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Citation

Steenbeek, E. D., Pondaag, W., Tannemaat, M. R., Zwet, E. W. van, Malessy, M. J. A., & Groen, J. L. (2023). Optimal timing of needle electromyography to diagnose lesion severity in traumatic radial nerve injury. *Muscle & Nerve*, 67(4), 314-319. doi:10.1002/mus.27787

Version: Publisher's Version

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Note: To cite this publication please use the final published version (if applicable).

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How to cite this article: Nandedkar SD, Barkhaus PE. Defective E2 electrode lead gives low-amplitude compound muscle action potential. *Muscle & Nerve.* 2023;67(4):310-314. doi:10.1002/mus.27786

Optimal timing of needle electromyography to diagnose lesion severity in traumatic radial nerve injury

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Abstract

Introduction/Aims: In patients with traumatic radial nerve injury (RNI), the chance of spontaneous recovery must be balanced against the benefits of early surgical reconstruction. We aimed to explore the time-specific value of needle electromyography (NEMG) to diagnose nerve lesion severity.

Methods: In this retrospective diagnostic accuracy study at Leiden Nerve Center, patients at least 12 years of age with RNI caused by fractures or fracture treatment were included. The sensitivity and specificity of the patients' first NEMG examination were assessed, stratified by the timing after the nerve injury. The absence of motor unit potentials (MUPs) in muscles distal to the nerve lesion was considered a positive test result. Lesion severity was dichotomized to moderate injury (spontaneous Medical Research Council grade ≥ 3 recovery) or severe injury (poor spontaneous recovery or surgical confirmation of a mainly neurotmetic lesion).

Results: Ninety-five patients were included in our study. The sensitivity of NEMG to detect severe RNI was 75.0% (3 of 4) in the fourth, 66.7% (2 of 3) in the fifth, and 66.7% (2 of 3) in the sixth month after the nerve injury. The specificity in the first to the sixth month was 0.0% (0 of 1), 50.0% (2 of 4), 77.3% (17 of 22), 95.5% (21 of 22), 95.8% (23 of 24), and 100.0% (12 of 12), respectively.

Abbreviations: APL, abductor pollicis longus; BR, brachioradialis; CI, confidence interval; ECRB, extensor carpi radialis brevis; ECRL, extensor carpi radialis longus; ECU, extensor carpi ulnaris; EDC, extensor digitorum communis; EDQ, extensor digiti quinti; EIP, extensor indicis proprius; EPB, extensor pollicis brevis; EPL, extensor pollicis longus; IQR, interquartile range; LNC, Leiden Nerve Center; MRC, Medical Research Council; MUP, motor unit potential; NEMG, needle electromyography; PIN, posterior interosseous nerve; RNI, radial nerve injury; SBRN, superficial branch of the radial nerve.

This study was presented online at the annual national educational meeting of the Dutch Society for Clinical Neurophysiology, on April 8, 2022. It was also presented at the national annual winter meeting of the Dutch Society for Neurosurgery, on November 25, 2022 in Rotterdam, The Netherlands.

Discussion: The specificity of NEMG is higher than 95% and therefore clinically relevant from the fourth month after the nerve injury onward. Absence of MUPs at this time can be considered an indication to plan nerve exploration. Moreover, the presence of MUPs on NEMG does not completely exclude the necessity for surgical reconstruction.

KEYWORDS

diagnostic accuracy, electrodiagnostic testing, fracture, needle electromyography, peripheral nerve injury, radial nerve, surgery

1 | INTRODUCTION

Traumatic radial nerve injury (RNI) is most frequently caused by fractures, either directly by the fracture itself (primary RNI) or iatrogenically during fracture treatment (secondary RNI).¹⁻³ The overall prognosis of RNI after fractures or fracture treatment is good, justifying a relatively expectant approach; for example, in the setting of humeral shaft fractures, 77% to 94% of patients recover spontaneously, with a mean recovery onset of 8 weeks after the nerve injury (range, 3 to 30 weeks).⁴⁻⁶ However, success rates of nerve reconstruction decline with delay.⁷⁻¹⁰ Therefore, one must balance between minimizing the chance of avoidable surgery in case of self-limited palsy and maximizing the chance of successful reconstruction in case of severe nerve lesions without spontaneous recovery.

The absence of electrical nerve continuity as shown by needle electromyography (NEMG) testing is the key factor that determines the indication for surgical nerve exploration. However, the optimal timing of referral to a tertiary-level nerve center to evaluate surgical indication is currently unknown. Although NEMG has been widely implemented in routine care for RNI patients all over the world, its time-dependent diagnostic value has never been studied before in this population. The aim of this study was to explore the time-specific accuracy of NEMG to diagnose lesion severity in patients with RNI caused by fractures or fracture treatment presenting to a tertiary-level nerve center.

2 | METHODS

2.1 | Study design and participants

We performed a retrospective diagnostic accuracy study in a consecutive cohort of patients with RNI caused by fractures or fracture treatment who were referred to Leiden Nerve Center (LNC), The Netherlands, from January 2006 to January 2021. In this study, RNI includes injuries of the radial nerve itself as well as injuries of the posterior cord and posterior interosseous nerve. Inclusion criteria comprised: (1) RNI caused by fractures or fracture treatment; (2) patients aged 12 years or older; and (3) timing of the first NEMG examination at LNC within 6 months after the nerve injury. Exclusion criteria were:

(1) an incomplete NEMG examination; and (2) comorbidity that impeded effective evaluation of radial nerve recovery. The relevant institutional medical ethics committee declared the study exempt from review given its retrospective nature.

2.2 | Needle electromyography examination (index test)

The NEMG examination entailed recording the recruitment pattern of motor unit potentials (MUPs) at maximal voluntary contraction with concentric needle electrodes in the muscles relevant to indicate reinnervation. Three levels of nerve injury were distinguished according to the branching pattern of the radial nerve: (1) proximal to the nerve branch to the brachioradialis muscle; (2) proximal to the nerve branches to the extensor carpi radialis longus and brevis muscles but distal to level 1; and (3) proximal to the extensor carpi ulnaris and extensor digitorum muscles but distal to level 2 (Figure S1).¹¹⁻¹³ Classification was based on the pattern of muscle weakness identified on examination immediately after the nerve injury, conventional radiography images, and the pattern of NEMG abnormalities indicating previous denervation. Electrical discontinuity (ie, a positive index test result) was concluded if the level of innervation during testing was in accordance with the level of nerve injury; electrical continuity (ie, a negative index test result) was concluded if any MUP was detected in previously denervated muscles. All NEMGs were performed by an experienced clinical neurophysiologist with Medelec Synergy electromyography equipment (Oxford Instruments, Abingdon, Oxfordshire, UK).

2.3 | Reference standard

Lesion severity was dichotomized as severe or moderate injury. In operatively managed patients, severe RNI was defined as the surgical finding of a nerve rupture or neuroma with loss of fascicular continuity and absence of muscle contractions during intraoperative nerve stimulation. Traumatic neuroma was confirmed by histological assessment of the resected specimen. In nonoperatively managed patients, severe RNI was defined as Medical Research Council (MRC) grade 0 to 2 recovery in wrist, finger, and thumb extensors

at least 18 months after the nerve injury.¹⁴ Moderate RNI was defined as spontaneous MRC grade 3 to 5 recovery in any of these muscles. In case moderate injury was suspected during nerve exploration and no reconstruction was performed for this reason, lesion severity was always confirmed by clinical follow-up. In brief, severe injury corresponds to a mainly neurotmetic lesion (Sunderland grade 4 or 5) and moderate injury to a mainly axonotmetic lesion (Sunderland grade 2 or 3).¹⁵

2.4 | Analysis

Numeric variables were reported as median values and interquartile range (IQR) because of their non-normal data distribution. Patients were divided into six 1-month-interval groups according to the time between the nerve lesion and NEMG examination. For every group, NEMG sensitivity and specificity were calculated, irrespective of any clinical signs of muscle recovery if present at the time of NEMG

TABLE 1 Characteristics of the study population

	Severe RNI (n = 10)	Moderate RNI (n = 85)	Total population (n = 95)
Age at the time of nerve injury, in years, median (IQR)	27.1 (16.7-36.6)	37.1 (22.8-58.0)	34.3 (22.2-57.0)
Male (%)	5 (50.0)	45 (52.9)	50 (52.6)
Side of the lesion: right (%)	3 (30.0)	42 (49.4)	45 (47.4)
Fracture location ^a (%)			
Proximal humerus	2 (20.0)	6 (8.5)	8 (9.9)
Humeral shaft	4 (40.0)	38 (53.5)	42 (51.9)
Distal humerus	2 (20.0)	20 (28.2)	22 (27.2)
Elbow/proximal forearm	2 (20.0)	7 (9.9)	9 (11.1)
Injury mechanism ^a (%)			
Primary (ie, direct)	2 (20.0)	30 (40.5)	32 (38.1)
Secondary ^a (ie, iatrogenic)	8 (80.0)	44 (59.5)	52 (61.9)
Conservative	0 (0.0)	3 (7.1)	3 (6.0)
Plate fixation	4 (50.0)	28 (66.7)	32 (64.0)
Nail fixation	3 (37.5)	7 (16.7)	10 (20.0)
K wires/screw fixation	1 (12.5)	3 (7.1)	4 (8.0)
Elbow prosthesis	0 (0.0)	1 (2.4)	1 (2.0)
Injury location proximal to the nerve branch/branches to the (%)			
BR muscle	7 (70.0)	79 (92.9)	86 (90.5)
ECRB/ECRL muscles	2 (20.0)	3 (3.5)	5 (5.3)
EDC/ECU muscles	1 (10.0)	3 (3.5)	4 (4.2)
Nerve exploration (%)	10 (100.0)	2 ^b (2.4)	12 (12.6)
Interval nerve injury and exploration, in months, median (IQR)	6.5 (5.0-9.0)	4.3 (3.8-4.8)	6.0 (4.9-8.0)
Follow-up, in months, ^a median (IQR)	24.6 (20.4-25.1) ^c	6.8 (5.0-11.6) ^d	7.7 (5.0-14.2)
MRC grade ≥3 recovery ^{a,e} (%)			
Wrist extension ^f	8 (88.9)	80 (98.8)	88 (97.8)
Finger extension	6 (66.7)	61 (71.8)	67 (71.3)
Thumb extension	5 (55.6)	51 (63.8)	56 (62.9)

Abbreviations: RNI, radial nerve injury; IQR, interquartile range; BR, brachioradialis; ECRB, extensor carpi radialis brevis; ECRL, extensor carpi radialis longus; EDC, extensor digitorum communis; ECU, extensor carpi ulnaris; MRC, Medical Research Council.

Note: Italic values indicates the percentages refer to the proportion within the group of patients with a secondary injury mechanism and not within all patients of that column.

^aThese variables had missing values, all <12.0%.

^bOne of these patients underwent surgery for pseudoarthrosis. In the other patient with high radial nerve injury, needle electromyography showed a single motor unit potential in the extensor pollicis longus muscle, whereas the intermediate muscles showed no continuity at 3.8 months after the nerve injury.

^cInterval between reconstructive surgery and the last clinical outcome assessment. One patient was lost to follow-up.

^dInterval between the nerve injury and the last clinical outcome assessment.

^eThese grades reflect recovery after reconstructive surgery using an autologous sural nerve graft in the severe injury group and spontaneous recovery in the moderate injury group.

^fExcluding patients with an injury location distal to the nerve branches to the extensor carpi radialis longus/brevis muscles.

examination. If multiple examinations were performed at LNC on the same patient (20% of cases), only the first test was analyzed. All analyses were performed using SPSS Statistics for Windows version 27 (IBM Corporation, Armonk, NY), and 95% confidence intervals of proportions were calculated as proposed by Wilson.^{16,17}

3 | RESULTS

In total, 231 patients with RNI underwent NEMG examination at LNC and 109 patients met the inclusion criteria. Six patients were excluded, leading to a total study population of 103 patients (see Figure S2 for a detailed flowchart). The reference standard was available in 92.2% (n = 95) of cases.

Ten patients had severe and 85 had moderate RNI (Table 1). There was a binomial distribution of age, peaking at the ages of 24 and 59 years, and the injury location was proximal to the nerve branch to the brachioradialis muscle in 90.5% of cases. All patients with severe RNI underwent nerve exploration after a median delay of 6.5 months after the nerve injury. The overall MRC grade ≥ 3 recovery rates for wrist, finger, and thumb extension were high (Table 1).

Most patients presented to LNC in the third, fourth, or fifth month after their nerve injury (Table 2). All patients who underwent NEMG examination in the first 3 months after the nerve injury had moderate RNI, whereas the proportions of severe injuries were 15.4%, 11.1% and 20.0% in the fourth, fifth, and sixth month, respectively. The sensitivity of NEMG for diagnosis of severe RNI was 75.0% in the group of patients undergoing examination in their fourth month after the nerve injury and 66.7% in the groups presenting in the fifth and sixth month. As shown in Figure 1, specificity increased from 0.0% in the first month to 100.0% in the sixth month after the nerve injury and reached 95.5% in the fourth month.

4 | DISCUSSION

In this diagnostic accuracy study, NEMG was found to be nonspecific for severe vs moderate traumatic RNI in the first quarter after the

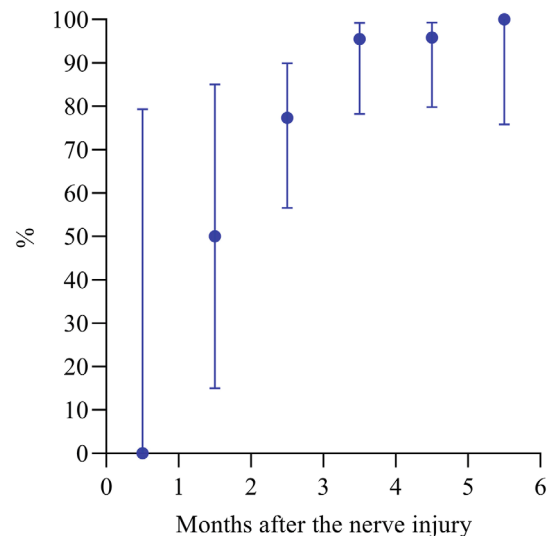


FIGURE 1 Specificity of needle electromyography in radial nerve injury caused by fractures or fracture treatment, stratified by the timing of testing after the nerve injury, with 95% confidence intervals.

nerve injury. In the second quarter, sensitivity was 67% to 75% and specificity 95% to 100%. The 5% increase in specificity from the fourth to the sixth month after the nerve injury must be weighed against the disadvantage of postponing surgery. Although the exact effect of a 2-month delay in surgical nerve reconstruction is currently unknown, multiple case series consequently show that early nerve grafting leads to better results.⁷⁻¹⁰

In three of ten patients with severe RNI, NEMG indicated nerve continuity, emphasizing the relevance of adequate follow-up and clinical judgment. These false-negative test results may be related to needle placement or mixed injuries (Table S1). Sensitivity may be improved and reconstruction delay may be decreased through additional use of nerve ultrasonography.¹⁸

In a previous study (n = 27), Malikowski et al explored the prognostic instead of the diagnostic value of NEMG in patients with traumatic RNI.¹⁹ They concluded that the test is prognostic for spontaneous recovery with a higher discriminative value in the second

TABLE 2 Diagnostic accuracy of NEMG to distinguish between severe and moderate injury of the radial nerve, stratified by the timing of testing after the nerve injury (n = 95)

Timing of testing	Total (n)	Severe RNI (n)		Moderate RNI (n)		Sensitivity		Specificity	
		NEMG ⁺	NEMG ⁻	NEMG ⁺	NEMG ⁻	%	95% CI	%	95% CI
Month 1	1	0	0	1	0	—	—	0.0	0.0-79.3
Month 2	4	0	0	2	2	—	—	50.0	15.0-85.0
Month 3	22	0	0	5	17	—	—	77.3	56.6-89.9
Month 4	26	3	1	1	21	75.0	30.1-95.4	95.5	78.2-99.2
Month 5	27	2	1	1	23	66.7	20.8-93.9	95.8	79.8-99.3
Month 6	15	2	1	0	12	66.7	20.8-93.9	100.0	75.8-100.0

Abbreviations: CI, confidence interval; NEMG⁺, positive needle electromyography test (ie, absence of motor unit potentials in muscles distal to the nerve lesion); NEMG⁻, negative needle electromyography test (ie, presence of motor unit potentials in muscles distal to the nerve lesion); RNI, radial nerve injury.

quarter after the nerve injury as compared with the first quarter, which is in line with our findings.

This study was limited by its retrospective design and wide confidence intervals, and it was too small for subgroup analyses regarding injury location and mechanism. Also, dichotomization of lesion severity is a simplification of the continuous spectrum of these lesions. Furthermore, selection bias may play a role when comparing diagnostic accuracy between the six 1-month intervals because each calculation was done in different patients. Nevertheless, the increasing prevalence of severe RNI over time as observed in this study reflects clinical practice; patients are more likely to be referred to a tertiary center when spontaneous recovery is not observed as time progresses.

In conclusion, NEMG appears to be sufficiently specific for severe RNI from the fourth month onward after traumatic RNI. Electrical nerve discontinuity at this time can be considered an indication to plan surgical nerve exploration, and, if planning surgery takes more than 1 month, a second test in the more immediate preoperative period is advisable as final check. Complementary to NEMG, clinical judgment is essential, and additional modalities like nerve sonography and conduction studies may be valuable in clinical decision-making. In future studies, repeated NEMG examinations in the same patient should be compared, and larger sample sizes can be achieved through multicenter cooperation. This study is a first step toward timely and accurate identification of severe injury, aiming to minimize nerve reconstruction delay while avoiding needless surgery in traumatic RNI.

ETHICAL PUBLICATION STATEMENT

We confirm that we have read the Journal's position on issues involved in ethical publication and affirm that this report is consistent with those guidelines.

AUTHOR CONTRIBUTIONS

Esli D Steenbeek: Conceptualization; data curation; formal analysis; investigation; methodology; project administration; resources; software; validation; visualization; writing – original draft; writing – review and editing. **Willem Pondaag:** Conceptualization; formal analysis; investigation; methodology; resources; validation; writing – review and editing. **Martijn R Tannemaat:** Conceptualization; formal analysis; investigation; methodology; resources; validation; writing – review and editing. **Erik W van Zwet:** Formal analysis; methodology; resources; writing – review and editing. **Martijn JA Malessy:** Conceptualization; investigation; methodology; resources; writing – review and editing. **Justus L Groen:** Conceptualization; formal analysis; investigation; methodology; resources; supervision; validation; writing – review and editing.

CONFLICT OF INTEREST

None of the authors has any conflict of interest to disclose.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

How to cite this article: Steenbeek ED, Pondaag W, Tannemaat MR, Van Zwet EW, Malessy MJA, Groen JL. Optimal timing of needle electromyography to diagnose lesion severity in traumatic radial nerve injury. *Muscle & Nerve*. 2023; 67(4):314-319. doi:[10.1002/mus.27787](https://doi.org/10.1002/mus.27787)