3	9
Heo *et al*[75]	Retrospective cohort	4	2	3	9
You *et al*[76]	Retrospective cohort	3	0	3	6
Park *et al*[77]	Retrospective cohort	3	0	3	6
Song *et al*[78]	Retrospective cohort	4	2	3	9
Chang *et al*[79]	Retrospective cohort	4	2	3	9
Wang *et al*[80]	Retrospective cohort	3	0	3	6
Gao *et al*[82]	Retrospective cohort	3	0	3	6
Hua *et al*[83]	Retrospective case control	4	2	3	9
Park *et al*[84]	Retrospective case control	4	2	3	9
Kang *et al*[85]	Retrospective cohort	3	0	3	6
Czigleczki *et al*[86]	Retrospective cohort	3	0	3	6

TABLE 2. (*continued*)

Study	Design	Selection	Comparability	Exposure	Total Score
Kim *et al*[87]	Retrospective cohort	3	0	3	6
Heo *et al*[88]	Prospective case control	4	2	3	9
Segawa *et al*[89]	Retrospective cohort	3	0	2	5
Heo *et al*[90]	Retrospective cohort	3	0	3	6
Kang *et al*[91]	Retrospective cohort	3	0	3	6

*Studies scoring 7 to 9 were considered low risk of bias, 5 to 6 moderate risk, and 0 to 4 high risk.

Studies comparing lumbar BESS with another minimally invasive lumbar approach, UESS, showed higher overall complication rates for UESS, although these results were not statistically significant.[55,83,92] These studies noted advantages of lumbar BESS when compared with lumbar UESS, including better field of vision, better access to the lesion, increased workspace, and reduced soft tissue injury, which may contribute to lower complication rates of this approach.[11,55,92] Hua *et al*[83] found that surgical duration was significantly shorter in BESS than UESS, while time to ambulation and length of hospitalization were not significantly different. While the literature suggests that both BESS and UESS are effective in treating lumbar spinal stenosis, BESS offers the advantages of a better visual field and access to the lesion when compared with UESS. BESS also provides intraoperative endoscopic visualization akin to microscopic surgical procedures, but with the advantage of minimal posterior musculoligamentous injury.[83] More research is needed to further compare relative advantages and limitations of BESS to UESS and other MISS approaches for treatment of lumbar spine pathologies.

In addition, one study suggested that differences in surgeons' skill levels, techniques, and familiarity with UESS and/or BESS may have influenced reported complication rates, increasing variability in the studies evaluated.[55] For example, surgeons unfamiliar with the visual field of BESS are more likely to encounter dural tears, especially in situations of continued irrigation and failure to control hemorrhage.[11] Despite differences in surgeon skill and technique, long-term outcomes of BESS studies are often comparable, highlighting the safety and efficacy of BESS. Although studies comparing BESS and UESS exist, more direct comparisons between BESS and other MISS techniques are warranted to better define their relative advantages.

Dural Tears

The pooled complication rate for dural tears in lumbar BESS from our study was 2.64%, based on sixty-one studies. Occurrence of dural tears can be associated with factors such as complex anatomy surrounding the surgical site, instrument manipulation, and high-speed drilling. Risk factors for dural tears include female sex, advanced age, degenerative spondylolisthesis, and juxtafacet cysts.[11] Park and colleagues reported dural tears as the most common complication associated with BESS, at an overall rate of 2.23%, which is lower when compared with the range of complication rates associated with dural tears in other BESS studies. Biportal discectomy had the lowest complication rate of 1.8%, while biportal TLIF had the highest rate of 2.1%, possibly due to the usage of osteotomes to perform facetectomy in TLIF.[13] Similarly, Chen and colleagues and Liang and colleagues reported dural tears as the most reported complication with incidence rates of 4.75% and 2%, respectively, with the latter attributing frequency of dural tears to the complicated anatomy associated with LSS and the surgeon's skill level. In Kim *et al*,[60] the largest study in our review (797 patients), dural tears were one of the major sources of patient dissatisfaction. Increased incidence of dural tears in the initial 50 surgeries of this study was likely because the four spine surgeons performing BESS were primarily experienced in microscopic and uniportal techniques rather than the biportal approach. They may have become more accustomed to the biportal approach as the study continued, leading to lower incidence of dural tears after the first 50 patients. Overall, based on our study and the existing literature, the pooled rate of dural tears in BESS is similar to that in UESS and in spine surgery overall, and is the most common complication associated with BESS.[93,94]

Implementing proper treatment of dural tears is important to avoid further complications, such as pseudomeningocele, surgical site infection, and meningitis.[11] While lumbar BESS does not have a defined management plan for dural tears, there are a few methods to reduce incidence of dural tears that are commonly used in MISS.[11] For example, if the laceration is small

TABLE 3. Study Evaluation Using the Cochrane Risk of Bias Tool for Randomized Clinical Trials

Study	Design	Random Sequence Generation	Allocation Concealment	Blinding	Incomplete Outcome Data	Selective Reporting	Other Biases
Park *et al*[28]	Randomized clinical trial	Low	Low	Low	Low	Low	Low
Park *et al*[81]	Randomized clinical trial	Low	Low	Low	Low	Low	Low

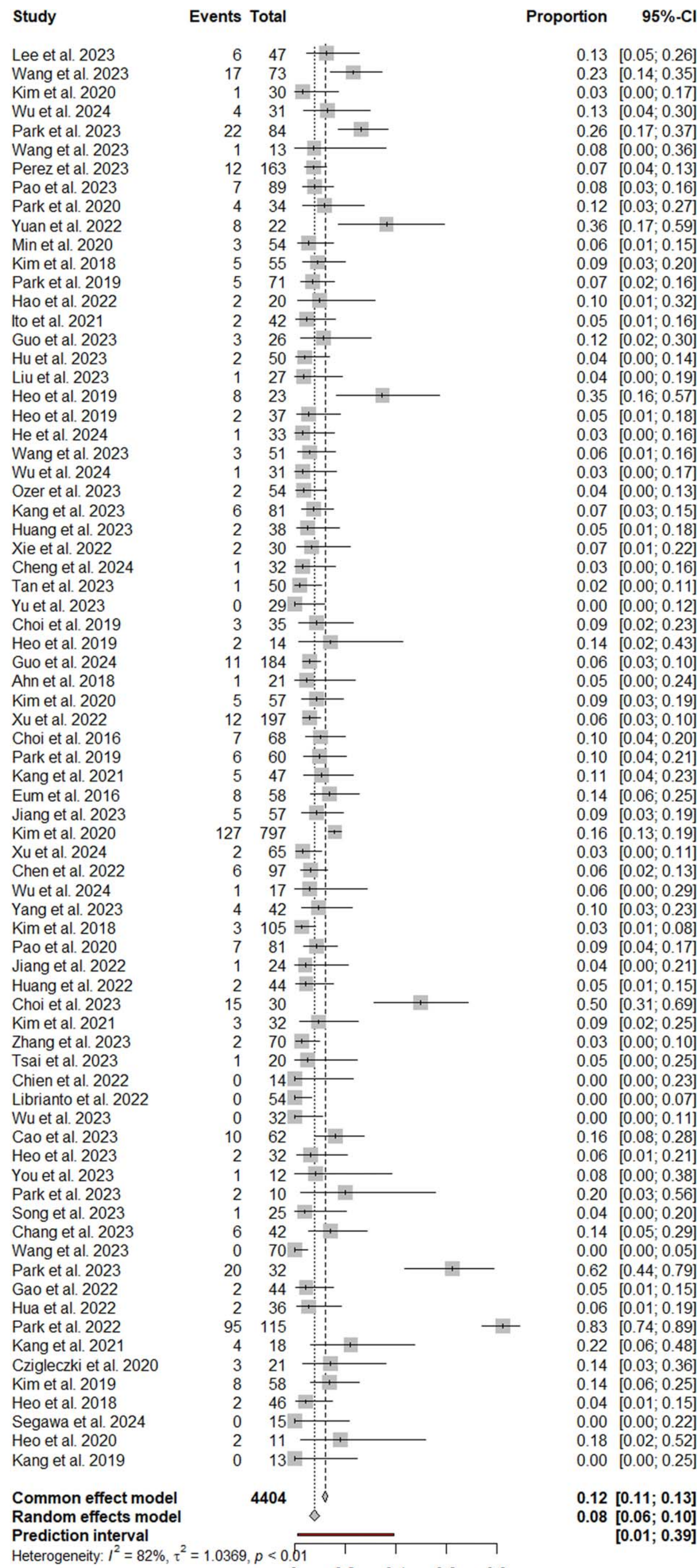

Figure 2. Forest plot for the incidence of total complications in lumbar biportal endoscopic spine surgery.

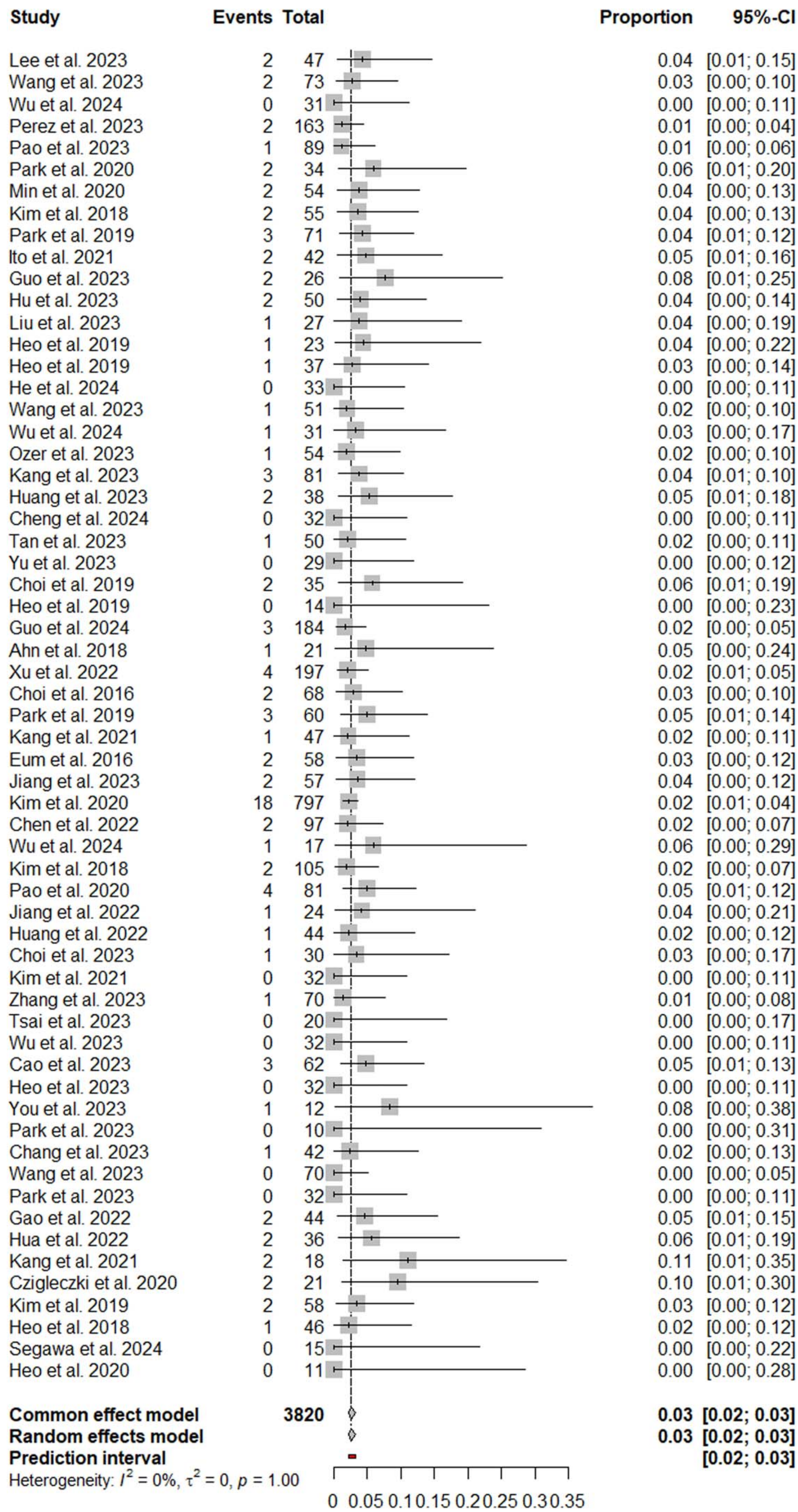

Figure 3. Forest plot for the incidence of dural tears in lumbar biportal endoscopic spine surgery.

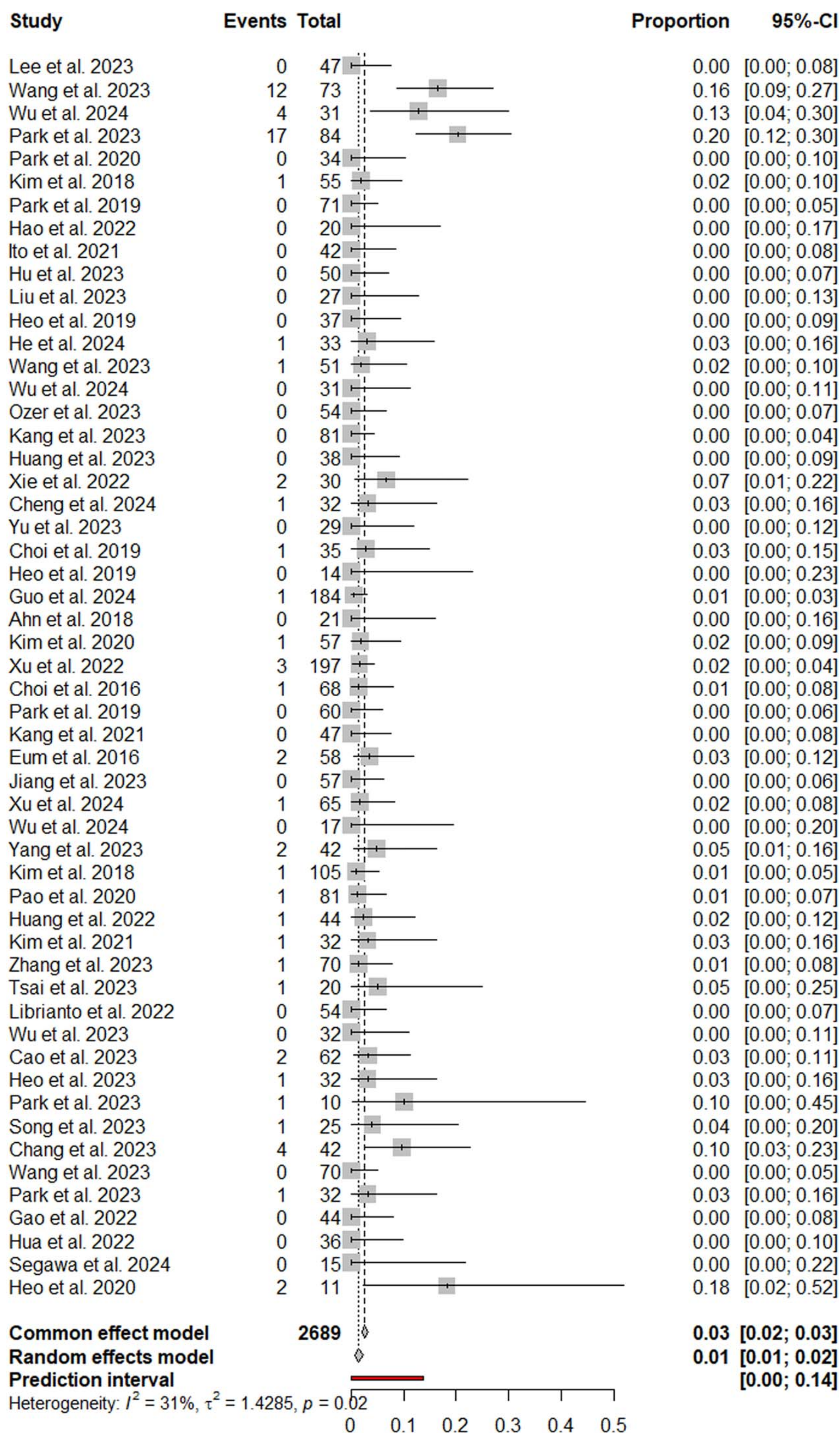

Figure 4. Forest plot for the incidence of nerve palsies in lumbar biportal endoscopic spine surgery.

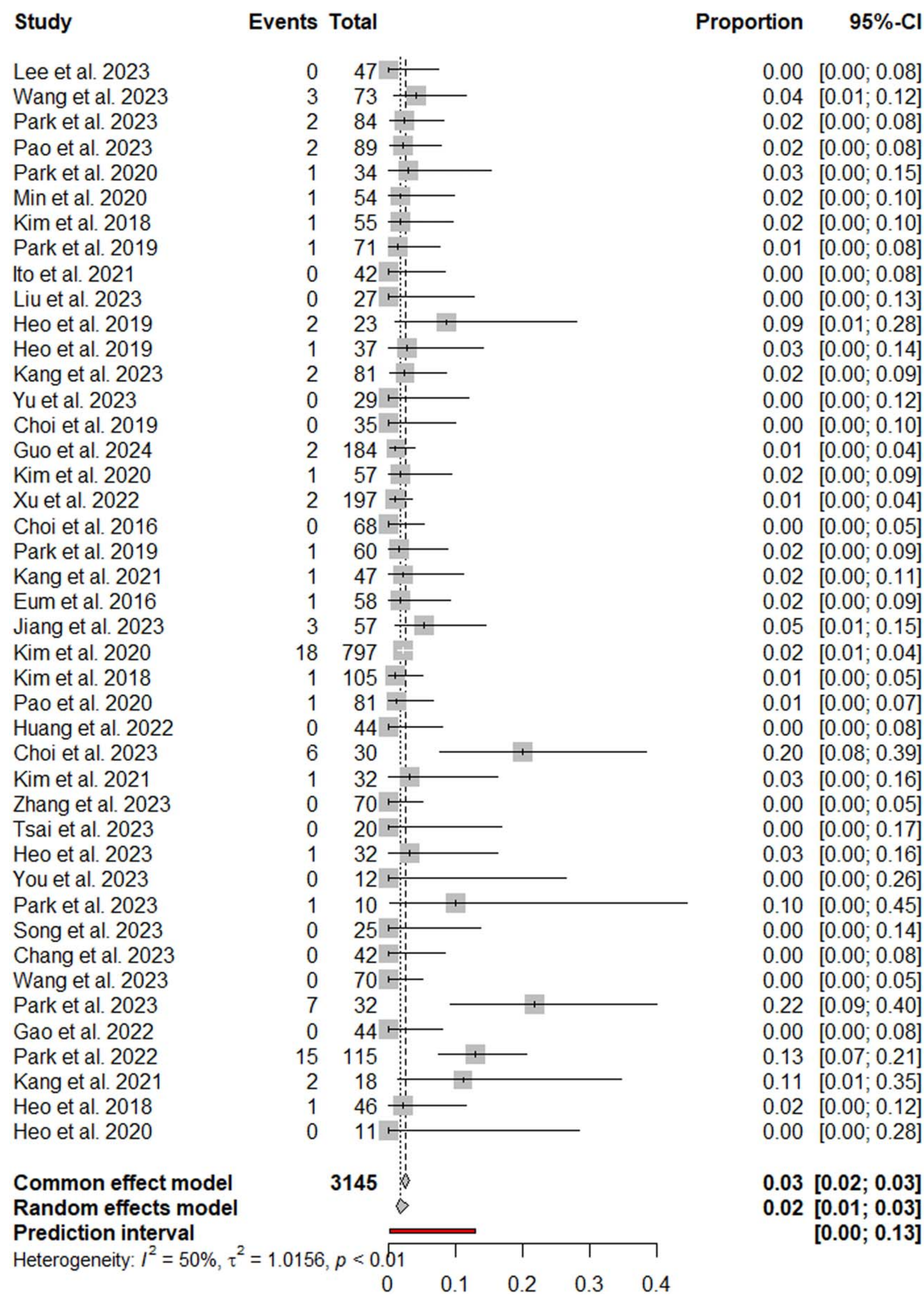

Figure 5. Forest plot for the incidence of postoperative hematoma in lumbar biportal endoscopic spine surgery.

enough, placing an artificial dural (spinal) patch, applying fibrin glue, or placing a fat flap via endoscopic surgery are all options to close the tear. For lacerations longer than 1 cm, clipping sutures with at least 2 days of rest are recommended for sufficient healing.[11] If the patient experiences headache, wound redness, swelling, and/or other related symptoms beyond 2 days, open surgery is necessary.[11]

Nerve Palsies

The pooled complication rate for nerve palsies in lumbar BESS from this meta-analysis was 1.33%, based on fifty-four studies. Incidence of transient palsies may be associated with increased hydrostatic pressure from continuous irrigation in procedures of longer duration.[10] Other factors leading to nerve palsies in lumbar BESS may include nerve root compression, nerve root retraction,

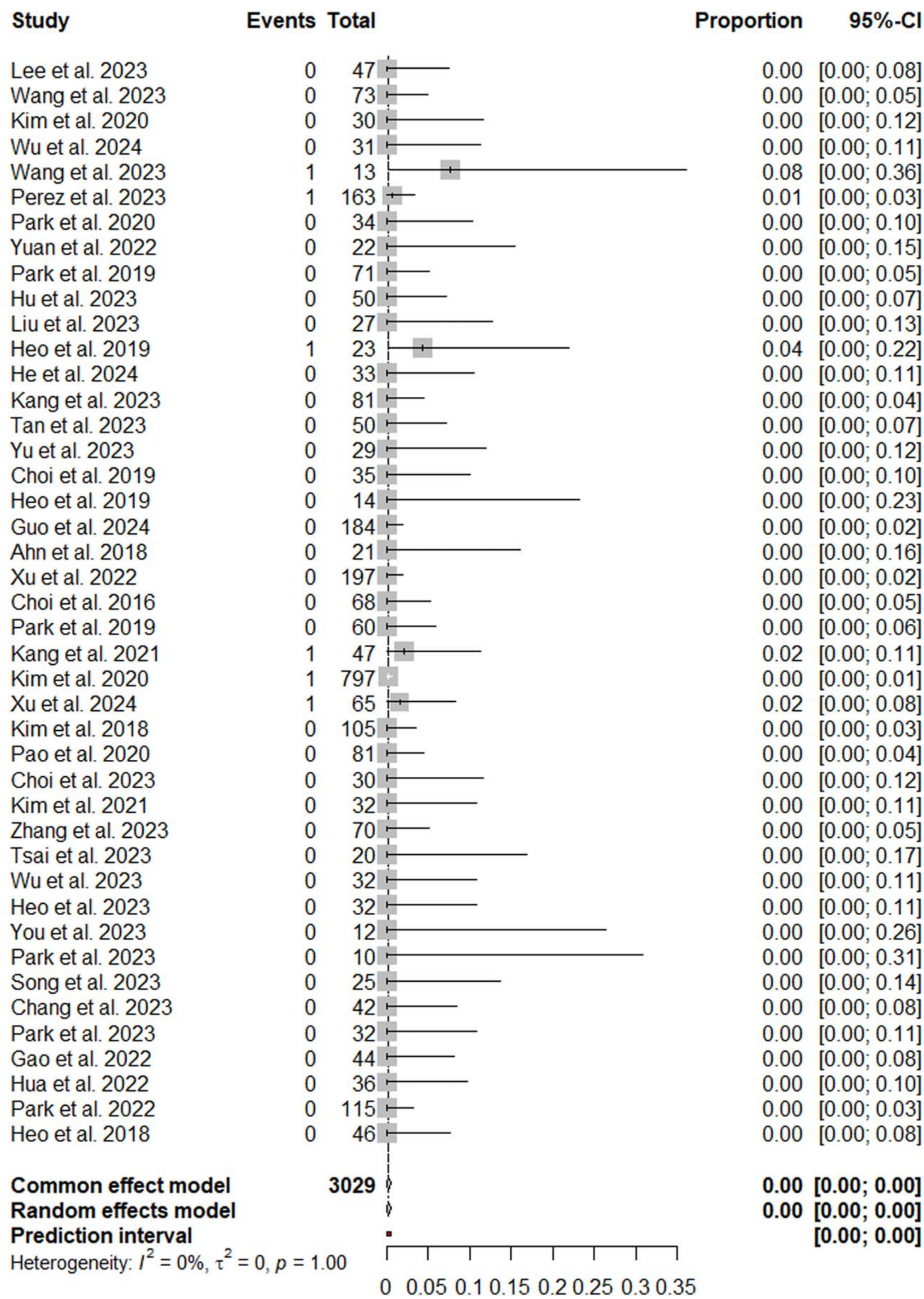

Figure 6. Forest plot for the incidence of surgical site infections in lumbar biportal endoscopic spine surgery.

intraoperative irregularities, and/or thermal injury from surgical tools (*e.g.* radiofrequency ablation).[11,95] For nerve root injury in BESS, Park *et al*[96] noted that biportal laminectomy had the lowest incidence rate of 0%, biportal discectomy had the next highest rate of 0.7%, and TLIF demonstrated the highest incidence rate of 0.9%. The proposed reason for these varying rates is that endoscopic irrigation fluid creates hydrostatic pressure that helps displace the thecal sac and important neural components away from the working instruments without significant retraction.

Strategies to minimize the risk of nerve palsies in lumbar BESS include careful identification and delicate handling of neural structures, avoiding excessive retraction, and using low-intensity energy settings for thermal devices near nerve roots.[11] In cases involving

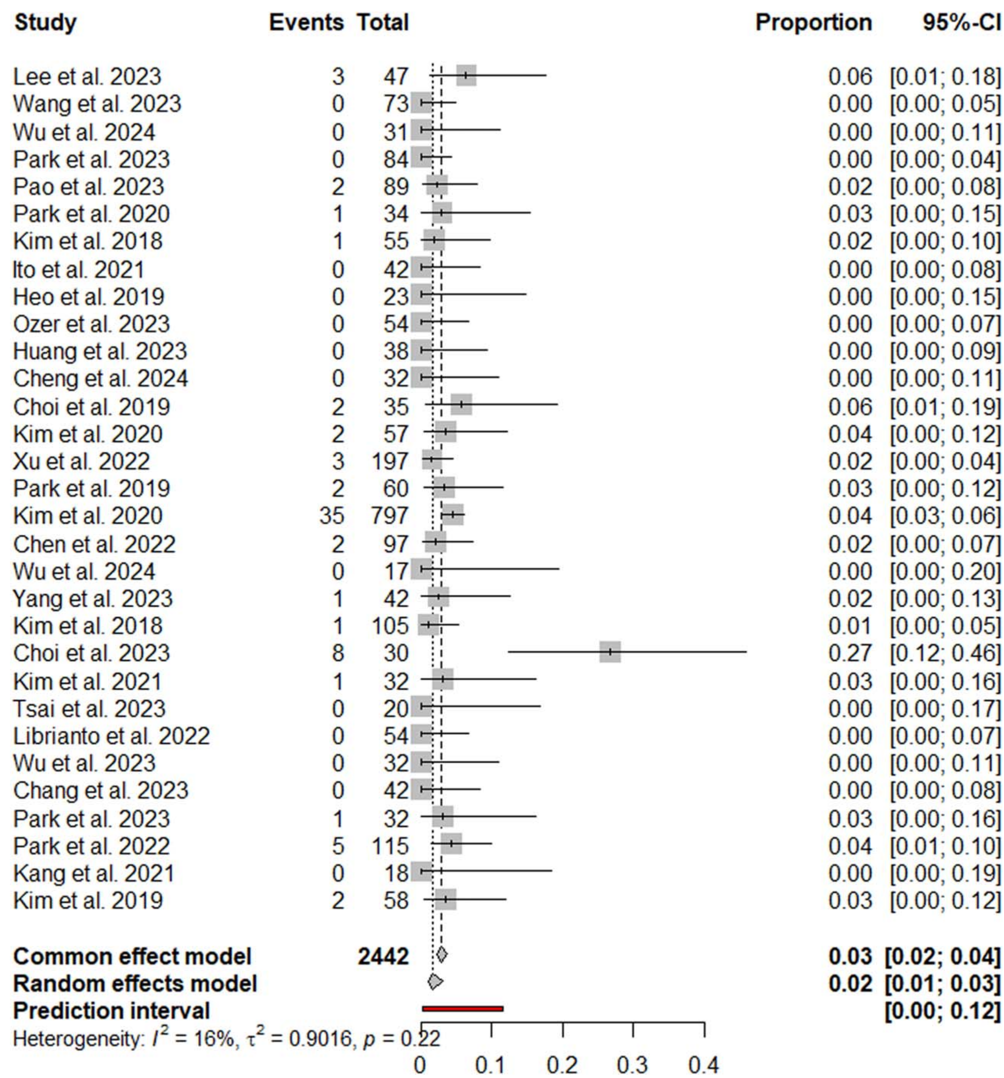

Figure 7. Forest plot for the incidence of revisions in lumbar biportal endoscopic spine surgery.

incidental dural tears, if nerve incarceration is a concern, expanded durotomy should be considered even in tears < 1 cm. For dural tears with uneven margins, large lesions, and/or nerve incarceration, open repair is the best treatment option.[11]

Postoperative Hematomas

Our pooled complication rate for postoperative hematomas in lumbar BESS was 1.80%, based on forty-three studies. This finding is higher in comparison to a recent review investigating MISS complications, which reported rates of hematomas for lumbar tubular, uniportal, and biportal cases as 0.27%, 0.17%, and 0.97%, respectively.[2] Although hematoma subtype was not consistently reported across all included studies, epidural hematomas are most commonly observed in BESS.[23,38,44] The risks of resulting infection, epidural fibrosis, and especially of permanent neurological deficits due to neural compression all highlight the importance of detecting postoperative hematomas as early as possible.[97,98] Independent risk factors for subdural hematoma following MIS-TLIF include diabetes mellitus and postoperative anticoagulant therapy, while multilevel surgical procedures and presence of preoperative coagulopathy (*i.e.* thrombocytopenia, coagulation factor deficiency, and anticoagulation therapy) have been identified as a significant risk factors for postoperative epidural hematoma.[97,98] In open lumbar spine surgery, risk factors for postoperative hematomas include multilevel surgical procedures, presence of preoperative coagulopathies, larger exposures of the epidural space, and the patient's primary disease being prone to bleeding (for example, abnormal coagulation associated with liver cirrhosis).[98]

Existing literature suggests that BESS generally exhibits a higher risk of postoperative epidural hematoma in comparison to conventional decompression surgery, due to several of the previously mentioned risk factors along with increased water pressure due to use of infusion

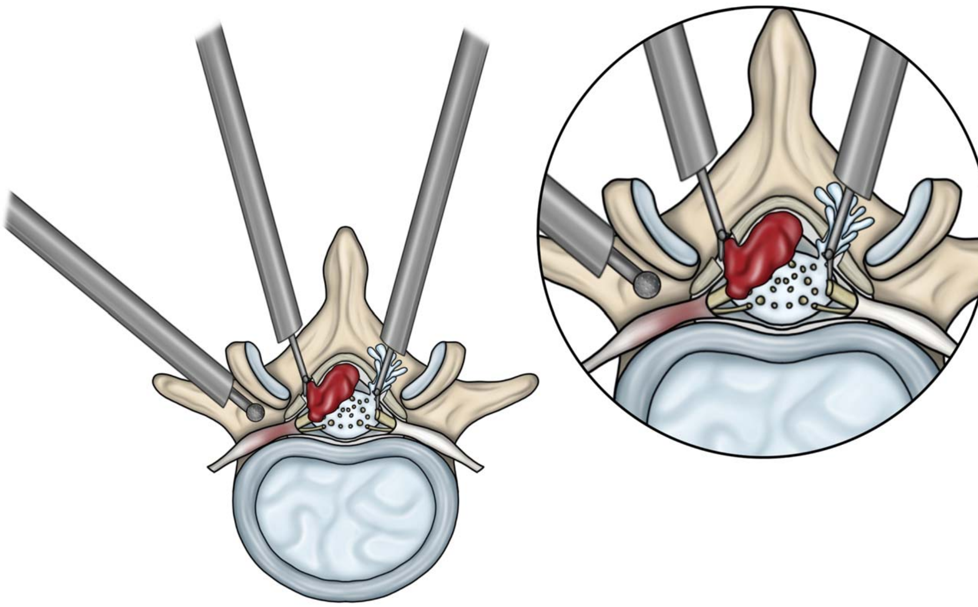

Figure 8. Illustration depicting hematoma, dural tear, CSF leak, and potential nerve injury mechanisms during endoscopic minimally invasive lumbar spine surgery. CSF indicates Cerebrospinal Fluid.

pumps.[99,100] This may also reflect inherent limitations in endoscopic visualization and hemostatic control. Strategies to lower this risk could include careful intraoperative irrigation management, since continuous irrigation can conceal vessels that are still bleeding, and controlling bleeding from soft tissue and the epidural venous plexus.

Surgical Site Infections

The pooled complication rate for surgical site infections (SSIs) in lumbar BESS from our study was remarkably low at a rate of 0.20%, based on 43 studies. Other MISS studies have reported similarly favorable outcomes associated with this complication. For example, Kulkarni *et al*[101] reported an incident rate of only 0.29% for SSIs based on 1043 patients who underwent 763 noninstrumented MISS and 280 MIS-TLIF procedures. Procedural factors such as inadequate treatment of dural tears and patient-specific factors including female sex, diabetes, obesity, BMI, prolonged operation time, prolonged hospital stay, hypertension, previous surgery, and presence of chronic conditions can increase SSI risk following lumbar spine surgery.[60,102] However, factors contributing to the minimal risk of SSIs associated with endoscopic surgery in general include minimal tissue disruption, minimal blood loss, and the use of a continuous irrigation system during procedures.[60,103]

Surgical Revisions

The pooled incidence of surgical revisions for lumbar BESS from this meta-analysis was 1.68%, based on 31 studies. This is lower than the reoperation rate of standard lumbar laminectomy or discectomy (2.2%) reported by Park *et al*.[96] In the largest biportal study included in this meta-analysis, the primary reasons for reoperation were lesion recurrence (88.89% of reoperation cases), inadequate decompression (44.44%), and postoperative hematoma (27.78%). While postoperative hematoma led to fewer reoperations than the other causes, it was still identified as a significant factor associated with unsuccessful outcomes.[60] In this study, “unsuccessful outcomes” for which reoperation rates were recorded were characterized by the need for reoperation and/or a hospital stay longer than 2 weeks. According to Kim *et al*,[60] common reasons for revisions include lesion recurrence, incomplete decompression, dural tear, hematoma, ascites, and infection. Meticulous intraoperative attention and consistent adherence to best practices are essential to prevent unsuccessful outcomes needing surgical revision.

Limitations

This meta-analysis has a few limitations. Firstly, many of the studies included are nonrandomized trials or single-arm clinical studies, which may introduce bias and limit overall strength of the evidence. The absence of randomized controlled trials may undermine direct comparisons of BESS to UESS and other MISS techniques. Furthermore, the concentration of research from China raises questions about how applicable the results may be to more diverse populations. Variability in surgeon experience may play a significant role influencing higher complication rates in certain studies, and reporting on learning curve stage was inconsistent and not standardized across studies, limiting our ability to assess its impact. Also, outcomes following complications and their subsequent management strategies were not consistently reported, limiting further analysis. In addition, most studies did not clearly differentiate between unilateral and bilateral BESS, which may introduce heterogeneity in the pooled complication rates. To validate these findings and enhance their relevance, future multicenter, appropriately designed randomized controlled trials are warranted. In addition, future research should aim to identify predictors of certain complications, comparing long-term outcomes with traditional techniques. Such studies will ultimately improve the optimization of BESS in modern minimally invasive spine surgery.

CONCLUSION

This systematic review and proportional meta-analysis provides a comprehensive assessment of complication rates in lumbar BESS, with an overall complication rate of 7.75%. Dural tears and nerve palsies were the most frequently reported complications, though outcomes may be influenced by patient selection and surgical experience. Significant heterogeneity across studies highlights the need for further research. Future multicenter studies and randomized controlled trials are essential to better characterize risk factors, refine surgical techniques, and compare long-term outcomes with other MISS approaches.

➢ Key Points

- ❑ BESS Has Low Overall Complication Rates: Lumbar biportal endoscopic spine surgery demonstrated a pooled complication rate of 7.75%, with dural tears (2.64%) and nerve palsies (1.33%) being the most frequent.
- ❑ Findings Support BESS as a Safe MISS Approach: Rates were comparable or favorable to other minimally invasive techniques, particularly uniportal endoscopic approaches.
- ❑ Complication Risk Influenced by Technique and Experience: Variation in complication rates likely reflects differences in surgeon familiarity, visualization techniques, and irrigation control.
- ❑ Need for Future Comparative and Risk-Stratified Studies: Prospective, multicenter studies are needed to identify predictors of complications and clarify the advantages of BESS over other MISS techniques.

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