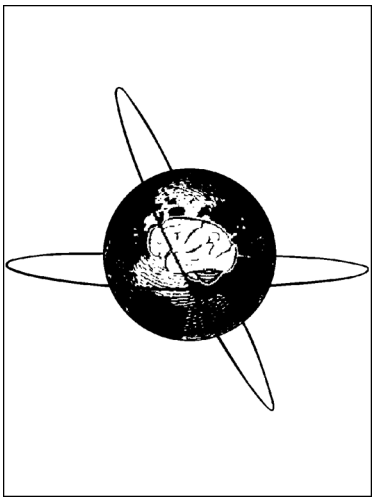

Motor unit number index (MUNIX) in chronic inflammatory demyelinating polyneuropathy: a potential role in monitoring response to intravenous immunoglobulins

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Motor unit number index (MUNIX) in chronic inflammatory demyelinating polyneuropathy: a potential role in monitoring response to intravenous immunoglobulins

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Abstract

Objective: To compare motor unit number index (MUNIX) values in patients with chronic inflammatory demyelinating polyneuropathy (CIDP) and healthy controls, to assess correlations between MUNIX and clinical assessments used in CIDP and to assess short-term changes in MUNIX in CIDP following intravenous immunoglobulins (IVIg).

Methods: MUNIX sum scores were calculated from three muscles in patients and healthy controls. CIDP patients also underwent a series of clinical assessments and completed the Overall Neuropathy Limitations Scale (ONLS) and the Rasch-built Overall-Disability Scale (R-ODS). Repeat assessments were performed in CIDP patients receiving IVIg and CIDP patients not on active treatment.

Results: MUNIX sum scores were significantly lower in CIDP patients than healthy controls (mean values 214.0 *vs* 516.9, respectively; $p<0.001$). MUNIX sum scores correlated with clinical assessment of motor and sensory function and ONLS and R-ODS scores in CIDP patients. Significant short-term improvements were seen in MUNIX values on repeat testing following IVIg (188.3 to 226.4, $p=0.001$), but not in CIDP patients not receiving IVIg.

Conclusions: MUNIX values show stronger correlation with commonly-used clinical assessments and disability scores than other routinely used electrophysiological parameters. Rapid improvements in MUNIX sum scores are seen following IVIg.

Significance: MUNIX sum score may provide an objective marker of response to IVIg.

Highlights

- MUNIX sum scores are lower in chronic inflammatory demyelinating polyneuropathy (CIDP) patients representing a lower number of functional motor units.
- MUNIX sum scores correlate with motor and sensory function and patient disability in CIDP.
- Improvements in MUNIX sum scores can be seen 2 weeks following IVIg therapy in CIDP.

Keywords:

CIDP; MUNIX; IVIg; Monitoring.

1. Introduction

Intravenous immunoglobulins (IVIg) are an effective therapy in chronic inflammatory demyelinating polyneuropathy (CIDP), improving disability and preventing disease relapse (Eftimov et al. 2013). In relapsing CIDP response to IVIg may be biphasic, with an initial rapid response seen within days, followed by a "wearing-off effect" (Harbo et al. 2009; Pollard and Armati 2011) requiring repeat infusions to maintain therapeutic effect in around 65% of patients (Querol et al. 2013). Doses should be given at the maximal interval required to maintain a stable clinical response (Van den Bergh et al. 2010), which may vary from 2 to 6 weeks (Rajabally et al. 2006; Kuitwaard et al. 2013; Lunn et al. 2016; Rajabally and Afzal 2019), possibly reflecting interindividual-variability in pharmacokinetics of IVIg (Kuitwaard et al. 2009, 2013; Rajabally et al. 2013).

Monitoring response to therapy and determining optimal dose interval typically involves a combination of clinical assessments of muscle strength, including Medical Research Council (MRC) grading of muscle strength, grip dynamometry and self-report disability scales, such as the INCAT Overall Disability sum score (Merkies et al. 2010), Overall Neuropathy Limitations Scale (ONLS) (Graham and Hughes, 2006), or the Rasch-built Overall Disability Scale (R-ODS) (van Nes et al. 2011). Potential pitfalls of over-reliance on subjective reports of treatment benefit have been highlighted (Allen and Lewis 2015) and there is ongoing interest in objective markers that may be useful in predicting or monitoring response to therapy in CIDP (Rajabally et al. 2013; Katzberg et al. 2017).

Nerve conduction studies have been used to assess outcomes in clinical trials involving CIDP (Hahn et al. 1996; Hughes et al. 2008). Several studies suggest that changes in proximally-evoked compound muscle action potential (CMAP) amplitude most consistently reflect clinical improvement following therapy (Dyck et al. 1994; Hahn et al. 1996; Ashworth et al. 2000; Bril et al. 2009, 2010; Otto et al. 2017). There is disagreement as to whether use of averaged or aggregate CMAPs (Dyck et al. 1994; Bril et al. 2009) or recording of CMAP from the single most severely affected nerve (Ashworth et al. 2000) is the more reliable method. Reported changes in parameters such as distal motor latency (DML), motor conduction velocity, CMAP area and duration are inconsistent, and new demyelinating electrophysiological features may also develop despite clinical improvement (Vucic et al. 2007; Chin et al. 2015).

Motor unit number index (MUNIX) is a relatively recent neurophysiological method (Nandedkar et al. 2010), which provides measures that reflect the number and size of functioning motor units. MUNIX was initially developed for monitoring disease progression in amyotrophic lateral sclerosis (Neuwirth et al. 2010). Aggregated MUNIX values from three muscles have also been demonstrated to correlate with MRC muscle sum scores and disability scores in CIDP (Delmont et al. 2016). A single study reports improvement in MUNIX recorded from abductor pollicis brevis following 12 weeks of treatment with subcutaneous immunoglobulins compared to placebo in CIDP. Improvement in MUNIX was comparable to averaged proximally evoked CMAPs, but in view of the small sample size involved this finding was interpreted with caution (Otto et al. 2017).

The current study had three aims; 1) To compare MUNIX values in a cohort of patients with CIDP to those to healthy control subjects, 2) To assess correlation between MUNIX values and clinical scores in order to determine the clinical relevance of MUNIX in CIDP and 3) To assess short-term changes in MUNIX values following treatment with IVIg, to ascertain the eventual value of MUNIX in follow-up of patients with CIDP.

2. Methods

2.1 Subjects and timing of assessments

Patients with CIDP attending specialist Inflammatory Neuropathy Clinic at the Queen Elizabeth Hospital, Birmingham, were invited to participate, irrespective of treatment status. Inclusion criteria were age 18-85 years, diagnosis of "definite" or "probable" CIDP as per EFNS/PNS Guidelines (van den Bergh et al., 2010). Thirty-four patients were invited. Eight declined. In addition, 20 healthy controls were recruited.

All patients attended an initial appointment. Patients receiving IVIg therapy were seen 2 to 3 days prior to a planned infusion and had a repeat appointment on average 15 days after the infusion. 5 patients not receiving regular therapy also attended a repeat appointment on average 43 days later. Clinical assessments, electrophysiological and MUNIX studies were performed at both appointments. Healthy controls underwent MUNIX studies only for comparison. These studies were repeated by the same author (AL) 1 month later to assess test intra-rater reliability.

All patients provided written consent for participation and ethical approval was obtained from the NHS Health Research Authority (IRAS no. 206150) as part of an ongoing observational study.

2.2 Clinical assessments

Motor strength was assessed using MRC grading (range 0-5) of shoulder abduction, elbow flexion, wrist extension, finger abduction, hip flexion, knee flexion, ankle dorsiflexion and hallucis dorsiflexion was assessed bilaterally, giving a maximal score possible of 80. Grip strength was assessed using a hand-held Jamar grip dynamometer (Rajabally and Narasimhan 2013). 10-metre timed walking test was used to assess "focal disability" (Collen et al. 1990). ONLS and R-ODS disability scores were collected (Graham and Hughes 2006; van Nes et al. 2011).

Sensory function was assessed using the modified INCAT sensory sum score, incorporating revised assessment of two-point discrimination (Merkies et al. 2000; van Nes et al. 2008). Sensory function was also assessed using a Rydell-Seiffer tuning fork (Martina et al. 1998), calculating a sum score for vibration thresholds at the interphalangeal joint of hallucis, the medial malleolus, the patella, the distal interphalangeal joint of the index finger, the ulnar styloid and the medial epicondyle of the humerus. Maximal possible score was 48, with lower scores corresponding to greater abnormality.

2.3 Electrophysiology

Unilateral nerve conduction studies (NCS) were performed using disposable surface electrodes according to standard protocols (Kumbhare et al. 2016). All studies were performed by the same author (AL). Skin surface temperature was checked prior to testing in all participants and raised to above 32°C in the hands and 30°C in the feet if needed. Antidromic sensory NCS of sural and superficial radial nerves and orthodromic sensory NCS of median and ulnar nerves were performed measuring amplitude and sensory conduction velocity. Median nerve motor NCS were performed recording from abductor pollicis brevis (APB) and stimulating at the wrist, elbow and axilla. Ulnar nerve motor NCS were performed recording from the abductor digiti minimi (ADM) and stimulating at the wrist, below the elbow, above the elbow and axilla. Tibial nerve motor NCS were performed recording from the abductor hallucis (AH) and stimulating posterior to the medial malleolus and popliteal fossa. Peroneal nerve motor NCS were performed recording from the extensor digitorum brevis (EDB) and stimulating at the ankle, below and above the fibular head. For each motor NCS, distal motor latency (DML), onset-to-peak amplitude, negative peak area, negative peak duration, minimum F-wave latency and F-wave persistence were evaluated. Average values for each parameter were calculated by summation then division by the number of nerves from which values could be recorded.

2.4 MUNIX

MUNIX technique was performed according to well-described protocols (Nandedkar et al. 2010). Data were exported to an Excel file designed to calculate MUNIX values. Motor unit size index (MUSIX) was calculated by dividing CMAP amplitude by MUNIX. MUNIX and MUSIX sum scores were calculated unilaterally from APB, ADM and tibialis anterior (TA) muscles. Sum scores have been demonstrated to show better correlation with clinical data (Neuwirth et al. 2010; Delmont et al. 2016; Grimaldi et al. 2017). An active electrode was placed over the muscle belly and a reference electrode was placed over the proximal thumb interphalangeal joint (for ABP), the fifth metacarpal-phalangeal joint (for ADM) and the distal tibia (for TA). Care was taken to ensure the active electrode was placed over the muscle belly when recording from ABP to prevent misleadingly low MUNIX values (Neuwirth et al. 2011a).

2.5 Statistical analysis

Distribution of all variables was assessed using the one-sample Kolmogorov-Smirnov test. Intraclass correlation coefficient (ICC) was used to assess test-retest reliability of MUNIX in healthy controls using a 2-way, mixed effects model looking for absolute agreement. ICC values nearer 1.0 indicate greater similarity between results, with ICC>0.75 indicating excellent reliability (Fleiss et al. 2003). Differences between groups were assessed using independent, two-tailed student t-test for parametric variables and Mann-Whitney U test for nonparametric variables. Changes in variables across repeat appointments were assessed using paired, two-tailed student t-test for parametric variables and Wilcoxon signed ranks test for nonparametric variables. Pearson correlation coefficient was used to assess statistical association between variables. P-values <0.05 were deemed significant. All statistical analysis was performed using IBM SPSS statistical software (version 25).

3. Results

3.1 Demographics

Twenty-six patients were included (5 female; age range 49–79y; mean age 62.5y). Average time between diagnosis of CIDP and enrolment was 61 months. All patients were clinically stable; 15 undergoing regular IVIg therapy at 3 to 6 weekly intervals; 1 receiving subcutaneous immunoglobulins and 10 receiving physiotherapy input only. 20 healthy controls (10 female; age range 29–80y; mean age 44.4y) had MUNIX studies performed for comparison.

3.1 MUNIX and MUSIX values

Repeat MUNIX studies were performed first in healthy controls with a 1-month interval. ICC was 0.85 for MUNIX sum scores and 0.75 for MUSIX sum scores. ICC was higher for MUNIX sum scores than any of the individual muscles, with highest ICC for APB (0.78), then ADM (0.75) and lowest for TA (0.53). Average change between tests was 9.3% for MUNIX sum scores (maximum 21.4%) and 10.1% for MUSIX sum scores (maximum 30.6%).

MUNIX and MUSIX values in CIDP and controls are summarised in **table 1**. MUNIX values were significantly higher in controls than patients with CIDP at baseline and MUSIX values were significantly lower in the control group. No difference was found between MUNIX or MUSIX values in treated versus untreated patients with CIDP at baseline (*p=0.343* and *p=0.947*, respectively).

3.2 Correlations between MUNIX and clinical assessments

Mean (SD) MRC muscle strength sum scores in all CIDP patients was 68.4 (9.7) out of 80 at baseline. Mean grip strength was 25.7kg (12.1) with no significant difference observed between hands. Mean INCAT sensory sumscore was 7.6 (4.4) and vibration threshold sumscore 26.3 (10.7). Mean 10m walk

time was 12.3s (6.0). Mean R-ODS was 54.6 (17.7) and median ONLS was 4.5. Vibration threshold sum scores were higher in untreated than treated CIDP patients at baseline (mean value 33.4 *vs* 23.9, respectively; *p=0.42*). No significant differences were seen in any of the other assessments.

In CIDP patients at baseline positive linear correlation was observed between MUNIX sum scores and MRC sum score (r=0.696, *p<0.001*), hand grip strength (r=0.412, *p=0.037*), vibration threshold sum score (r=0.618, *p=0.001*) and R-ODS (r=0.480, *p=0.013*). Negative linear correlation was observed in CIDP patients between MUNIX and MUSIX sum scores (r=-0.439, *p=0.025*), INCAT sensory sum score (r=-0.598, *p=0.001*) and ONLS (r=-0.607, *p=0.001*) (see **figure 1**). No significant correlation was observed between MUNIX sum scores and patient age or time since diagnosis. Positive linear correlation was observed between MUSIX sum scores and patient age (r=0.419, *p=0.033*) but none of the other variables.

MRC muscle strength sum scores correlated with distal CMAP area (r=0.593, *p=0.007*). R-ODS also correlated with distal CMAP area (r=0.472, *p=0.041*). No significant correlations were observed with any of the other electrophysiological parameters. INCAT sensory sumscore and vibration threshold sum scores correlated with sensory nerve conduction velocity (r=-0.630, *p=0.003* and r=0.622, *p=0.003*, respectively) but not sensory nerve action potential amplitude.

3.3 Changes following IVIg therapy

Repeat assessments were performed in 15 patients immediately before IVIg therapy and on average 15 days after IVIg infusion. Significant improvements were seen in MRC muscle strength sum scores (mean value 67.5 to 69.4, *p=0.033*) and 10m walk time (mean value 13.2s to 11.4s, *p=0.044*). There was no statistically significant change in R-ODS, in keeping with recruitment of patients established on IVIg therapy (mean R-ODS 53.3 before IVIg and 55.2 after IVIg, *p=0.085*). In comparison, a small improvement in 10m walk time was found in 5 untreated patients participating in ongoing physiotherapy between appointments (mean value 9.7s to 9.3s, *p=0.017*), but no improvement was observed in other clinical assessments in this group.

Significant improvements were seen in MUNIX sum scores (mean value 188.3 to 226.4, *p=0.001*) but not MUSIX sum scores (mean value 266.5 to 253.5, *p=0.312*) following IVIg therapy. There was no significant change in MUNIX sum scores on repeat assessment in untreated patients (see **figure 2**).

In addition to MUNIX sum scores, small but significant improvement was seen following IVIg therapy in DML (median value 6.4 to 6.1, *p=0.036*), amplitude of the distal-evoked CMAP (median value 5.0 to 5.7, *p=0.035*) and duration of the proximal-evoked CMAP (median value 8.7 to 7.5, *p=0.041*). No significant changes were seen in any of the other electrophysiological parameters.

4. Discussion

MUNIX values for individual muscles and MUNIX sum scores were significantly lower in patients than controls. Normal values and intra-rater reliability calculated in control subjects were similar to previous reports (Ahn et al. 2010; Nandedkar et al. 2010; Neuwirth et al. 2011b, 2011a; Delmont et al. 2016). High test-retest reliability of MUNIX sum scores is demonstrated in control subjects, suggesting this is a valid method for measuring changes in motor unit function over time. Use of MUNIX sum scores improved test-retest reliability over reliance on a single muscle. We observed lowest reliability when recording from TA, which may result from placement of the reference electrode, other authors utilising placement over the patella tendon (Neuwirth et al. 2011b).

MUNIX sum scores correlate with clinical measures of motor function and disability scores in patients with CIDP. These findings are similar to previous reports (Delmont et al. 2016). In addition, we found

correlation between MUNIX sum scores and clinical measures of sensory function. MUNIX sum scores showed stronger correlation with clinical data than any of the other electrophysiological parameters. MUNIX values reflect the number of functioning motor units and it is therefore intuitive that patients with lower MUNIX values would present with greater weakness and higher perceived level of disability. Whilst not directly assessing sensory nerve function, the correlation between MUNIX sum scores and clinical measures of sensory function is likely to reflect overall disease severity. Such associations have been found previously with levels of sensory dysfunction in CIDP (Rajabally and Narasimhan 2010).

Short-term improvement was seen in MUNIX sum scores comparing studies performed immediately before and 2 weeks following IVIg therapy. Conversely, no significant change in MUNIX sum scores was seen on repeat testing in a small group of untreated patients. In contrast to previous studies, we saw no significant change in proximally-evoked CMAP amplitude. A small improvement in muscle strength was also observed and mean values in self-reported disability were higher following IVIg therapy, but failed to reach statistical significance. This was despite recruitment of clinically stable patients, reflecting the well-reported "wearing off effect" of IVIg therapy observed in CIDP (Pollard and Armati 2011). Previous authors have suggested a minimum clinically relevant change in MUNIX sum scores of 50% in CIDP (Delmont et al. 2016), based on the maximum variation seen in stable patients receiving IVIg therapy. The maximum change in MUNIX sum scores we observed on repeat testing in controls was 21.4% and in untreated patients (albeit in a small cohort) was 32.9%. This suggests a smaller change in MUNIX sumscores may be clinically relevant, although this study was not designed to determine minimum clinically significant changes.

Lower MUNIX values observed in CIDP have been attributed to chronic axonal loss (Paramanathan et al. 2016). We observed higher MUSIX values than in controls, suggesting motor unit remodelling related to chronic axonal loss in our patients. However, the improvement in MUNIX values following IVIg appears too rapid to be explained by axonal regeneration or even nerve remyelination. Similar observations have been made regarding functional improvements following IVIg therapy in CIDP (Berger et al. 2013). Nerve excitability studies in CIDP suggest disruption of nodal sodium-channel function and resulting hyperpolarisation may interfere with nerve conduction and cause block (Cappelen-Smith et al. 2000, 2001; Boerio et al. 2010; Lin et al. 2011). Elevated thresholds on nerve excitability studies have also been demonstrated in CIDP patients with and without conduction block compared to healthy controls, possibly related to changes in the paranodal region (Garg et al. 2019). Although autoantibodies are only identified in a minority of patients (Devaux et al. 2016), it is hypothesized that IVIg competes with functionally important autoantibodies, producing rapid although reversible improvement in nodal function (Boerio et al. 2010; Berger et al. 2013). It is possible the observed improvements in MUNIX values result from functional axonal recovery due to improved nodal function after IVIg therapy. Given that motor unit size relates to motor unit remodelling in association with gradual, chronic axonal loss, it is unsurprising that no significant change in MUSIX values was observed on repeat testing over a short interval. However, a large improvement in MUSIX values was observed in a single patient. This patient had one of the lowest MUNIX values in the study cohort and although it is difficult to make hypotheses based on a single observation, it is possible the increase in MUSIX reflected presence of large motor units that were "non-functioning" at the time of assessment prior to IVIg therapy.

5. Conclusion

Our study confirms that MUNIX sum scores correlate with measures of motor function and disability levels in patients with CIDP. We were also able to demonstrate correlations with sensory function. None of the other assessed electrophysiological parameters demonstrated these correlations. In

addition, improvement in MUNIX values is demonstrated two weeks after IVIg therapy in clinically-stable patients on long-term treatment. This new finding suggests a potential role for MUNIX sum scores as an objective marker of response to IVIg therapy. IVIg availability and cost issues are of paramount importance in CIDP treatment and the limitations of motor and disability scores as sole monitoring tools are real and concerning in long-term patients in whom placebo effects are not uncommon.

Future larger-scale studies in newly-diagnosed, treatment-naïve patients are needed to explore this role further, particularly to compare responses in responders and non-responders and to help establish values for minimum clinically relevant changes.

Conflict of Interest

AL and SS have no disclosures.

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Legends

Fig. 1. Linear regression between MUNIX sumscores and (a) Rasch-built overall disability score, R^2=0.23, Pearson correlation coefficient 0.48 (*p=0.013*), (b) Overall neuropathy limitations scale, R^2=0.37, Pearson correlation coefficient -0.61 (*p=0.001*), (c) MRC muscle strength sumscores, R^2=0.49, Pearson correlation coefficient 0.70 (*p<0.001*), (d) Grip strength assessed using a Jamar-grip dynamometer, R^2=0.17, Pearson correlation coefficient 0.41 (*p=0.037*), (e) INCAT sensory sumscore, R^2=0.36, Pearson correlation coefficient 0.60 (*p=0.001*), (f) Vibration threshold sumscore assessed using a Rydell-Seiffer tuning fork, R^2=0.38, Pearson correlation coefficient 0.62 (*p=0.001*). Graph shows best-fit line and 95% confidence band of best-fit line.

Fig. 2. Scatterplots demonstrating changes in MUNIX and MUSIX sumscores between repeat appointments in CIDP patients receiving regular IVIg infusions (*n=15*) and patients not receiving active treatment (*n=5*). Changes in values within patient groups assessed using paired, 2-tail student t-test.

Table 1.
MUNIX and MUSIX values in controls and CIDP patients.

	Controls (*n=20*)	CIDP (*n=26*)	*p-values*
MUNIX APB	195.8 (50.0)	94.3 (59.6)	*p<0.001*
MUSIX APB	65.0 (19.8)	92.8 (46.5)	*p=0.010*
MUNIX ADM	176.1 (40.5)	73.4 (49.0)	*p<0.001*
MUSIX ADM	66.5 (14.0)	105.8 (59.3)	*p=0.003*
MUNIX TA	145.1 (36.8)	46.3 (41.7)	*p<0.001*
MUSIX TA	47.0 (6.5)	61.5 (29.2)	*p=0.030*
MUNIX sumscore	516.9 (91.4)	214.0 (124.4)	*p<0.001*
MUSIX sumscore	178.5 (32.2)	251.2 (96.2)	*p=0.001*

Results are presented as mean values with standard deviations in brackets.
p-values are displayed for comparison of controls and CIDP patients using the independent, 2-tail student t-test.