

Predictive value of intraoperative D-wave and m-MEP neurophysiological monitoring in patients with preoperative motor deficits in immediate and late postoperative period

ABSTRACT

Background: Presence of preoperative motor deficits in patients poses a distinct challenge in monitoring the integrity of corticospinal tracts during spinal surgeries. The inconsistency of the motor-evoked potentials in such patients, limits its clinical utility. D-wave is a robust but less utilized technique for corticospinal tract monitoring. The comparative clinical value of these two techniques has not been evaluated in the patients with preoperative deficits.

Objectives: The objective of the study was to compare the predictive utility of myogenic Motor Evoked Potentials (m-MEP) and D-wave in terms of recordability and their sensitivity and specificity in predicting transient and permanent new motor deficits.

Materials and Methods: Thirty-one patients with preoperative motor deficit scheduled to undergo spinal surgery were included in the study. Intraoperative m-MEP and D-wave changes were identified and correlated with postoperative neurology in the immediate postoperative period and at the time of discharge.

Results: The mean preoperative motor power of the patient pool in left and right lower limb was 2.97 ± 1.56 and 3.32 ± 1.49 , respectively. The recordability of m-MEPs and D-wave was observed to be 79.4% and 100%, respectively. The m-MEP predicted the motor deterioration in immediate postoperative period with 100% sensitivity and 80% specificity, while D-wave had 14% sensitivity and 100% specificity. At the time of discharge, m-MEPs' specificity reduced to 61%, while D-wave demonstrated 100% specificity.

Conclusions: D-wave has a better recordability than m-MEPs in neurologically compromised patients. D-wave predicts development of long-term deficits with 100% specificity, while m-MEPs have a high sensitivity for transient neurological deficit. A combination of D-wave and m-MEP is recommended for monitoring the integrity of the corticospinal tract in patients with preoperative motor deficits.

Keywords: Corticospinal tract monitoring, D-wave, epidural potentials, intraoperative neurophysiological monitoring, motor evoked potentials

INTRODUCTION

Intraoperative neuromonitoring techniques are utilized to prevent/limit the risk of development of new neurological deficits during neurosurgical procedures. Monitoring of the motor tract is an important component of the multimodal intraoperative neuromonitoring technique in the context of spinal surgeries.

Physiological differentiation of a transient loss of motor function due to inadvertent handling of the spinal cord from

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the potentially permanent loss of motor function due to injury to the cord is extremely critical to determine the course of the action during ongoing surgery.^[1]

Intraoperatively, the functional integrity of the motor pathways can be assessed by transcranial stimulation of the motor cortex^[2,3] and recording the evoked potentials at the level of spinal cord (D-wave)^[4,5] or at the level of the muscles (m-MEP).^[3] There are only a handful of reports comparing the utility of recording and monitoring D-wave and m-MEP simultaneously.^[6-10] The presence of preoperative motor deficits has been a limiting factor in the recording and hence monitoring of integrity of motor tracts. The recordability of m-MEP is poor in such patients,^[7,8,11,12] while D-wave recordability has been shown to unaffected^[7] or poor.^[6,8,11,12]

Decrease in the amplitude of m-MEP during the surgery correlates well with the immediate postoperative neurological deficit^[13,14] but poorly with long-term postoperative neurological status.^[6-8] Intact D-wave in the face of decreased m-MEP amplitudes accurately predicts the recoverability of the transient deficits and therefore predicts the long-term neurological status.^[6,7,12] However, most of this information is based on data from patients without any preoperative motor deficits. Most of these studies have included only a small number of patients with preoperative motor deficits while others none at all.^[6,12,15]

Thus, the present study was designed to prospectively study the comparative monitorability of D-wave and m-MEP in patients with preoperative motor deficits undergoing spinal neurosurgical procedures and their relative clinical utility in predicting postoperative new motor deficits in terms of sensitivity and specificity.

MATERIALS AND METHODS

After approval by the institute ethics committee, patients scheduled for spinal surgeries requiring intraoperative monitoring of corticospinal tracts were screened. Thirty-one patients (19 males [26.89 ± 14.18 years] and 12 females [35.5 ± 17.95 years]; mean age: 32.2 ± 16.03 years) with preoperative motor deficits were included in the study after exclusion of patients younger than 5 years of age, patients with a history of irradiation, previous spinal surgery, or lesions extending caudal to T9 thoracic spinal segment. Written informed consent was obtained from all the patients or from their legal guardians in case of minors. Etiologic distribution of the patients is presented in Table 1. In all patients, the preoperative assessment of the motor power was done, and the m-MEP and D-wave recordings were

attempted during the course of the neurosurgery with NIM-ECLIPSE® NS System (Medtronic, USA).

Assessment of motor power

All patients underwent neurological evaluation by attending neurosurgery resident doctor of motor power the day before the surgery, the day after the surgery, and at the time of discharge. The motor power of the patients was graded according to the MRC scale [Medical Research Council, UK, Table 2]. Thereafter, each limb was given a separate motor score ranging from 0 to 5 by averaging the power of each joint of the same limb. The average preoperative motor score of the patients is presented in Table 3.

Anesthesia

All the patients were maintained with total intravenous anesthesia using propofol (100–150 µg/kg/min) and fentanyl (1 µg/kg/h) infusions. Short-acting muscle relaxant was used only at the time of induction.

Neurophysiological monitoring

Transcranial muscle motor-evoked potentials (m-MEP)

Transcranial electrical stimulus was delivered through corkscrew electrodes placed at C3' and C4' position (1 cm anterior to C3 and C4 electrode position, respectively) according to the international 10–20 system of electrode placement. Motor cortex was stimulated with a train of 8, 75 µs long biphasic pulses with a frequency of 250–400 Hz. To determine threshold stimulation, voltage

Table 1: Etiologic distribution of patients

Diagnosis	Number of patients
Spinal cord tumors	16
Extramedullary tumors	10
Intramedullary tumors	6
Spinal deformities	6
Kyphosis	4
Kyphoscoliosis	2
Atlantoaxial dislocation	6
Compressive myelopathy	1
Pott's spine	1
Cervicodorsal OPLL	1

OPLL - Ossified posterior longitudinal ligament

Table 2: Medical Research Council scale for motor power assessment

Grade	Observation
0	No contraction
1	Flicker or trace of contraction
2	Active movement with gravity eliminated
3	Active movement against gravity
4	Active movement against resistance
5	Normal power

Used with permission of Medical Research Council^[16]

Table 3: Preoperative motor score of the patients (n=31)

Limb	Average motor score (mean±SD)
Left upper limb	3.97±1.64
Right upper limb	3.84±1.70
Left lower limb	2.97±1.56
Right lower limb	3.32±1.49

SD - Standard deviation

was gradually increased from 50 V till m-MEP responses were consistently obtained. This was considered as threshold stimulation, and the same strength was used for subsequent monitoring.

m-MEPs were recorded using dual-twisted needle electrodes placed bilaterally in at least four muscles supplied by motor nerves arising at or caudal to the spinal lesion. The muscles chosen were among brachioradialis, abductor pollicis brevis, abductor digiti minimi, rectus abdominis, vastus lateralis, tibialis anterior, extensor hallucis longus, and abductor hallucis. The m-MEPs were recorded in a 100 ms window with a band pass filter of 30–3000 Hz.

D-wave

The D-wave was elicited using the same electrode montage that was used for m-MEP. A single pulse of 75 μ s was used. The stimulation threshold was determined in the same manner as described for m-MEP. Thereafter, supramaximal stimulation voltage was determined by step-wise increment in the stimulation voltage till no further increase in the amplitude of the D-wave occurred. The D-wave monitoring was done at supramaximal voltage.

The D-wave was recorded using a 2-point semi-rigid catheter type recording electrode with recording points 1.5 cm from each other at the tip (Inomed, Germany). The catheter electrode was inserted in epidural space (25 patients) or in subdural space (six patients) caudal to the lesion after laminectomy and was secured with sutures. The recording window of D-wave was of 20 ms duration and band pass filter of 30–1500 Hz was used. 5–10 sweeps were averaged to improve the signal-to-noise ratio whenever necessary.

Alarm criteria

The alarm criteria were set at 50% decrease in the peak-to-peak amplitude of the m-MEP record and D-wave record. In cases where the decrease in amplitude showed consistent trend of recovery, such cases were considered as partially recovered.

Statistical analyses

The distribution of data of each parameter was tested by Shapiro–Wilk test. Parametric data are presented as mean \pm standard deviation and nonparametric data are

presented as median with interquartile range. The comparison of thresholds of m-MEP and D-wave was done using Mann–Whitney U-test. The association of m-MEP or D-wave alarm with immediate deficit or deficit at the time of patient discharge was evaluated using Fisher's exact test. The level of statistical significance was set at $P < 0.05$. All statistical analyses were performed using SPSS (Statistical Package for the Social Sciences, version 25, IBM SPSS Statistics).

RESULTS

Intraoperative neurophysiological monitoring was attempted in 31 patients. m-MEPs could be recorded at the beginning of the surgery in 24 out of 31 patients (79.4%). In one of these 24 patients, monitoring had to be aborted mid-surgery because of occurrence of seizures and was excluded from analysis. In one patient, the m-MEP was recordable only after decompression, and in another patient, m-MEP was recordable only from abductor hallucis on the right side. These two patients were also excluded from the analysis for assessing clinical utility.

D-wave baseline could be recorded in all 31 patients (100%). In 17 of these cases, D-wave was monitored throughout the surgery. In the remaining cases, D-wave was not monitored till the end of surgery because the catheter electrode was removed for surgical reasons (10 cases) or was accidentally pulled out mid-surgery (4 cases).

Thresholds for D-wave and m-MEP

The mean threshold stimulation strength required for obtaining D-wave in the patients was 400 ± 137.5 V, which was significantly lower as compared to the mean threshold stimulation strength (700 ± 200 V) required for obtaining m-MEP ($P < 0.0001$ by Mann–Whitney U-test).

Analyses for clinical utility

The sensitivity, specificity, positive predictive value, and negative predictive value of m-MEP and D-wave alarms were calculated in immediate and late postoperative periods (at the time of discharge). The terminologies used in this section have been described in Table 4.

Clinical utility of m-MEP and D-wave in predicting new motor deficit in the immediate postoperative period

m-MEPs were monitored till the end of surgery in 23 patients. The alarm was raised in 16 patients. Intraoperative recovery of m-MEP amplitude was observed in five patients (three complete and two partial) and none of them developed any new deficit in the immediate postoperative period. In 11 patients, m-MEP alarm was persistent through the surgery, and of these, eight developed new motor deficit in

the immediate postoperative period. The m-MEP monitoring was uneventful in 12 patients and none of them developed any new deficits in the immediate postoperative period. One of these patients died in the postoperative period and was excluded from analysis of long-term postoperative motor status.

D-wave was monitored throughout the surgery in 17 patients. The D-wave alarm was raised only in one patient who had new motor deficit in the immediate postoperative period. In one patient, there was a surgical complication because, of which he underwent a revision surgery which was not supported with neuromonitoring and his data were thus not included in the analysis. Even though D-wave monitoring was uneventful in 15 patients and new motor deficits in immediate postoperative period were noted in six patients. Overall results of clinical utility analysis in the immediate postoperative period are presented in Table 5.

Clinical utility of m-MEP and D-wave in predicting new motor deficit in the long-term postoperative period

Of 11 patients who had persistent m-MEP alarm, eight had developed new motor deficit in the immediate postoperative motor deficit. Two of these 11 patients who died in the postoperative period were excluded from this analysis. Of the remaining nine patients, two had persistent decrease in motor power as compared to preoperative motor status at the time of discharge.

D-wave amplitude alarm was raised one patient. The patient had persistent motor deficit at the time of discharge. Among

the other 15 patients with uneventful D-wave monitoring throughout, two died and were excluded from the analysis at discharge. Of the remaining 13 patients with uneventful D-wave monitoring, one patient had not completely recovered motor from motor deficit time of discharge. Rest 13 recovered to preoperative status while in hospital. Overall results of clinical utility analysis at the time of discharge are presented in Table 6.

There were two cases of special interest in whom the amplitude of neurophysiological parameters increased during the course of surgery. Case 1 operated for Pott’s spine at D4–D6. Initially, only D-wave was recordable in this case, m-MEPs were not. As the surgery ensued, first, the amplitude of D-wave increased, and after some time, the m-MEPs also appeared in the lower limbs. Case 2 operated for extramedullary tumor at C4–C5. Both D-wave and m-MEPs showed increased amplitudes after resection of tumor. The intraoperative findings in both these patients corroborated with postoperative neurology with both patients showing improvement in motor power.

DISCUSSION

m-MEP and D-wave are the primary neurophysiological modalities employed for monitoring of corticospinal tracts during spinal surgeries. Patients with preoperative deficits present challenges in recording and interpretation of intraoperative changes in m-MEP and D-wave waveforms. The present study was designed to compare the utility of m-MEPs and D-wave monitoring in predicting immediate

Table 4: Definitions of terminologies

Term	Description
True positive	Patients in whom intra-operative drop in amplitude of m-MEP/D-wave did not recover till the end of surgery and had new motor deficit in the postoperative period
True negative	Patients in whom there was no intraoperative drop in amplitude of m-MEP/D-wave and had no new motor deficit in the postoperative period. It also included the patients in whom there was intraoperative drop of m-MEP/D-wave amplitude, but there was a trend of recovery observed in the intraoperative period and the patient had no new motor deficit in the postoperative period
False positive	Patients in whom there was intraoperative drop in the amplitude of the m-MEP/D-wave, but the patient had no new motor deficit in the postoperative period
False negative	Patients in whom there was no intraoperative drop in the amplitude of the m-MEP/D-wave, but the patient had new motor deficit in the postoperative period

m-MEP/D - Myogenic motor evoked potential deficit

Table 5: Clinical utility (sensitivity, specificity, positive, and negative predictive value) of myogenic motor-evoked potential and D-wave for predicting new motor deficits in the immediate postoperative period

Parameter	Alarm	Postoperative motor deficit		Sensitivity	Specificity	PPV	NPV
		Yes	No				
m-MEP (n=23)	Yes (11)	8	3	1	0.8	0.72	1
	No (7+5)	0	12				
D wave (n=16)	Yes (1)	1	0	0.14	1	1	0.6
	No (15)	6	9				

P for mMEP in predicting deficit: 0.0003 (Fisher’s exact test), P for D-wave in predicting deficit: 0.438 (Fisher’s exact test). m-MEP - Myogenic motor-evoked potential; PPV - Positive predictive value; NPV - Negative predictive value

Table 6: Clinical utility (sensitivity, specificity, positive, and negative predictive value) of amplitude changes in myogenic motor-evoked potential and D-wave for predicting new motor deficits in the long-term postoperative period

Parameter	Alarm	Postoperative motor deficit		Sensitivity	Specificity	PPV	NPV
		Yes	No				
m-MEP (n=20)	Yes (9)	2	7	1	0.61	0.22	1
	No (11)	0	11				
D wave (n=14)	Yes (1)	1	0	0.5	1	1	0.92
	No (13)	1	12				

P for mMEP in predicting deficit: 0.189 (Fisher's exact test), P for D-wave in predicting deficit: 0.143 (Fisher's exact test). m-MEP - Myogenic Motor Evoked Potentials; PPV - Positive predictive value; NPV - Negative predictive value

and long-term postoperative motor deficit in neurologically compromised patients.

In our study, a reliable m-MEP baseline could be recorded in 79.4% of the patients with preoperative deficits. In previous reports, recordability of m-MEP in patients has shown to range from 82.5% to 97% in group of patients with or without preoperative deficits.^[6-8,12,13,15,16] All the patients in the present study had preoperative motor deficits, and hence the recordability is lower than previously reported where the patients were included irrespective of preoperative motor deficit.

There is limited literature available on D-wave and most of them have reported a wide range of recordability. In their 1997 study, Morota *et al.* could record D-wave in 59.3% of their patients undergoing surgery for intramedullary spinal cord tumor at cervical/thoracic levels. Similar results were reported by Kothbauer *et al.* (68.6%), Sala *et al.* (70%), and Korn *et al.*, (73%).^[6,8,11,12] Costa *et al.*^[7] have reported relatively better recordability of D-wave (94.1%). Ghadirpour *et al.*^[10] have recently reported a recordability of 92.2%. All of them documented significant difficulty in eliciting the D-wave in neurologically compromised patients. Having excluded patients with a history of irradiation, previous spinal surgery, or patients with lesion extending beyond T9 thoracic spinal segment as part of the study protocol we were able to record D-wave successfully in all study participants.

The D-wave is the direct wave elicited by a single stimulation of the motor cortex and is recorded from the spinal cord. The elicitation of the m-MEP, however, requires polysynaptic transmission followed by temporal summation of a volley of 4–8 action potentials (D-wave) at the alpha motor neurons and is recorded from the muscle. For efficient temporal summation at the alpha motor neuron, the D-waves should be temporally coherent and reach the alpha motor neuron at an optimal frequency to generate an action potential. We speculate that, in patients with preoperative motor deficits, the associated spinal pathology alters the conduction velocity of the corticospinal tract fibers affecting the

temporal summation, leading to absent/inconsistent m-MEPs. The spinal pathologies, adhesions due to prior surgery/radiotherapy, may cause wide dispersion even of the D-waves such that it may be difficult to record it consistently in such patients.^[11]

The clinical utility of an intraoperative neurophysiological monitoring modality is characterized by its ability to predict and prevent new motor deficits. High sensitivity is important for timely identification of an insult/injury to neural tissue, to limit it and early institution of corrective measures. High specificity on the other hand helps discern alarms related to reversible “surgically induced transient paraplegia” from the “real” injury to the motor tract which may lead to persistent deficits. A combination of high sensitivity with high specificity is ideal for maximum safe resection with minimal risk of new neurological deficit.

In the immediate postoperative period, the m-MEP showed 100% sensitivity and a negative predictive value of 1. The specificity of this technique was 80%. The D-wave on the other hand showed high specificity (100%) and positive predictive value but low sensitivity (14.2%) in immediate postoperative period. Thus, intraoperative m-MEP alarms correlated well with the immediate postoperative outcome in terms of sensitivity, but the specificity of D-wave was better.

In the immediate postoperative period, it is not possible to differentiate transient physiological deficit from permanent motor deficit. The distinction between the two manifests later during the follow-up. At the time of discharge in the present study, the m-MEP sensitivity was 100%, but the specificity decreased to 61%. D-wave on the other hand had high specificity (100%). This suggests that the D-wave alarms correlate better in predicting severe motor tract/real anatomical injuries with high specificity, and it has higher sensitivity for detecting severe spinal cord injuries than minor insults which result in only transient changes. Furthermore, it was noted that, overall, m-MEPs were relatively more prone to drop during resection of intramedullary tumors as compared to extramedullary pathologies probably owing

Table 7: Sensitivity and specificity of simultaneous myogenic motor-evoked potential and D-wave monitoring in literature

Modality	Study (MEP)	Immediate postoperative		Long term		Remarks
		Sensitivity	Specificity	Sensitivity	Specificity	
m-MEP	Korn <i>et al.</i> , 2015	65.20 [#]	81.08 [#]	85.70 [#]	74.40 [#]	Both transient and persistent MEP alarms were included
	Costa <i>et al.</i> , 2013	100.00 [#]	94.30 [#]	100.00 [#]	85.50 [#]	Both transient and persistent MEP alarms were included
	Kothbauer <i>et al.</i> , 1998	100.00	91.00	-	-	None of the patients had long-term deficits
D wave	Korn <i>et al.</i> , 2015	28.50 [#]	100.00 [#]	50.00 [#]	93.75 [#]	All alarms were persistent
	Costa <i>et al.</i> , 2013	-	-	-	-	None of the patients had significant drop in D wave amplitude
	Kothbauer <i>et al.</i> , 1998	-	-	-	-	The surgery was aborted on D-wave alarm at 50% drop in amplitude

[#]Calculated from authors data. MEP - Motor-evoked potential

to greater degree of cord handling. However, D-wave was stable in such cases, thus allowing the neurophysiological monitoring to continue to ensure maximal resection without compromising the integrity of corticospinal tracts.

These results suggest that, in patients with preoperative motor deficits, the greater sensitivity of m-MEP has importance of alerting surgeon of ongoing insult, thus limiting injury, but the D-wave helps the surgeon distinguish between the severities of insult and take appropriate measures to prevent injury without sacrificing extent of excision of lesion or correction of deformity or malformation.

There are only a few reports which have compared the clinical utility of m-MEP and D-wave and their findings have been presented in Table 7.^[6-8]

Ghadirpour *et al.* have reported a sensitivity and specificity of 62.5% and 97.03 for m-MEP and 100% and 98.4% for D-wave, respectively. However, the time point at which these calculations were done is not clear from their report.

CONCLUSIONS

Our results suggest that D-wave can be successfully recorded and monitored in patients with preoperative neurological deficits but without the history of previous surgery, irradiation, and the lesions caudal to T9. A combination of m-MEP and D-wave cater to two distinct requirements of successful monitoring of functional integrity of motor tracts with high sensitivity of m-MEP alerting surgeons so that corrective measures can be taken at the very early stages of injury/insult, while the D-wave helps surgeons differentiate between the severity of injury so that judicious decision can be taken preventing conservative excision of lesion or under-correction of deformity. Therefore, a combination of m-MEP and D-wave is recommended for monitoring the functional integrity of the corticospinal motor tract, especially in patients with preoperative motor deficits.

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Conflicts of interest

There are no conflicts of interest.

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