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Original Article

Adhesive surface electrodes versus needle-based neuromonitoring in lumbar spinal surgery

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ABSTRACT

Background: The relative safety and more widespread utility of an adhesive surface electrode-based neuromonitoring (ABM) system may reduce the time and cost of traditional needle-based neuromonitoring (NBM).

Methods: This retrospective cohort review included one- and two-level transforaminal lumbar interbody fusion procedures (2019–2023). The primary variables studied included were time (in minutes) from patient entry into the operating room (OR) to incision, time from patient entry into the OR to closure, and time from incision to closure. Univariate and bivariate analyses were performed to compare the outcomes between the ABM (31 patients) and NBM (51 patients) modalities.

Results: We found no significant differences in the time from patient entry into the OR to incision (ABM: 71.8, NBM: 70.3, $P = 0.70$), time from patient entry into the OR to closure (ABM: 284.2, NBM: 301.7, $P = 0.27$), or time from incision to closure (ABM: 212.4, NBM: 231.4, $P = 0.17$) between the two groups. Further, no patients from either group required reoperation for mal-positioned instrumentation, and none sustained a new postoperative neurological deficit. The ABM approach did, however, allow for a reduction in neurophysiologist-workforce and neuromonitoring costs.

Conclusion: The introduction of the ABM system did not lower surgical time but did demonstrate similar efficacy and clinical outcomes, with reduced clinical invasiveness, neurophysiologist-associated workforce, and overall neuromonitoring cost compared to NBM.

Keywords: Cost efficiency, Spine surgery, Surface electrodes, surgical time, Transforaminal lumbar interbody fusion (TLIF)

INTRODUCTION

The frequency of late starts in neurosurgery is similar to that in other specialties.[10] That said, a potential source of late starts that is unique to neurosurgery is the use of intraoperative neuromonitoring, an integral part of spine procedures. Neuromonitoring, with a sensitivity and specificity ranging from 70% to 100% and 90% to 100%, respectively, reliably identifies and helps avert or limit intraoperative adverse events.[8] A potential source of delay in surgical spine cases is the time required for the insertion of subcutaneous needle electrodes for stimulating/ acquiring motor-evoked potentials (MEPs), somatosensory-evoked potentials (SSEPs), and electromyographic (EMG) signals. To mitigate the potential time and cost inefficiency of needle-based neuromonitoring (NBM), a new adhesive surface electrode-based neuromonitoring (ABM) system was introduced at our center in 2019. This system utilizes adhesive solid gel surface electrodes for both acquisition and stimulation to capture MEPs, SSEPs, and EMGs and can be set up by multiple members of the operating room (OR) staff.[1] Neuromonitoring may then be conducted solely by the operating neurosurgeon, independent of a specialist neurophysiologist.

Here, we conducted a retrospective cohort review comparing the preparation time (patient entry into the OR to incision), total duration (time from patient entry into the OR to closure), case duration (time from incision to closure), and need for revision surgery before and after the introduction of the ABM system in a single neurosurgical center in the US.

MATERIALS AND METHODS

Strengthening the Reporting of Observational Studies in Epidemiology guidelines were utilized to limit potential bias in presenting the findings.

Case acquisition

For our series, we included 82 patients undergoing one- (n = 63) or two-level (n = 19) transforaminal lumbar interbody fusion (TLIF) between 2019 and 2023. The baseline characteristics of the included participants are detailed in Table 1. The mean age was 69 ± 13.2 years, and the majority were female (64.6%). TLIF pedicle screws were placed under the guidance of intraoperative computed tomography navigation (without fluoroscopy) in 32 cases (39%), while the free-hand technique was used in the remaining 50 cases (61%). The ABM system was employed in 31 cases, while traditional NBM was utilized in 51 cases, serving as controls.

Parameters used to assess the efficiency of ABM versus NBM

Three major parameters were used to compare the time and cost efficiency of ABM versus NBM cases: (1) preparation time, The time in minutes from patient entry into the OR to incision, (2) total duration: Time in minutes from patient entry into the OR to closure, and (3) case duration: Time in minutes from incision to closure. We also assessed the rate of postoperative complications, re-operation, and incidence of postoperative instrumentation revision/removal. All patients were followed for a minimum of 6 postoperative months to capture all postoperative instrumentation revisions.

Table 1: Baseline characteristics of included cases.

Covariate (n=82)	Result (mean [SD]/%)
Age (years)	69.0 (13.2)
Sex	
Males	29 (35.4)
Females	53 (64.6)
Number of levels of interbody fusion	
1	63 (76.8)
2	19 (23.2)
Number of levels treated	
1	43 (52.4)
2	26 (31.7)
3	8 (9.8)
4	5 (6.1)
Total duration (min)	295.1 (70.8)
Preparation duration (min)	70.9 (17.2)
Case duration (min)	224.2 (62.4)
Surgical status	
Redo case	20 (24.4)
Virgin case	62 (75.6)
Use of navigation	
Yes	32 (39.0)
No	50 (61.0)
Number of intraoperative O-arm spins	
0	50 (61.0)
1	32 (39.0)
Intraoperative complications (durotomy)	
Yes	3 (3.7)
No	79 (96.3)
Monitoring type	
ABM	31 (37.8)
NBM	51 (62.2)

ABM: Adhesive surface electrode-based neuromonitoring, NBM: Needle-based neuromonitoring, SD: Standard deviation

Statistical analysis

All statistical analyses were performed using RStudio statistical software, version 3.3.2 (The R Foundation, Vienna, Austria). Continuous variables were presented as mean and standard deviations; these variables were analyzed through the student t-test. Categorical variables were presented as frequency percentages; these variables were analyzed using the Chi-squared test.

RESULTS

In bivariate analyses [Table 2], there were no statistically significant differences in time efficiency parameters between the cases using ABM versus those using NBM. The mean preparation time for ABM cases was 71.8 ± 17.7 versus 70.3 ± 17.1 min in NBM cases, and the mean case duration was 212.4 ± 57.4 in ABM versus 231.4 ± 64.8 min in NBM. There was a modest absolute difference in total duration in ABM cases (284.2 ± 67.9) compared to NBM (301.71 ± 72.3 min),

Table 2: Bivariate analyses comparing adhesive surface electrode-based neuromonitoring and needle-based neuromonitoring systems.

Covariate (*n*=82)	ABM (*n*=31)	NBM (*n*=51)	*P*-value
Age (years)	68.9 (9.7)	69.1 (15.1)	0.95
Sex			
Men	13 (41.9)	16 (31.4)	0.46^
Women	18 (58.1)	35 (68.6)	
Number of levels of interbody fusion			
1	26 (83.9)	37 (72.5)	0.36^
2	5 (16.1)	14 (27.5)	
Number of levels treated			
1	19 (61.3)	24 (47.1)	0.58^
2	8 (25.8)	18 (35.3)	
3	3 (9.7)	5 (9.8)	
4	1 (3.2)	4 (7.8)	
Total duration (min)	284.2 (67.9)	301.71 (72.3)	0.27
Preparation duration (min)	71.8 (17.7)	70.3 (17.1)	0.70
Case duration (min)	212.4 (57.4)	231.4 (64.8)	0.17
Surgical status			
Redo case	6 (19.3)	14 (27.5)	0.57^
Virgin case	25 (80.6)	37 (72.5)	
Use of navigation			
Yes	16 (51.6)	16 (31.4)	0.11^
No	15 (48.4)	35 (68.6)	
Number of intraoperative O-arm spins			
0	15 (48.4)	34 (66.7)	0.13^
1	16 (51.6)	17 (33.3)	
Intraoperative complications (durotomy)			
Yes	0 (0)	3 (5.9)	0.44^
No	31 (100)	48 (94.1)	

^Chi-squared test. ABM: Adhesive surface electrode-based neuromonitoring, NBM: Needle-based neuromonitoring

but this was not statistically significant. None of the patients in either the ABM or NBM groups required postoperative hardware revision due to pedicle screw mal-positioning.

DISCUSSION

Study findings

In our retrospective cohort review, we found no significant differences in preparation time, total duration, or case duration for one- and two-level lumbar TLIF procedures between cases using an ABM system (n = 31) versus an NBM system (n = 51). The ABM approach employs gel electrodes and does not require needle insertion into subcutaneous tissues [Table 3]. Randomized controlled trials (such as NERFACE Parts I and II) have already established that the sensitivity and specificity of this ABM system are comparable to traditional NBM approaches.[7,9] The lack of difference in time efficiency in our study may be because factors other than neuromonitoring electrode modality contribute to OR delays. For instance, Pridgeon and Proudlove attributed neuromonitoring-related delays to neurophysiologists missing morning surgical team briefings and redundancy in performing baseline measurements with the patient supine and prone.[18] Overdyk *et al.* reviewed individual case delays/timing for 1787 cases and found that major delays in first-case start times were due to the lack of availability of surgeons, anesthesiologists, and residents.[17] Once all groups underwent multidisciplinary OR efficiency awareness training, these times markedly improved. Suboptimal anesthesia staffing ratios have also been shown to impact surgical start times negatively.[5]

Added value of ABM over NBM despite lack of significant temporal differences

Table 4 summarizes the findings of previous studies that support the use of ABM versus NBM in lumbar spine surgery. Although no significant differences in temporal efficiency were observed for using ABM versus NBM, other major advantages were identified. Surface electrodes are non-invasive and pose no risk of infection, hemorrhage, or damage to surrounding tissue.[2,6] They also eliminate the potential for needle-stick injuries to operative personnel, unlike NBM.

Comparable efficacy and clinical outcomes using ABM and NBM

Large trials have established that surface electrodes have equivalent excitability, thresholds, variability, and accuracy in detecting neurological compromise.[7,9] The two electrode types also result in comparable clinical outcomes. Notably, none of the ABM patients required repeat surgery to correct mal-positioned instrumentation, and there were no new postoperative neurological deficits, similar to the NBM cases.

Cost savings of ABM due to lack of need for specialized neurophysiology input

The lack of need for a specialized neurophysiologist to input data with the ABM-based system would likely prove more cost-effective for neuromonitoring of TLIF cases versus NBM (where a neurophysiologist must be present). We estimated the cost of spinal neuromonitoring based on historical norms for comparable cases. The national average cost per TLIF procedure in the US was $29,948 in 2019.[19] In the same year, at a single neurosurgical center of comparable size and in the same geographical region, the average cost of services for anterior lumbar interbody fusions (ALIF)/posterior spinal fusions, ALIF/TLIF, and lateral/TLIF was 37.6% of the total cost.[4] 10.6% of this service cost was attributed to neuromonitoring (independent of material expenses). As the ABM-based neuromonitoring system can be used solely by the operating neurosurgeon(s), the service cost of

Table 3: Manufacturer-suggested monitoring plans for ABM system in TLIF procedures.

Monitoring type	Stimulating point	Recording location
EMG	Peroneal	Bilateral quadriceps, bilateral biceps femoris, bilateral tibialis anterior
EMG and SSEP	Peroneal, bilateral saphenous (SSEP), bilateral tibial (SSEP)	Bilateral quadriceps, bilateral biceps femoris, bilateral tibialis anterior, cortical (SSEP), transcortical (SSEP)

EMG: Electromyogram, SSEP: Somatosensory-evoked potentials, TLIF: Transforaminal lumbar interbody fusion, ABM: Adhesive surface electrode-based neuromonitoring

Table 4: Summary of studies supporting the use of ABM in lumbar spinal surgery.

Theme	Authors	Main finding
Late starts in surgery – causes and impact	Kelz *et al*. (2008)[12]	Time of day is associated with postoperative morbidity, with later surgeries being associated with higher morbidity.
	Linzey *et al*. (2020)[14]	Patients undergoing emergent operations with a later SST were significantly more likely to have a postoperative complication.
	Neifert *et al*. (2020)[15]	Later, SST is associated with a longer length of stay and higher cost in cervical spine surgery.
	Neifert *et al*. (2020)[16]	Afternoon SST is associated with higher cost and longer length of stay in posterior lumbar fusion.
Complications associated with NBM	Bahat *et al*. (2021)[3]	Most needle-stick injuries were unreported in this single-center cross-sectional study of 844 health workers from different sectors.
	Joshi *et al*. (2022)[11]	The placement of subdermal needles was associated with a high rate of sharps injury.
	Tamkus and Rice (2014)[20]	Needle-stick exposure from subdermal needle electrodes during IONM was an infrequent but distressing event occurring in 0.34% of the study group and was not limited to the IONM technologist.
The impact of ABM on neuromonitoring costs	Krause *et al*. (2020)[13]	Neuromonitoring for lumbar discectomy using a needle-based approach confers greater operative time and cost without any difference in neurological outcome
	Weiss and Elixhauser (2001–2011)[21]	The cost associated with neuromonitoring is likely to become more significant with the rising incidence of lumbar spine surgeries in the United States.

NBM: Needle-based neuromonitoring, ABM: Adhesive surface electrode-based neuromonitoring, SST: Surgical start time, IONM: Intraoperative neuromonitoring

neuromonitoring may be avoided using ABM. Over 3 years, 31 of our ABM cases likely saved $36,207 (3.9%).

CONCLUSION

Although there were no significant differences in temporal efficiency between the ABM and NBM systems, ABM may be a safer and more cost-effective alternative that maintains comparable efficacy and clinical outcomes.

Ethical approval

The Institutional Review Board has waived the ethical approval for this study.

Declaration of patient consent

The authors certify that they have obtained all appropriate patient consent.

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Nil.

Conflicts of interest

There are no conflicts of interest.

Use of artificial intelligence (AI)-assisted technology for manuscript preparation

The authors confirm that there was no use of artificial intelligence (AI)-assisted technology for assisting in the writing or editing of the manuscript and no images were manipulated using AI.

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