



Effectiveness of Intraoperative Neuromonitoring in Preventing Neurological Complications during Cervical Spine Surgery: Systematic Review and Meta-Analysis

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Article info

Received: 23.10.2025

Accepted: 06.12.2025

Available Online: 11.12.2025

Checked for Plagiarism: Yes

Keywords:

Intraoperative Neuromonitoring,
Neurological Complications,
Cervical Spine Surgery

ABSTRACT

Background and aim: Cervical spine surgeries are associated with a risk of neurological complications. Intraoperative neurological monitoring (IONM) is used as a tool to prevent these complications, but the results of previous studies are conflicting, the present study aimed to investigate the effectiveness of IONM in preventing neurological complications during cervical spine surgery.

Method: present systematic review and meta-analysis included 12 cohort studies from international databases, PubMed, Scopus, Web of Science, and Embase, from January 1, 2015 to May 10, 2025, using keywords aligned with the study objective. The statistical analysis was performed with Stata/MP. v17 as fixed effect models.

Result: The sensitivity of IONM was 0.916 (95% CI:0.872-0.960) and specificity was 0.851 (95% CI:0.827-0.876). The positive predictive value (PPV) was estimated to be 0.926 (95% CI:0.902-0.951) and the negative predictive value (NPV) was estimated to be 0.833 (95% CI:0.751-0.916).

Conclusion: IONM is a highly sensitive and specific tool for preventing neurological complications during cervical spine surgeries. Despite the positive effect, heterogeneity between studies and differences in protocols indicate the need for further studies and standardization of monitoring protocols.

Introduction

Over the past few decades, cervical spine surgeries have received much attention for the treatment of osteochondrosis, cervical myelopathy, spinal stenosis, and cervical fractures(1); studies have reported the risk of neurological complications resulting from manipulation of the spinal cord or nerve roots for cervical spine surgeries, which can lead to motor weakness, sensory impairment, or paralysis in patients(2-4). Therefore, research suggests that Intraoperative Neurophysiological Monitoring (IONM) techniques can detect changes in neural function in real time and allow for interventions before permanent damage occurs; IONM can monitor the function of neural pathways, including sensory evoked potentials (SSEPs), motor evoked potentials (MEPs), and electromyography (EMG)(5-7). Studies have shown that the diagnostic accuracy of IONM in spinal surgery is considered acceptable.

In one study, the sensitivity for SSEP was 71.4% (95% CI 54.8-83.7), for MEP was 90.2% (95% CI 86.2-93.1), and for multimodality was 83.5% (95% CI 81-85.7), while the specificity for SSEP was 97.1% (95% CI 95.3-98.3) and for MEP was 96.0% (95% CI 94.3-97.2)(8). These findings indicate that IONM has the potential to detect early intraoperative neurological risks, but there is still insufficient strong evidence regarding its direct effect on reducing postoperative neurological complications. Evidence for the effectiveness of IONM in reducing neurological complications in neck surgery is limited and inconsistent. One study showed that IONM in spine surgery only reduced the risk of neurological complications by about 50% (9). This means that although IONM seems technically sound, the evidence for its effectiveness in neck surgery is still controversial. The need for a meta-analysis and systematic review in this area is of great importance for several reasons.

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Given the anatomical complexity of the neck (proximity to the spinal cord, nerve roots, major vessels) and potential risks, it is important to determine to what extent IONM can reduce neurological complications at this level of surgery; Although several studies have examined IONM in spinal surgery, it is important to specifically examine the risk of neurological complications due to the higher structural delicacy; ultimately, more precise determination of multilevel fusions, patients with advanced myelopathy, and reconstructive cases could pave the way for the development of better practice guidelines. Given the need for research, the present study aimed to investigate the effectiveness of IONM in preventing neurological complications during cervical spine surgery.

Method

Search strategy and Selection criteria

The design of the present study followed the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines proposed in 2020(10). For the initial search of relevant keywords in each international database PubMed/Scopus, MEDLINE(Ovid), Cochrane Library was performed between 2015 and 2025 (Table 1), the reason for choosing a ten-year time period was to review new results and compare them. The selection criterion for studies was the PICO strategy (Table 1); a control group was not required in the present study. Any type of Reviews studies, in vivo studies, case reports, and references that were unavailable or incomplete, studies that did not include human subjects, and studies without quantitative data were excluded from the research.

Table 1. Search Strategy and PIO strategy

PIO Component	Description	Keywords / Search Terms	Databases
Population (P)	Patients undergoing cervical spine surgery	"Cervical spine surgery" OR "Cervical discectomy" OR "ACDF" OR "Cervical fusion" OR "Laminoplasty" OR "Posterior cervical surgery"	PubMed, Scopus, Embase, Cochrane Library, Web of Science
Intervention (I)	Intraoperative neuromonitoring (IONM)	"Intraoperative neuromonitoring" OR "IONM" OR "Somatosensory evoked potentials" OR "SSEP" OR "Motor evoked potentials" OR "MEP" OR "Electromyography" OR "EMG" OR "Multimodal monitoring"	PubMed, Scopus, Embase, Cochrane Library, Web of Science
Outcomes (O)	Sensitivity, specificity, positive predictive value, and negative predictive value	"Sensitivity" OR "specificity" OR "positive predictive value" OR "negative predictive value"	PubMed, Scopus, Embase, Cochrane Library, Web of Science

Data Extraction and bias assessment

In the present study, the process of data extraction and risk of bias assessment was carefully conducted according to the standards of systematic review and meta-analysis by two blinded and independent authors. In the first stage, data were collected from the selected studies using a predefined researcher-made form. The extracted information included the names of the authors, year of publication, type of study, characteristics of the study population (mean age, gender, and sample size), and Type of cervical spine surgery. Using the Newcastle Ottawa scale (NOS)(11), quality evaluation was carried out in three areas: outcome, comparability, and selection. "High quality" was defined as scores greater than 7 according to the NOS tool. Two researchers independently and blindly conducted the quality assessment and data extraction process. A third researcher provided final confirmation, and any disagreements were resolved

through re-examination and consultation. Also, to ensure the accuracy of the data, a re-examination of key sources and results was conducted. This approach ensured the accuracy and validity of the analyses in the systematic review and meta-analysis.

Statistical analysis

Meta-analysis was performed using STATA 17 software. Effect sizes for sensitivity, specificity, and predictive value of IONM were extracted from the articles, and considering the heterogeneity between studies, which was assessed by the I² index (No heterogeneity: 0.0% < I² < 24.9%; low heterogeneity: 25.0% < I² < 49.9%; Moderate heterogeneity: 50.0% < I² < 74.9%; High heterogeneity: 75.0% < I² < 100%), the Random Effects model with DerSimonian-Laird method was selected. Egger's regression test and Begg's rank correlation test were used to examine publication bias. A funnel plot was also drawn to visually examine the symmetry of the data. The statistical

significance level was considered to be $p < 0.05$. Subgroup analyses were performed based on the type of IONM modality (SSEP, MEP, combined), type of surgery (anterior vs posterior), and number of surgical levels (single-level vs multi-level).

Result

Literature Search

849 articles were found by systematic literature review that matched the search strategy. 146 duplicates, 3 case reports, and 538 studies with other type of study (exclusion criteria) and based on titles relevant to the exclusion criteria. A total of 162 articles were screened and articles that did not meet the inclusion criteria were excluded ($n=114$). The full texts of 48 articles were reviewed by two independent, blinded authors and subjected to

screening for inclusion and exclusion criteria; only twelve articles met the inclusion criteria, which were selected for review in the present study (Figure 1).

Characteristics of included studies

A total of 3754 patients underwent various cervical spine surgeries. Nine studies were retrospective cohort studies and three were prospective cohort studies. Sample sizes ranged from 46 to 1,622 patients, and the mean age of participants ranged from 49.6 to 66.2 years. This dataset provides broad coverage of patient populations and types of surgeries, allowing for a comprehensive assessment of the effectiveness of intraoperative neurological monitoring in preventing neurological complications in various settings of cervical spine surgery. Table 3 shows the quality of the studies.

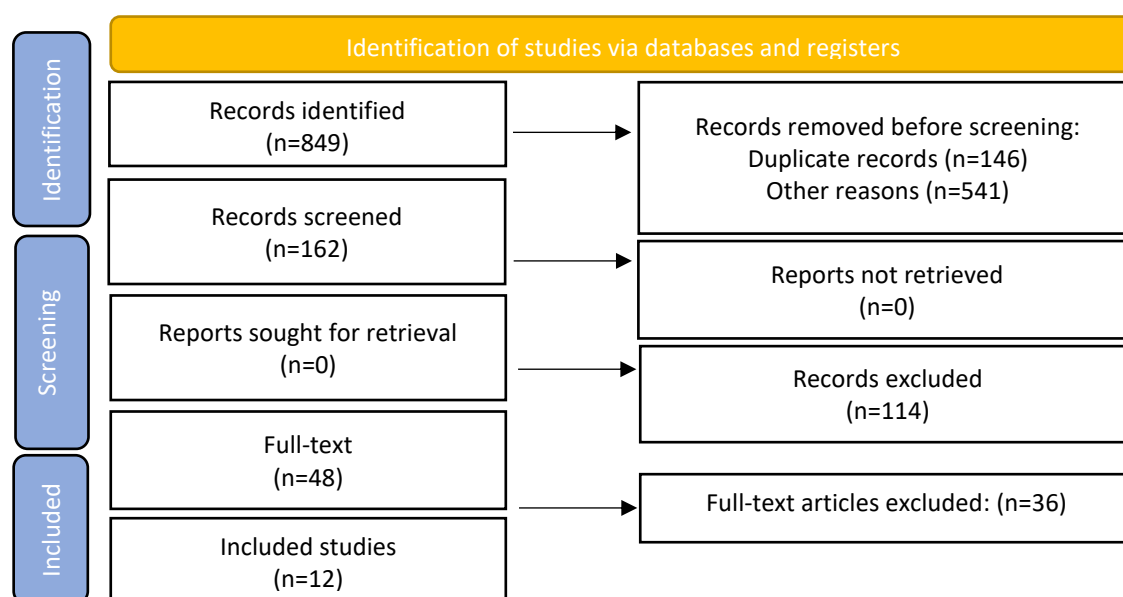


Figure 1. PRISMA 2020 Flow Diagram

Table 2. Summary of characteristics of studies selected for meta-analysis

No.	Study. Year	Design	Sample Size (N)	Mean Age (years)	Sex (female %)	Intervention Type
1	Cannizzaro et al., 2025 (12)	RCs	100	60.72	36	cervical spine surgery
2	Rucker et al., 2025 (13)	RCs	191	NR	NR	anterior cervical spine procedures
3	Corazzelli et al., 2025 (14)	RCs	442	NR	NR	ACDF
4	Burkhard et al., 2025 (15)	RCs	401	61	48.9	PLIF
5	Zhang et al., 2025 (16)	RCs	1622	66.2	45.49	Cervical spinal canal decompression surgery
6	Bai et al., 2025 (17)	RCs	127	62.0	55.90	UBE
7	Yu et al., 2024 (18)	PCs	46	NR	NR	ACSS

8	Ilhan et al., 2024 (19)	PCs	67	50	36	Surgical resection of intradural spinal cord tumors
9	Cabañes-Martínez et al., 2024 (20)	RCs	91	50.66	NR	Surgical resection of intradural spinal tumors
10	Ushirozako et al., 2023 (21)	PCs	350	NR	NR	Traumatic spinal injury surgery
11	Kim et al., 2021 (22)	RCs	196	56.6	32.65	ACDF
12	Ibrahim et al., 2017 (23)	RCs	121	49.58	41.4	Various spinal procedures

- ✓ RCs: Retrospective Cohort study.
- ✓ PPV: positive predictive value.
- ✓ NPV: negative predictive value.
- ✓ PCs: Prospective Cohort study.
- ✓ EELF: Extended endoscopic lumbar foraminotomy.
- ✓ TLIF: transformational lumbar interbody fusion.
- ✓ UBE: Unilateral portal endoscopic.
- ✓ RCT: randomized controlled study.
- ✓ ACSS: Anterior cervical spine surgery.
- ✓ ACDF: Anterior cervical spine discectomy with fusion.
- ✓ PLIF: Primary posterior lumbar interbody fusion.

Table 3. Newcastle-Ottawa Scale assessment of cohort included studies.

Study	Selection (max 4)	Comparability (max 2)	Outcome/Exposure (max 3)	Total NOS Score	Quality Category
Cannizzaro et al.	4	2	3	9	High
Rucker et al.	3	1	2	6	Moderate
Corazzelli et al.	3	1	2	6	Moderate
Burkhard et al.	4	2	3	9	High
Zhang et al.	4	2	3	9	High
Bai et al.	3	1	2	6	Moderate
Yu et al.	3	1	2	6	Moderate
Ilhan et al.	3	1	2	6	Moderate
Cabañes-Martínez et al.	3	1	2	6	Moderate
Ushirozako et al.	3	1	2	6	Moderate
Kim et al.	4	2	3	9	High
Ibrahim et al.	4	2	3	9	High

Sensitivity

Using the fixed-effects model and the inverse-variance method, the overall sensitivity of IONM in identifying neurological complications was calculated to be 0.912 (95% CI: 0.888-0.936) (Figure 2), indicating the high accuracy of IONM in detecting intraoperative neurological problems.

$I^2=61.1\%$ indicates moderate heterogeneity between studies. $H^2=2.57$ and Q test with $\chi^2(11) = 28.28$, $p=$

0.0029 also confirmed the existence of a significant difference between the results of the studies.

A random-effects model with the REML method was used to better account for differences between studies and heterogeneity observed in fixed-effect analysis. The pooled sensitivity was estimated to be 0.916 (95% CI: 0.872-0.960) (Figure 3).

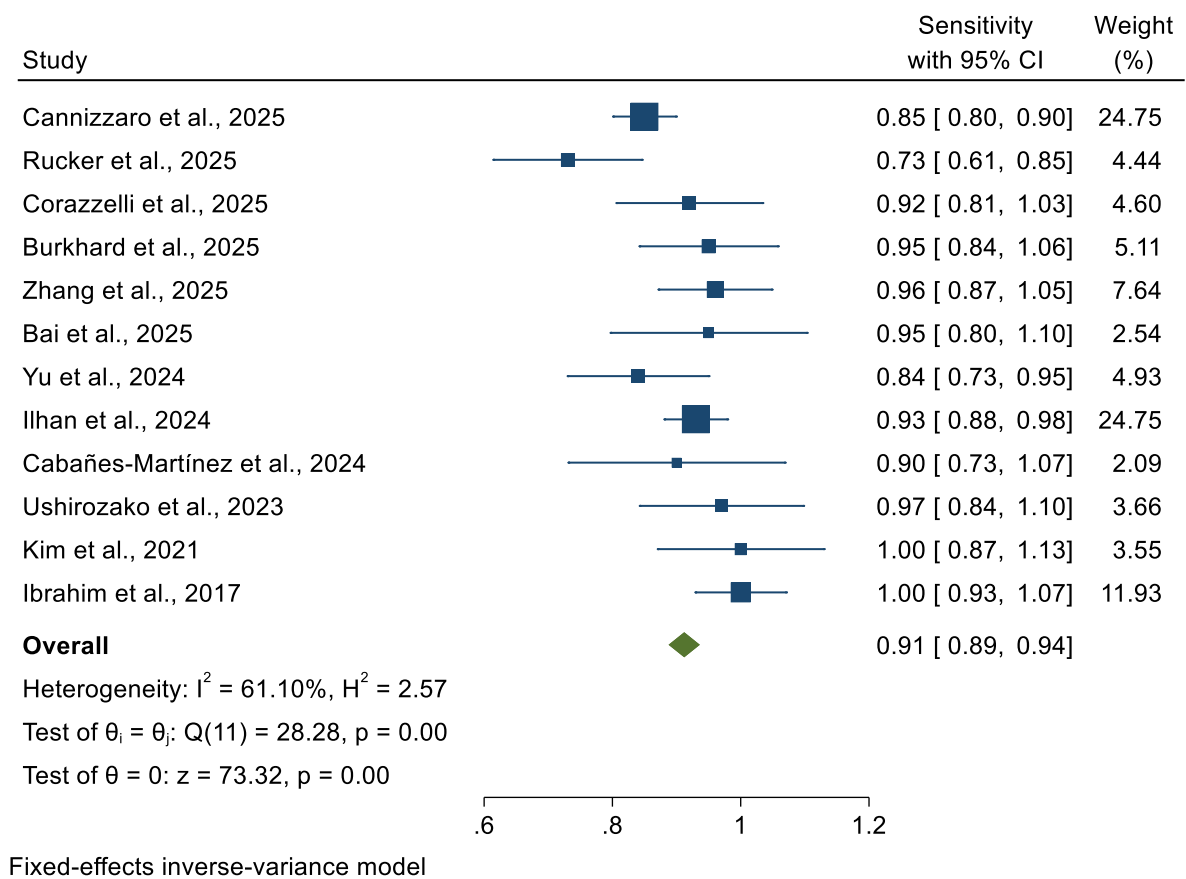


Figure 2. Forest plot showed sensitivity for IONM in predicting neurological deficits.

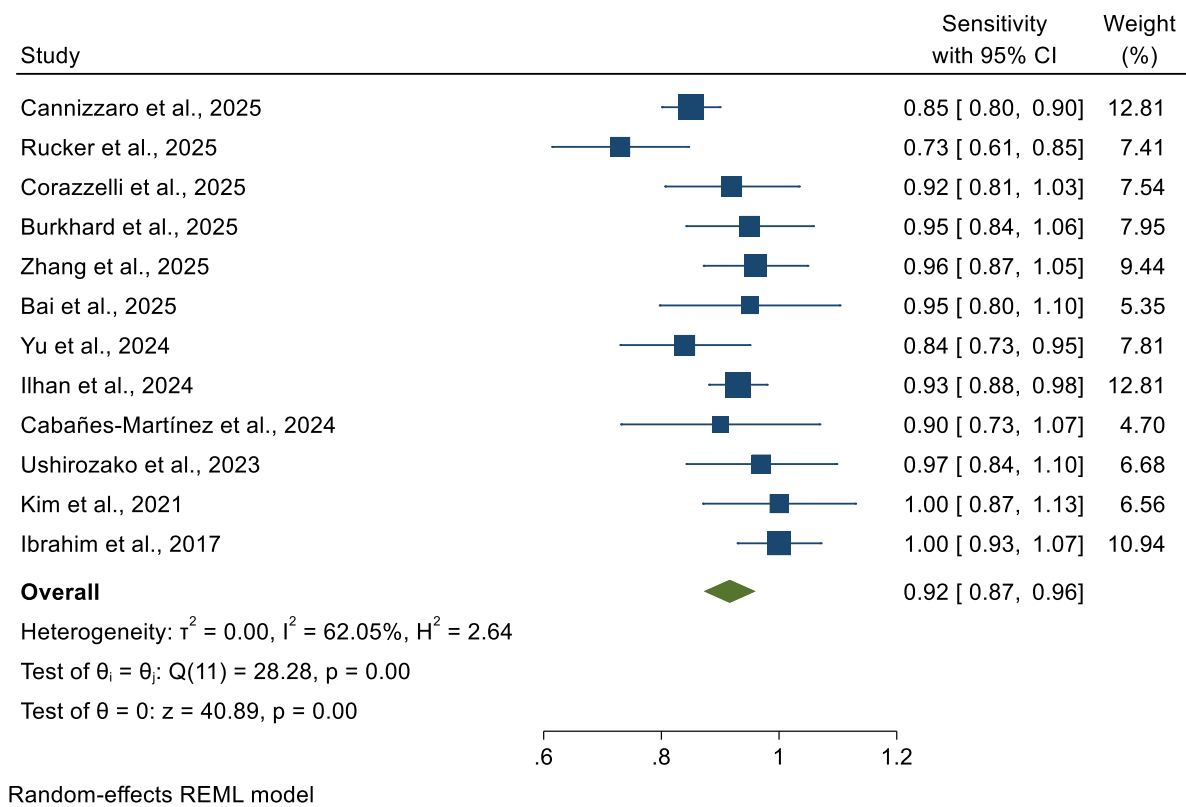


Figure 3. forest plot showed sensitivity for IONM in predicting neurological deficits.

Specificity

Using the fixed-effects model and the inverse-variance method, the overall specificity of IONM was calculated to be 0.851 (95% CI: 0.827–0.876)) (Figure 4), indicating the high ability of IONM to correctly detect the absence of neurological

complications during surgery. $I^2 = 36.6\%$ indicated low heterogeneity between studies. IONM is a reliable tool for identifying patients without neurological complications during surgery.

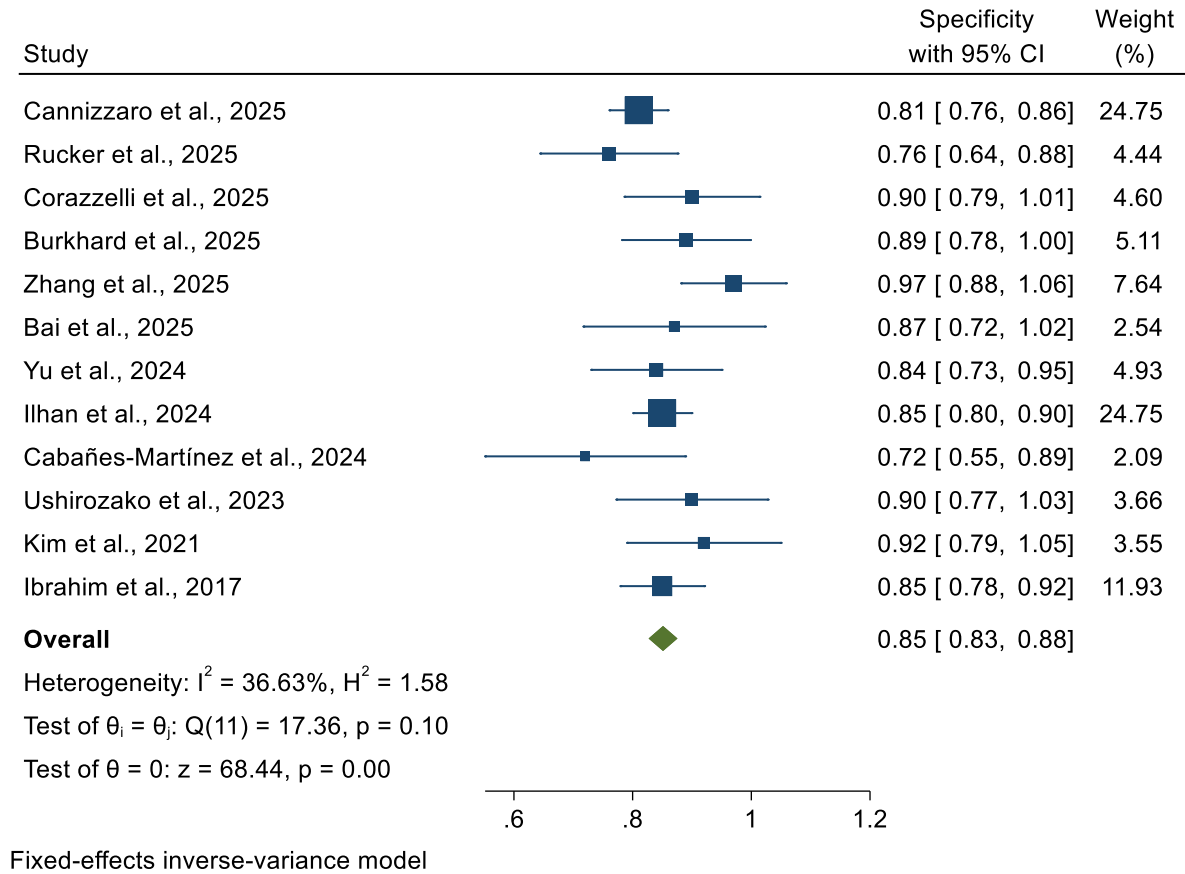


Figure 4. Forest plot showed specificity for IONM in predicting neurological deficits.

Positive predictive value (PPV)

Using the fixed-effects model and the inverse-variance method, the overall PPV of IONM was calculated to be 0.926 (95% CI: 0.902-0.951) (Figure 5). These results indicate the very high ability of IONM to correctly predict patients with neurological complications. $I^2=45.6\%$ indicates moderate heterogeneity between studies.

Negative predictive value (NPV)

Using the fixed-effects model and the inverse-variance method, the overall NPV of IONM was calculated to be 0.874 (95% CI: 0.850-0.898) (Figure 6). These results indicate that IONM negative alarms correctly identify patients without true neurological complications in most cases. $I^2= 87.3\%$ indicates very high heterogeneity between studies. Hence, using the random effects model and the REML method, the overall NPV was calculated to be 0.833 (95% CI: 0.751-0.916) (Figure 7).

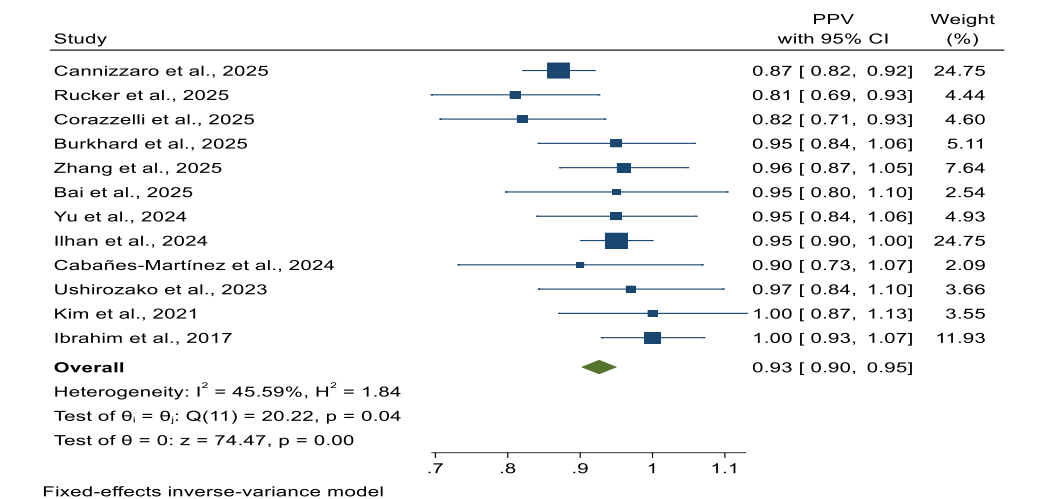


Figure 5. Forest plot showed PPV for IONM in predicting neurological deficits.

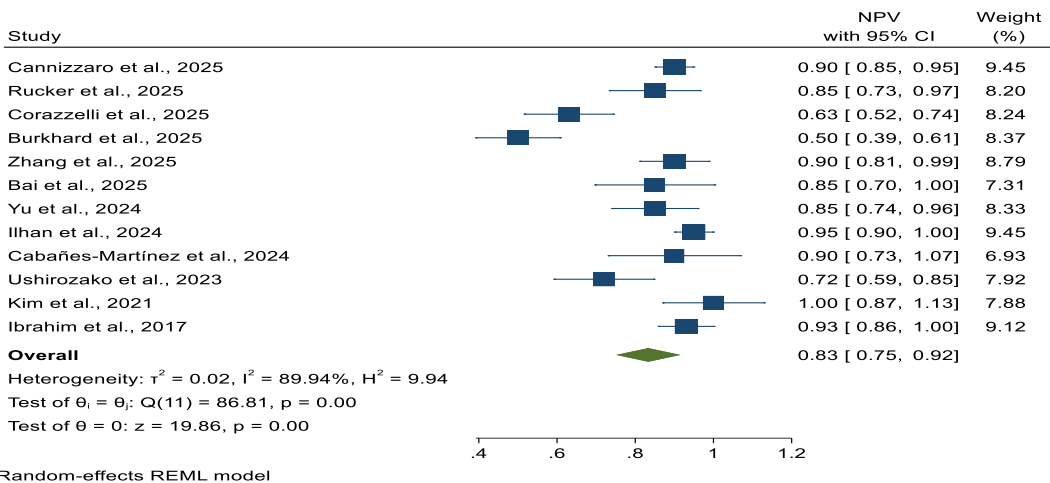


Figure 6. Forest plot showed NPV for IONM in predicting neurological deficits.

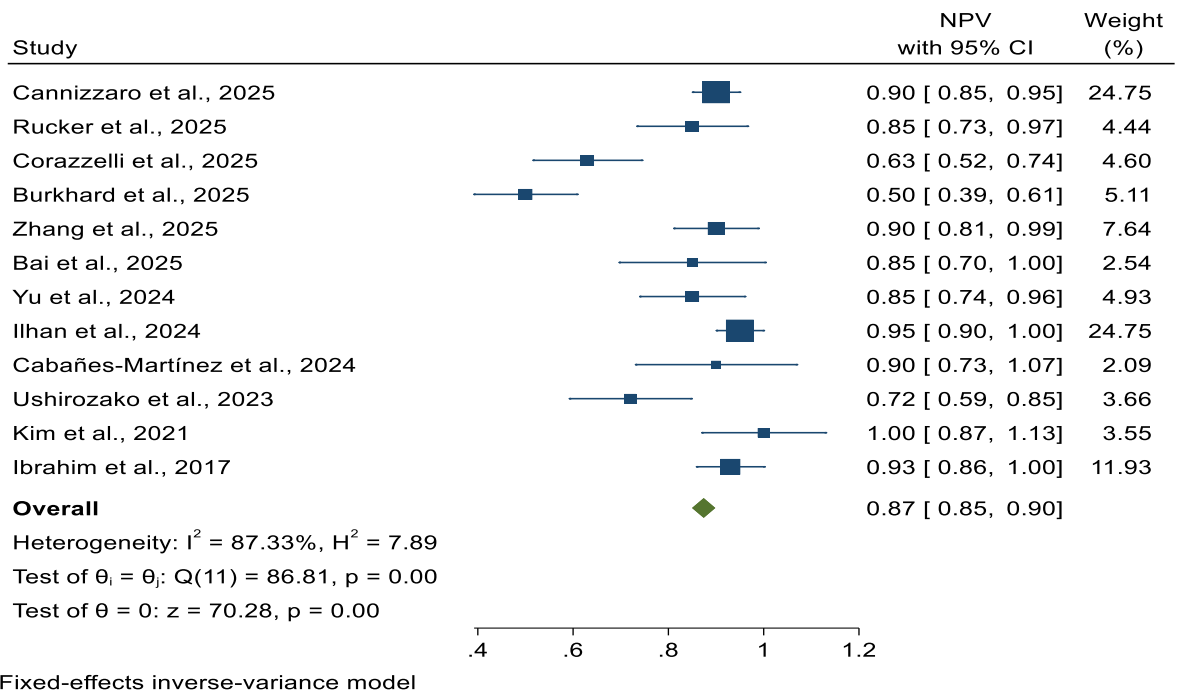


Figure 7. Forest plot showed NPV for IONM in predicting neurological deficits.

Discussion

In the present study, the diagnostic accuracy of IONM in predicting intraoperative neurological complications in cervical spine surgeries was estimated. In the present study, the diagnostic accuracy of IONM in predicting neurological complications during cervical spine surgeries was evaluated. Based on the present meta-analysis, it had high sensitivity (≈ 0.92), adequate specificity (≈ 0.85), very high positive predictive value (≈ 0.93), and fairly good negative predictive value (≈ 0.83). These percentages indicate the significant performance of IONM in detecting the occurrence or non-occurrence of neurological complications during surgery. The random effects model (REML) also confirmed that the sensitivity result is stable. Choueiri et al., 2025 showed that although IONM is widely used, it did not show a significant protective effect in reducing neurological complications in degenerative cervical surgeries(24). This finding is somewhat different from our results, as we achieved high sensitivity and specificity. This difference may be due to differences in population, type of surgery, or definition of neurological complications. Zanin et al., 2025 showed that IONM significantly improves neurological outcomes in spinal surgery (sensitivity (90.2), adequate specificity 97.1)(25). This finding is consistent with our results and emphasizes that IONM can play an important protective role in many spinal surgeries, especially complex or multilevel surgeries. The efficacy of IONM may strongly depend on the clinical characteristics of the patients, the type and complexity of the surgery, and how neurological complications are defined and recorded. This highlights the importance of designing standardized protocols and using combined modalities (SSEP+MEP) to increase diagnostic accuracy and prevent neurological damage.

The high heterogeneity could be related to the type of IONM modality (SSEP, MEP, EMG, or combined), type of surgery (anterior vs. posterior), number of surgical levels (single-level vs. multi-level), patient risk level, and center protocol. One of the limitations of the present study was that many of the studies were retrospective and single-center, which could lead to selection bias and limit the generalizability of the results; failure to fully report patient characteristics, such as the severity of preoperative myelopathy, history of underlying diseases, and differences in surgical protocols, could affect the results. Lack of a single standard for defining and recording neurological complications between different centers, which may reduce the accuracy of comparisons between studies.

Conclusion

According to the present meta-analysis, IONM has high sensitivity and specificity in cervical spine surgeries and can be used as an effective tool to predict and reduce intraoperative neurological complications. However, high heterogeneity between studies in some variables suggests that the findings should be interpreted with caution and the use of combined modalities (SSEP + MEP) is recommended.

Disclosure Statement

No potential conflict of interest reported by the authors.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Authors' Contributions

All authors contributed to data analysis, drafting, and revising of the paper and agreed to be responsible for all the aspects of this work.

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