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Letter to the Editor

MUNIX value dependence on surface electromyogram properties

Bostock et al. (2019) postulate that MUNIX does not provide more information in patients with neuromuscular disorders, particularly amyotrophic lateral sclerosis (ALS) than the sole measure of the CMAP. Thus, the analysis of the relation between area and power of surface recorded EMG signal (SIP) obtained at different levels of muscle contraction, which is part of the MUNIX calculation, would be completely irrelevant. The authors base their statement on three different lines of reasoning. I would like to make some comments about two of them.

Bostock et al. (2019) find that the "form factor" (G) - i.e. the quotient SIP RMS/SIP mean - that corresponds to a SIP mean of 20 μV ($G_{SIP(20\ \mu V)}$) has approximately the same value in all healthy controls. According to the authors, since the form factor (G) carries the information proportioned by SIP signals in the calculation of MUNIX (the other source is the CMAP), the constancy of $G_{SIP(20\ \mu V)}$ implies that the MUNIX value depends solely on the CMAP value. Nevertheless, $G_{SIP(20\ \mu V)}$ seems constant only in healthy controls but it is notably variable in ALS patients. In fact, as is pointed out by the authors, there is a non-linear trend for $G_{SIP(20\ \mu V)}$ to be higher for smaller CMAPs, both in controls and patients. Contrary to the interpretation of Bostock and co-workers (Bostock et al., 2019), this trend would show that SIPs really convey information about motor unit physiology. Moreover, in contrast to the great range of CMAP amplitudes in healthy subjects (from about 5 mV to 12 mV), $G_{SIP(20\ \mu V)}$ had much less variability. This would reinforce the idea that examining the relationship between SIP RMS and SIP mean aids in determining that the muscle explored is normal.

The article of Bostock et al. (2019) also shows that there is a power relationship between SIP RMS and SIP mean, both in controls and patients, because a straight line could be fitted to the log–log plot of these variables.

Thus,

$$\mathrm{SIP\ RMS} = \mathrm{C} \cdot \mathrm{SIP\ mean}^{\gamma} \tag{1}$$

being C a constant and γ the slope of the straight line fitted to the log–log plot.

This is consistent with my own result (Miralles, 2018) that there is a power relationship between SIP power and SIP area

$$\mathrm{SIP\ power} = \mathrm{B} \cdot \mathrm{SIP\ area}^{\beta} \tag{2}$$

The Eqs. (1) and (2) are related through the following equalities:

$$\mathrm{C} = \sqrt{\mathrm{B}} \cdot \mathrm{RT}^{\frac{\beta-1}{2}} \tag{3}$$

$$\gamma = \frac{\beta}{2} \tag{4}$$

being "RT" the length of time of the SIPs.

The value of γ found by Bostock and co-workers (Bostock et al., 2019) for controls was 0.971, which is very similar to the β value found by myself (1.88) divided by 2 (Miralles, 2018).

From Eq. (1) is clear that G is also related to SIP mean through a power function

$$\mathrm{G} = \mathrm{C} \cdot \mathrm{SIP\ mean}^{\gamma-1} \tag{5}$$

since $\gamma < 1$, Eq. (5) describes a decreasing power function.

The $G_{SIP(20\ \mu V)}$ of ALS patients was overall greater that of controls. According with the properties of power functions and the value of SIP mean at witch $G_{SIP(20\ \mu V)}$ is defined, this finding probably indicate that the value of the exponent γ (and, therefore, that of β exponent) is lower in ALS patients than in controls. This would be in agreement with previous observations in ALS patients (Nandedkar et al., 2010) and with my own results that showed that patients with motor carpal tunnel syndrome had a lower β than controls (Miralles, 2018). These findings reinforce the idea that the analysis of SIPs is relevant for the calculation and interpretation of MUNIX.

The second line of reasoning presented by Bostock et al. (2019) against the value of MUNIX consisted in arguing that since multiplying SIPs by a factor (for example, two) while keeping the CMAP amplitude unchanged did not suppose an equivalent change in MUNIX, this index is insensitive to changes in SIP amplitude. Nevertheless, the comportment observed by the authors when the CMAP or the SIPs are multiplied by a factor while the other signal is not modified is exactly what can be expected from the definition of the "ideal case motor unit count" (ICMUC) (Nandedkar et al., 2010) and the power relationship existing between SIP power and SIP area (Eq. (2)).

The ICMUC can be re-written (Miralles, 2018) as

$$\mathrm{ICMUC} = \frac{\mathit{CMAP\ power}}{\mathit{CMAP\ area}} \cdot \frac{1}{B} \cdot \mathrm{SIP\ area}^{1-\beta} \tag{6}$$

MUNIX is the ICMUC value when the SIP area for a 1 second epoch is 20 mV ms.

When a CMAP signal is multiplied by f, CMAP power is multiplied by f^2, CMAP area by f and the ratio (CMAP power/CMAP area) also by f. Nevertheless, when SIPs signals are multiplied by a factor, the power function that relates SIP power with SIP area (Eq. (2)) does not change. In other words, B and β are the same before and after changing the amplitude of SIPs signals. This explains why when CMAP is multiplied by f, MUNIX is also multiplied by f whereas the same operation on SIPs signals left the MUNIX value unchanged. Thus, the results on MUNIX of the simple multiplication of CMAP or SIPs signals should be not considered as a proof that MUNIX only depends on CMAP.

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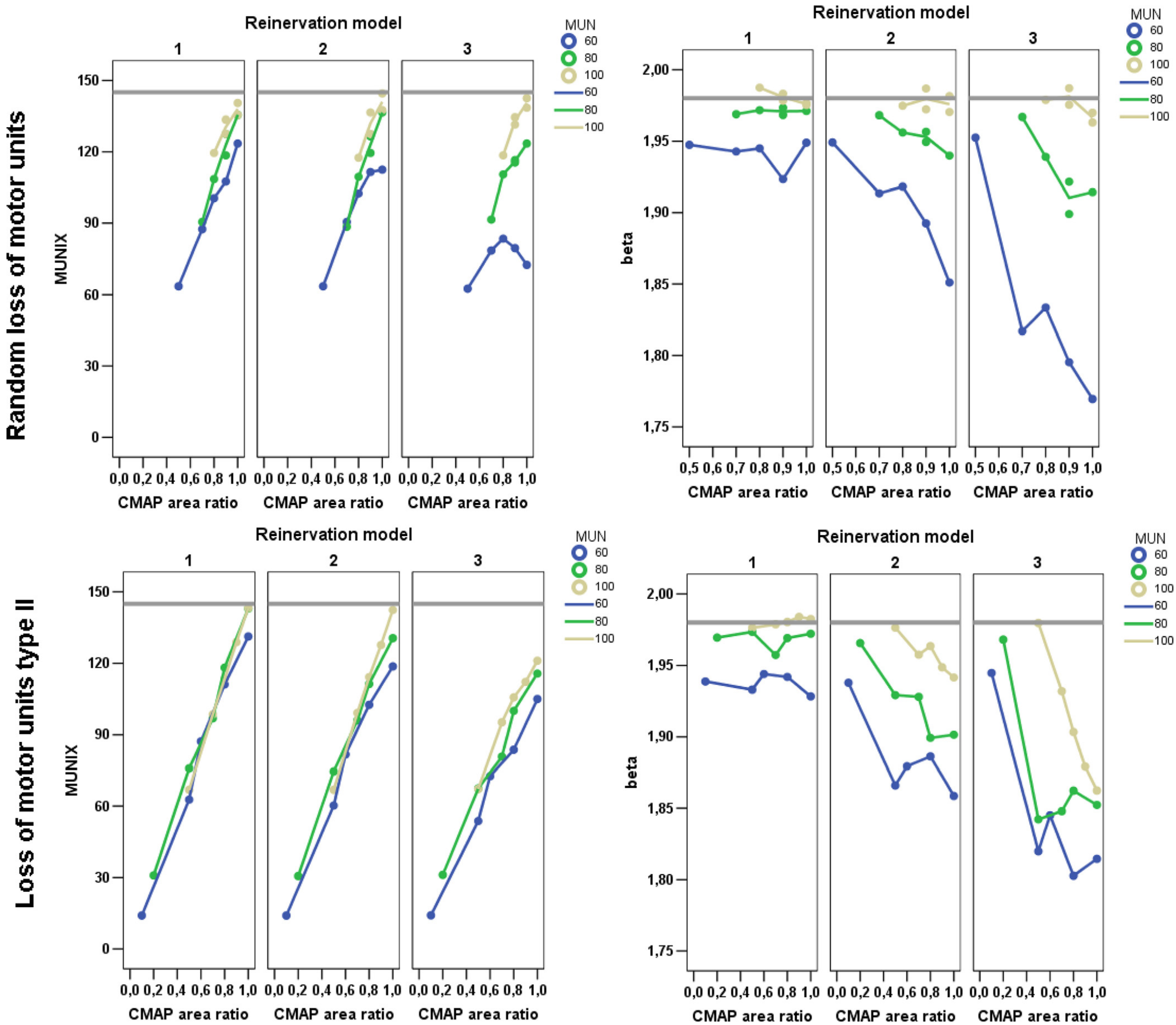

Fig. 1. β and MUNIX values depending on CMAP area predicted by a computer model of surface EMG generated by a muscle that has suffered (*A*) a random loss of motor units (MUs), and (*B*) an ordered loss of motor units beginning with the MU of greatest amplitude. Reinnervation models correspond to (1) an enlargement of the surviving MUs proportional to their normal amplitude, (2) an equal increase in amplitude for all remnant MUs, and (3) an enlargement of the surviving MUs inversely proportional to their normal amplitude. CMAP area ratio, which was calculated with respect to the normal CMAP area, indicates the efficacy of the reinnervation process: a value of 1 means that the reinnervation process has restored the CMAP area to its normal value. MUN means "Motor Unit Number". Normal MUN was 120. Gray bars indicate the value of β and MUNIX when MUN was 120.

The effects on MUNIX of changes in number or amplitude of motor units are better addressed through the use of mathematical models of surface EMG generation. The predictions of one of such models (Li et al., 2012) were that the relationship between the MUNIX value and the number of remnant motor units in a muscle that has been suffered a denervation and reinnervation process depend both on the type of loss of motor units and on the mechanism of reinnervation (Fig. 1) (Miralles, 2018). MUNIX was theoretically able to detect a loss of motor units even when the reinnervation process was so effective as to restore the CMAP area and power to its normal value (Fig. 1). This fact was due to the reduction in the value of β caused by the change in the amplitude distribution of motor units (Miralles, 2018).

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Francesc Miralles
Gabinet d'Electrodiagnòstic, Servei de Neurologia. Hospital Univesitari Son Espases, Carretera de Valldemossa, 79, 07010 Palma de Mallorca, Illes Balears, Spain
E-mail address: francesc.miralles@ssib.es

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