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Intraoperative Neurophysiological Monitoring in Spine Surgery: An Evidence Map of 66 Systematic Reviews With Evidence-Graded Recommendations

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Title Page

Intraoperative Neurophysiological Monitoring in Spine Surgery: An Evidence Map of 66 Systematic Reviews With Evidence-Graded Recommendations

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Author Contributions

Sathish Muthu: conceptualization, methodology, software, formal analysis, investigation, data curation, visualization, project administration, writing – original draft, writing – review and editing. Dhibin Vikash Kolarpatti Ponnusamy: data curation (data extraction), validation, writing – review and editing. Surabhi Subramanian: data curation (data extraction), validation, writing – review and editing. Ron El-Hawary: data curation (data extraction), validation, writing – review and editing. Vibhu Krishnan Viswanathan: data curation (data extraction), validation, writing – review and editing. All authors read and approved the final version of the manuscript.

Statements and Declarations

Ethical considerations

Not applicable. This study analysed data from published systematic reviews and their supplementary material; no human participants were involved and ethics approval was not required.

Consent to participate

Not applicable.

Consent for publication

Not applicable.

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Data availability

The extracted review data and the evidence-map table are provided in the Supplementary Material.

Use of artificial intelligence. A large language model was used to validate the human reviewers and support record deduplication, screening, eligibility assessment and data extraction within a published framework for auditable AI-assisted evidence synthesis. All automated determinations were logged and independently adjudicated by the authors, who accept full responsibility for the accuracy and integrity of the work.

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Intraoperative Neurophysiological Monitoring in Spine Surgery: An Evidence Map of 66 Systematic Reviews With Evidence-Graded Recommendations

Abstract

Study Design: Evidence map of systematic reviews with evidence-graded recommendations.

Objectives: Guidance on intraoperative neurophysiological monitoring (IONM) in spine surgery rarely links each recommendation to procedure-specific evidence on accuracy, patient outcomes and alert interpretation. We mapped that evidence and derived recommendations whose strength follows its certainty.

Methods: PubMed, Scopus and Web of Science were searched to 12 October 2026 for systematic reviews of IONM in spine surgery. Reviews were mapped by procedure and question, with AMSTAR 2 confidence and the GRADE certainty from three companion umbrella reviews that re-analysed deduplicated study-level data. Recommendations were formulated only where review-level evidence existed, and their strength was set with the GRADE evidence-to-decision approach.

Results: Sixty-six reviews were mapped; 56 (85%) were of critically low confidence. Evidence was concentrated on diagnostic accuracy in tumour, cervical and deformity surgery, and moderate certainty was limited to evoked potential accuracy in intradural tumour surgery. Fifteen recommendations were made, all conditional: 10 in favour (including multimodal monitoring with motor evoked potentials in intradural tumour and deformity surgery, and an early neurological examination whatever the monitoring findings) 4 against (including routine monitoring in short-segment anterior cervical surgery for radiculopathy) and 1 favouring a risk-based decision in cervical myelopathy. Eight questions, including the effect of alert checklists and blood pressure targets, had no review-level evidence.

Conclusions: Most IONM decisions in spine surgery rest on low or very low certainty evidence, so all recommendations are conditional. Prospective comparative studies with standard alert reporting are needed.

Keywords: intraoperative neurophysiological monitoring; spine surgery; evidence map; recommendations; motor evoked potentials; GRADE; umbrella review

Introduction

Intraoperative neurophysiological monitoring (IONM) is used widely in spine surgery to detect evolving injury to the spinal cord and nerve roots.[1,2] Its use, the choice of modalities and the response to an alert are decided team by team, and practice varies.[3,4] Society statements and a recent clinical practice guideline support monitoring when the cord is at risk,[1,5] and checklists and best-practice guidance exist for responding to alerts in deformity surgery.[6-8] However, these documents address selected procedures, and none links each recommendation to procedure-specific evidence on diagnostic accuracy, patient outcomes and the meaning of alerts.

That evidence is now spread across more than 60 systematic reviews, many of low methodological quality, overlapping in their primary studies and reaching different conclusions.[9,10] A clinician deciding whether to monitor a two-level anterior cervical discectomy, which modalities to use for an intramedullary tumour, or what to do when motor evoked potentials fall during deformity correction cannot easily tell which questions are answered and how certain the answers are. Evidence maps are designed to make such gaps visible,[11] and the GRADE approach provides an explicit way to move from evidence of known certainty to recommendations of matching strength.[12,13]

This study is the fourth of a programme of overviews built on one search. Three companion umbrella reviews re-analysed study-level data on the diagnostic accuracy of IONM modalities, the effect of IONM on new neurological deficits, and the meaning of alerts and the response to them. Here we aimed (1) to map all systematic reviews of IONM in spine surgery by procedure and clinical question, with their methodological quality and the certainty of their findings, and (2) to derive recommendations only where review-level evidence exists, with a strength that reflects its certainty, and to identify the questions for which no recommendation can yet be made.

Methods

Design and reporting

The evidence map follows the PRIOR statement for overviews of reviews[14] and PRISMA 2020,[15] with the JBI umbrella-review approach,[16] with the protocol registered retrospectively on OSF Registries on 27 October 2026 (https://doi.org/10.17605/OSF.IO/JNQEP). This study used published data only and did not involve human participants.

Search, eligibility and data extraction

PubMed, Scopus and Web of Science Core Collection were searched from inception to 12 October 2026 with terms for IONM, spine surgery and systematic review or meta-analysis, without language or date limits (Supplementary Table S1). We included systematic reviews, with or without meta-analysis, that reported on any IONM modality in spine surgery and on at least one of the following: diagnostic accuracy, patient outcomes with versus without monitoring, alerts (their frequency, causes, confounders, reversibility or response), or recommendations. Narrative reviews, conference abstracts and reviews outside spine surgery were excluded.

Screening and data extraction were supported by a large language model operating within a previously described framework for the transparent and auditable application of artificial intelligence to evidence synthesis, in which every automated decision is logged with its supporting rationale and independently verified by human reviewers.[17] All automated determinations in the present review were adjudicated by the reviewers before being accepted. The efficiency and reliability of machine-learning-assisted screening in orthopaedic evidence synthesis has been characterized previously.[18] From each review we extracted the procedure, population, modalities, questions addressed, number of primary studies, registration, certainty framework and conclusions. Methodological quality was rated with AMSTAR 2, with items 2, 4, 7, 9, 11, 13 and 15 treated as critical.[19]

Evidence map

Reviews were mapped on a grid of eight procedure groups (cervical, thoracic, lumbar, deformity, intramedullary tumour, extramedullary tumour, pedicle screw placement and mixed spine surgery) against

seven questions: the accuracy of somatosensory evoked potentials (SSEP), motor evoked potentials (MEP), multimodal monitoring, D-wave and electromyography (EMG); patient outcomes with versus without IONM; and the meaning of alerts. For accuracy and outcomes, each cell shows the number of reviews; for alerts, it shows the number of primary cohorts with alert data after deduplication. Each cell was coloured by the highest GRADE certainty assigned to an estimate in that cell in the companion umbrella reviews, which applied GRADE to deduplicated, re-pooled study-level data.[12] Cells with reviews but no graded estimate were labelled not graded.

From evidence to recommendations

Candidate questions were taken from the findings of the three companion reviews and from the recommendations in the included guideline reviews.[4,20-22] A recommendation was formulated only when at least one companion review provided a graded estimate relevant to the question; questions without such evidence were recorded as evidence gaps and received no recommendation. For each recommendation, the authors considered the certainty of the evidence, the balance between the benefit of detecting injury and the burden of false alerts (interrupted surgery, unnecessary interventions and resource use), and the consistency of the evidence across procedures, following the GRADE evidence-to-decision approach.[13] Recommendations were classed as for or against an intervention and as strong or conditional. In keeping with GRADE, recommendations supported by low or very low certainty evidence were made conditional and worded as "we suggest". Recommendations were drafted by one author and reviewed by all authors; disagreements were resolved by discussion. Each recommendation is reported with the evidence summary on which it rests (Supplementary Table S3).

Results

Included reviews

The search identified 1,680 records, of which 600 were duplicates. After screening 1,080 records and assessing 79 full texts, 66 systematic reviews were included (Figure 1; Supplementary Table S2).[3,4,20-

[83] They were published between 2009 and 2026, and 32 (48%) appeared from 2024 onward. Twenty-three (35%) were registered prospectively (Table 1). AMSTAR 2 confidence was critically low for 56 reviews (85%), low for 9 and high for 1;[4] the most frequent critical weaknesses were no list of excluded studies (63 reviews), no protocol established before the review (46) and no account of risk of bias when interpreting the results (38). Thirty-seven reviews reported diagnostic accuracy, 17 reported patient outcomes, 46 provided evidence on alerts, and 10 made recommendations; many addressed more than one question.

Evidence map

The evidence map is shown in Figure 2. Evidence was concentrated on diagnostic accuracy in intradural tumour, cervical and deformity surgery. Moderate certainty was found only for the accuracy of MEP in intramedullary tumour surgery and of SSEP in intradural tumour surgery. All other accuracy estimates were of low or very low certainty, mainly because the primary studies were retrospective and the postoperative examination was not blinded to monitoring results. Accuracy data for thoracic and lumbar surgery came from one or two reviews per modality, and D-wave data were limited to tumour surgery.

Evidence on patient outcomes was thinner. Comparative data showed fewer new deficits with IONM in intradural tumour surgery (low certainty) but no clear difference in cervical degenerative surgery or across all spine procedures (very low certainty), where database studies of low-risk procedures dominated. Outcome evidence for lumbar, lateral and deformity surgery was narrative and was not graded, and no review reported outcomes for thoracic surgery. Alert data were the most abundant in volume (more than 300 deduplicated primary cohorts) but came from single-arm cohorts; the proportion of alerts not followed by a new deficit varied mainly with the baseline risk of the procedure.

Recommendations

Fifteen recommendations were made (Table 2). All were conditional because the supporting evidence was of low or very low certainty; the only moderate-certainty evidence, for MEP accuracy in intramedullary tumour surgery, was paired with very low certainty evidence on outcomes. Six recommendations concern when to monitor. We suggest multimodal monitoring in intradural extramedullary and intramedullary tumour surgery and in deformity correction; in degenerative cervical myelopathy, a decision based on the risk of cord injury; and against routine monitoring to prevent deficits in short-segment anterior cervical surgery for radiculopathy and in lumbar surgery below the conus. Three concern modality choice: including MEP rather than relying on SSEP alone when the cord is at risk, and not relying on triggered or free-run EMG alone. Four concern interpretation: an early neurological examination whatever the monitoring findings, judging alerts against the baseline risk of the procedure, treating persistent changes as more predictive than recovered ones, and examining patients carefully even after signals recover. Two concern the response to an alert: considering reversal of the latest surgical manoeuvre first while other causes are checked in parallel, and anaesthetic management when MEP is monitored.

Eight questions had no review-level evidence and received no recommendation (Table 3). They include the effect of alert-response checklists, blood pressure targets during cord-at-risk steps, the timing of a wake-up test, alarm criteria for each modality and procedure, staffing models, outcomes in thoracic surgery, nerve monitoring in lateral lumbar interbody fusion and head-to-head comparisons of modalities.

Discussion

This evidence map brings together 66 systematic reviews of IONM in spine surgery and shows that, despite their number, most questions that matter for practice rest on low or very low certainty evidence. The literature is dense where it is easiest to produce, in diagnostic accuracy in procedures with a high baseline risk, and sparse where decisions are hardest: whether monitoring changes outcomes in

lower-risk procedures, and what to do after an alert. Accordingly, every recommendation we could make is conditional, and several common decisions have no evidence on which to base a recommendation.

The recommendations agree in direction with existing society statements and the AO Spine guideline, which support multimodal monitoring including MEP when the cord is at risk.[1,5,21] They differ in two respects. First, each recommendation is tied to a procedure-specific estimate of accuracy, outcome or alert behaviour, so that users can see the evidence and its certainty. Second, they distinguish procedures by risk. Comparative data favoured IONM in intradural tumour surgery but not in cervical degenerative surgery, where most data came from administrative databases with low event rates and limited clinical detail, and alerts in low-risk procedures were usually not followed by a deficit. The recommendations against routine monitoring in short-segment anterior cervical surgery for radiculopathy and in lumbar surgery below the conus are conditional and concern the prevention of new deficits; they do not address monitoring for other purposes, such as positioning in patients with severe stenosis, and teams may reasonably monitor selected patients.

The response to an alert is where evidence is most needed and least available. Checklists for deformity surgery were developed by expert consensus,[6,7] and a recent guideline formalised best practice,[8] but no review compared response strategies or tested whether checklists improve outcomes. Alerts that reverse with intervention cannot be classed as true or false, the so-called treatment paradox,[84] which limits what observational data can show. Our two recommendations in this domain rest on observational data on the causes of alerts and on anaesthetic confounders, and the questions without evidence (Table 3) are where expert consensus or, better, comparative studies are needed.

These findings point to specific research priorities: prospective multicentre registries with blinded neurological examination and standard alert reporting, head-to-head comparisons of modalities in the same patients, and comparative studies of alert-response strategies. Standard reporting of each alert, its

suspected cause, the response and the outcome would allow future reviews to separate true alerts from false ones and to estimate the effect of a response, which is not possible with the current literature.

Strengths and limitations

The map is based on a single comprehensive search, includes every eligible review regardless of quality, and draws its certainty ratings from re-analyses of deduplicated study-level data rather than from the conclusions of individual reviews. Recommendations were made only where graded evidence existed, and their strength follows its certainty. There are limitations. Certainty ratings come from our companion reviews and share their assumptions, including the choice of index reviews. The map counts reviews rather than primary studies for accuracy and outcomes, and many reviews overlap; a cell with several reviews may rest on few primary studies. The recommendations were formulated by the author group without an external panel, patient representatives or formal assessment of costs and acceptability, which the GRADE evidence-to-decision framework would ordinarily include. They should therefore be read as evidence-based suggestions that can inform, rather than replace, guidelines developed by multidisciplinary panels.

Conclusions

Most decisions about IONM in spine surgery rest on low or very low certainty evidence, and some common decisions, particularly the response to an alert, have no review-level evidence. The evidence supports conditional recommendations for multimodal monitoring including MEP in intradural tumour and deformity surgery, against relying on SSEP or EMG alone, and against routine monitoring in short-segment anterior cervical surgery for radiculopathy. Each recommendation should be read together with the certainty of its evidence. Prospective comparative studies with standard alert reporting are needed to strengthen them.

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Table 1. Characteristics of the 66 Systematic Reviews of IONM in Spine Surgery, by Procedure Group.

ure group	**Reviews, n**	**Published**	**From 2024, n**	**Accuracy, n**	**Patient outcomes, n**	**Alerts, n**	**Recommendations, n**	**AMSTAR 2: critically low / low / moderate–high**	**Re d,**
ty	22	2015–2026	14	6	2	18	3	19 / 2 / 1	9
/thoracic	14	2009–2026	6	9	6	4	4	13 / 1 / 0	2
	12	2018–2026	8	10	2	4	1	8 / 4 / 0	9
screw	9	2012–2026	2	8	2	2	1	8 / 1 / 0	2
	4	2015–2023	0	2	2	0	0	4 / 0 / 0	0
ther	5	2017–2026	2	2	3	2	1	4 / 1 / 0	1
ews	66	2009–2026	32	37	17	30	10	56 / 9 / 1	23

Reviews could address more than one question. Procedure group is the main focus of each review; reviews of several procedures are classed as mixed. The alert column counts reviews with thematic evidence on alerts; the companion review of alerts also used study-level data from 20 accuracy reviews (46 reviews in total). AMSTAR 2, A MeaSurement Tool to Assess systematic Reviews 2; IONM, intraoperative neurophysiological monitoring.

Table 2. Evidence-Based Recommendations for IONM in Spine Surgery, With the Supporting Evidence, Its Certainty and the Strength of Recommendation.

ecommendation	**Key evidence**	**Certainty (GRADE)**	**Strength**
to monitor			
/e suggest multimodal IONM during resection of tradural extramedullary tumours.	Intradural tumour surgery: new deficit OR 0.33 (95% CI 0.17–0.63; 6 studies) with versus without IONM; extramedullary subset OR 0.39. Multimodal sensitivity 63.1%, specificity 92%–97%.	Low	Condition
/e suggest multimodal IONM including MEP uring resection of intramedullary tumours, with -wave recording where feasible.	MEP sensitivity 70.9% (moderate certainty); multimodal 83.9%. Outcome data limited to two cohorts (OR 0.20, 0.04–1.04). Irreversible D-wave loss: sensitivity 64.2% and specificity 95.0% for long-term motor deficit.	Moderate (accuracy); very low (outcome)	Condition
/e suggest multimodal IONM including MEP uring corrective surgery for spinal deformity.	Multimodal sensitivity 89.1% (82.6–93.4; 36 studies), LR− 0.11. No comparative outcome data met the criteria.	Low (accuracy)	Condition
surgery for degenerative cervical myelopathy, e suggest that the decision to monitor be based the risk of cord injury (for example multilevel ompression, kyphosis or OPLL) rather than pplied routinely.	Cervical sensitivity: MEP 57.0%, multimodal 77.1%, SSEP 42.0%. New deficit OR 0.89 (0.49–1.61; 10 studies), dominated by database studies.	Low (accuracy); very low (outcome)	Condition based
/e suggest against routine IONM for the purpose preventing new deficits in one- or two-level nterior cervical discectomy and fusion for	No outcome difference in cervical surgery (OR 0.89, 0.49–1.61); baseline risk of a new deficit about 2.7 per 1,000; most alerts in cervical surgery (>70%) were not followed by a	Very low	Condition against

ecommendation	Key evidence	Certainty (GRADE)	Strength
diculopathy without myelopathy.	deficit.		
/e suggest against routine spinal cord monitoring lumbar decompression or fusion below the onus without deformity correction.	Lumbar SSEP sensitivity 31.9%; no comparative outcome benefit shown; >70% of alerts not followed by a deficit.	Very low	Condition against
ch modalities			
/hen the spinal cord is at risk, we suggest cluding MEP rather than relying on SSEP alone.	MEP sensitivity exceeded SSEP in every procedure where both were assessed (mixed spine 84.0% vs 60.7%; cervical 57.0% vs 42.0%). Comparisons are indirect.	Low	Condition
/e suggest against using triggered EMG resholds as the only check of pedicle screw osition.	Sensitivity for malposition 54.9% (lumbar) and 31.3% (thoracic); specificity 88%–96%.	Very low	Condition against
/e suggest against relying on free-run EMG alone detect nerve root injury.	Sensitivity 46.8% (32.1–62.0), specificity 91.2%.	Very low	Condition against
rpreting alerts and normal recordings			
/e suggest an early postoperative neurological xamination for every monitored patient, whatever e monitoring findings, because a stable cording does not exclude a new deficit.	New deficits not preceded by an alert: 13.7% with MEP, 41.0% with SSEP and 6.1% with multimodal monitoring.	Low	Condition
/e suggest interpreting an alert in light of the aseline risk of the procedure.	Alerts not followed by a deficit: >70% in cervical and lumbar surgery, <30% in intradural tumour surgery (Spearman ρ	Low	Condition

ecommendation	Key evidence	Certainty (GRADE)	Strength
	−0.85 across 22 strata).		
/e suggest treating a persistent signal change as ore likely to indicate a new deficit than a change at recovers.	Diagnostic odds ratio 22–168 for irreversible versus 0.7–14 for reversible changes.	Low	Condition
/e suggest a careful postoperative examination fter an alert even when signals recover.	11%–14% of recovered MEP or SSEP alerts in thoracic surgery were followed by a new deficit.	Very low	Condition
ponding to an alert			
fter an alert during a high-risk step, we suggest rst considering reversal of the most recent rgical manoeuvre, while technical, anaesthetic nd physiological causes are checked in parallel.	Surgical manoeuvres caused 86% of alerts in adult deformity surgery.	Very low	Condition
/hen MEP is monitored, we suggest total travenous anaesthesia and avoiding boluses of IEP-suppressing agents at critical steps.	TIVA preserved MEPs better than volatile agents; dexmedetomidine caused dose-dependent MEP loss; high-dose ketamine boluses caused transient suppression.	Low to very low	Condition

Recommendations supported by low or very low certainty evidence are conditional ("we suggest"): most informed clinicians would follow them, but different choices are reasonable for individual patients and settings. Estimates are from the companion umbrella reviews, which re-pooled deduplicated study-level data; the full evidence summary is given in Supplementary Table S3. CI, confidence interval; D-wave, spinal cord D-wave; EMG, electromyography; IONM, intraoperative neurophysiological monitoring; LR−, negative likelihood ratio; MEP, motor evoked potentials; OPLL, ossification of the posterior

longitudinal ligament; OR, odds ratio; SSEP, somatosensory evoked potentials; TIVA, total intravenous anaesthesia.

Table 3. Questions Without Review-Level Evidence (No Recommendation Made).

n	State of the evidence
onitoring in transpsoas lateral lumbar interbody fusion	Three reviews; narrative, not graded
f IONM on outcomes in thoracic (non-tumour) surgery	No review
f alert-response checklists on neurological outcomes	Expert checklists only; no comparative data
ressure target during cord-at-risk steps	Hypotension a recurring confounder; no target defined
perform a wake-up test or abandon correction	Described in checklists; no comparative data
riteria for each modality and procedure	Wide variation; criterion-specific data sparse
and supervision models for IONM	Not assessed in included reviews
-head comparison of modalities in the same patients	All comparisons indirect

Figures

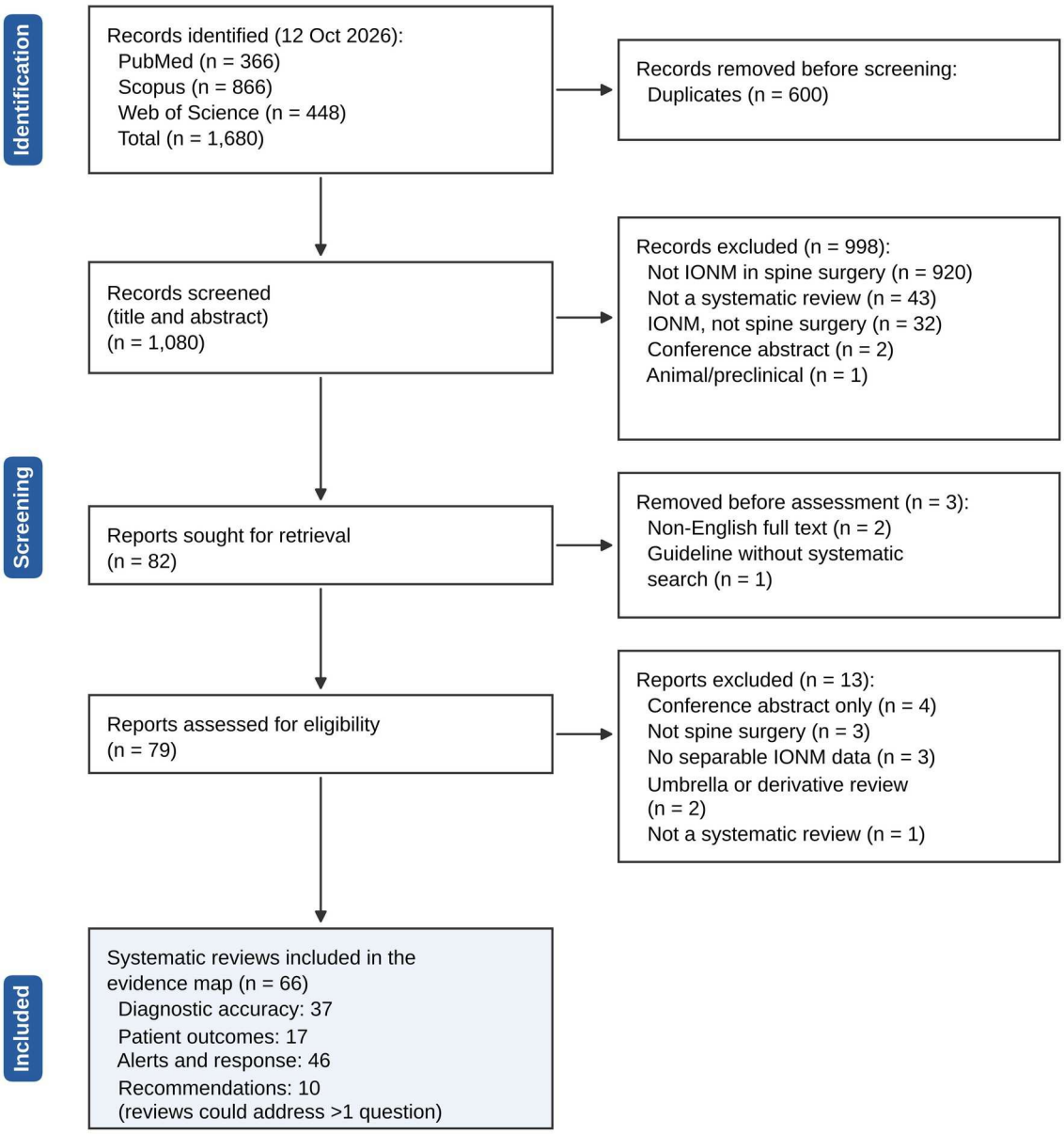

Identification
Records identified (12 Oct 2026):
PubMed (n = 366)
Scopus (n = 866)
Web of Science (n = 448)
Total (n = 1,680)
Records removed before screening:
Duplicates (n = 600)
Screening
Records screened
(title and abstract)
(n = 1,080)
Records excluded (n = 998):
Not IONM in spine surgery (n = 920)
Not a systematic review (n = 43)
IONM, not spine surgery (n = 32)
Conference abstract (n = 2)
Animal/preclinical (n = 1)
Reports sought for retrieval
(n = 82)
Removed before assessment (n = 3):
Non-English full text (n = 2)
Guideline without systematic
search (n = 1)
Reports assessed for eligibility
(n = 79)
Reports excluded (n = 13):
Conference abstract only (n = 4)
Not spine surgery (n = 3)
No separable IONM data (n = 3)
Umbrella or derivative review
(n = 2)
Not a systematic review (n = 1)
Included
Systematic reviews included in the
evidence map (n = 66)
Diagnostic accuracy: 37
Patient outcomes: 17
Alerts and response: 46
Recommendations: 10
(reviews could address >1 question)

Figure 1. PRISMA 2020 flow diagram of review selection. The search was shared with three companion umbrella reviews. Reviews could address more than one question.

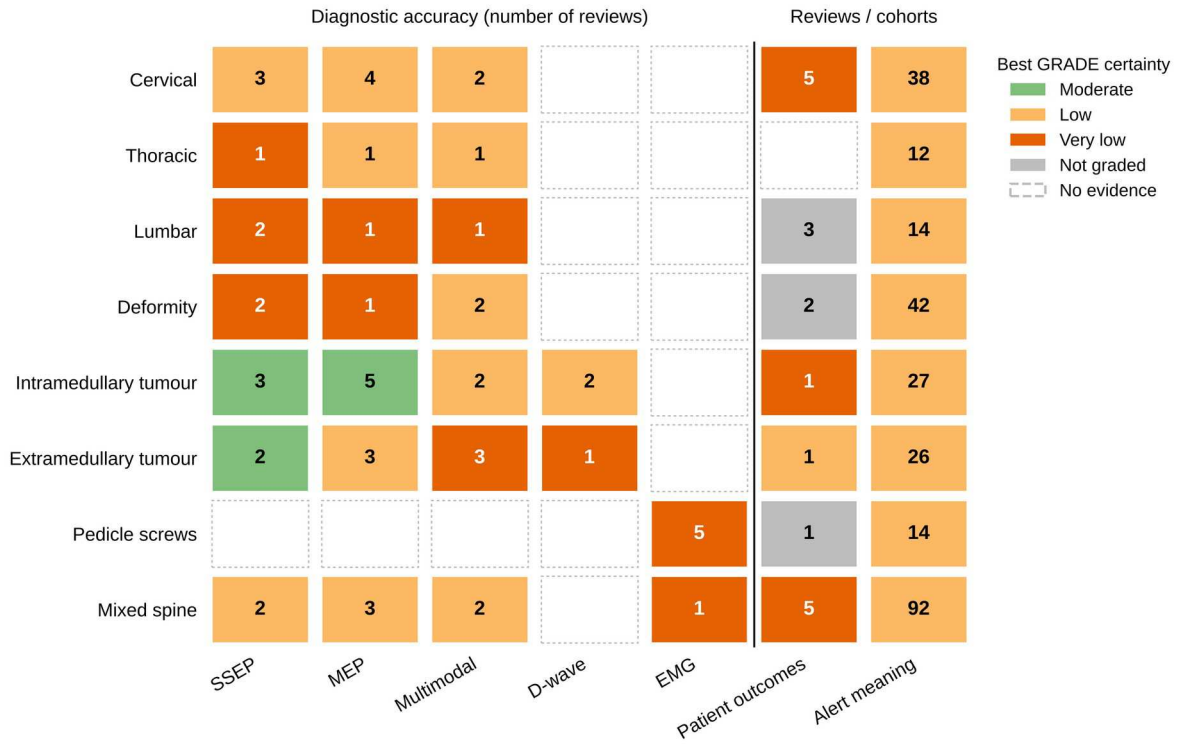


Figure 2. Evidence map of systematic reviews of IONM in spine surgery by procedure and question. Numbers are the number of reviews (accuracy and patient outcomes) or deduplicated primary cohorts with alert data (alert meaning). Colours show the highest GRADE certainty for any estimate in the cell from the companion re-analyses; grey cells had reviews but no graded estimate; dashed cells had no evidence. For alert meaning, certainty refers to the proportion of alerts not followed by a new deficit. EMG,

electromyography (free-run and triggered); MEP, motor evoked potentials; SSEP, somatosensory evoked potentials.

Supplementary Files

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- GSJSupplementaryMaterial.docx