A morphological analysis of the macro motor unit potential

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Abstract

The technique of macro EMG is used to investigate the motor unit architecture in a number of pathological conditions. Amplitude and area are the most commonly used criteria, but these parameters alone are not sufficient to assess the complexity of the macro MUP morphology. In an attempt to examine the morphology of the macro MUP in more detail, additional measures were investigated including, (i) average power, (ii) duration, and (iii) number of phases. Macro MUP duration was defined as the time parameter that contains a particular fraction (90%) of the total power of the potential. The above mentioned parameters were evaluated for normal subjects and for patients suffering with motor neuron disease (MND), spinal muscular atrophy (SMA), and Becker’s muscular dystrophy (BMD). It is shown that high amplitude and average power macro MUPs give shorter macro MUP duration than macro MUPs with normal amplitude. In contrast, in low amplitude macro MUPs there is a tendency towards a higher duration measure, as compared with the duration of the normal amplitude macro MUPs. Also, t-test results for the duration measure gave a significant difference between the NOR–MND, and no significant difference between the NOR–BMD and NOR–SMA groups at P<0.05. Significant difference between the NOR and the three disease groups investigated was obtained for the parameters log amplitude, log area, and log average power. The number of phases was not significantly different between the NOR and the rest of the groups. In conclusion, the average power and duration parameters can possibly be used as additional discriminators to detect abnormalities of the macro motor unit potential in both needle and surface EMG but further investigation is necessary. © 2000 IPEM. Published by Elsevier Science Ltd. All rights reserved.

Keywords: Quantitative EMG; Macro motor unit potential

1. Introduction

The introduction of the macro EMG technique in neuropsychology [1,2] has provided additional information to the assessment of patients with neuromuscular diseases [3–7]. The information gained with macro EMG findings, related to motor unit size, helps to evaluate with a greater certainty the observations made by conventional concentric needle EMG (CNEMG) and single fibre EMG (SFEMG). Equally, knowledge of SFEMG findings such as the fibre density (FD) may help the interpretation of the macro EMG results [8]. Furthermore, the significance of surface detected macro MUP’s has recently been demonstrated as a useful source of motor unit size information [9], where motor unit number estimation [10] has been related to the level of muscle activity [11]. According to Stashuk [12], the combination of macro EMG with CNEMG findings and/or firing pattern information may provide new clinical insights.

Amplitude and area are the most commonly used criteria to assess the macro MUP waveform. However, these parameters alone are not sufficient to assess the complexity of the macro MUP morphology. The use of signal representation basis vectors to reduce the dimensionality of the macro MUP was applied successfully by Nandedkar et al. [13]. However, this method is computationally demanding and the parameters estimated are rather difficult to interpret by the physician. In the present study, in an attempt to examine the morphology of the macro MUP in more detail, additional parameters that can easily be computed were introduced including, (i) average power, (ii) duration, and (iii) number of phases. Macro MUP duration was defined as the time...
measure that contains a particular fraction (90%) of the total power of the potential.

2. Materials and methods

From the biceps brachii muscle, eight hundred and twenty macro MUPs (20 macro MUPs per subject) were recorded from nine subjects with motor neuron disease (MND), 11 subjects with spinal muscular atrophy (SMA), 14 subjects with Becker’s muscular dystrophy (BMD) and seven normals (NOR). Diagnostic criteria were based on clinical opinion and muscle biopsy findings in the SMA and BMD groups. The length of history was not used as an inclusion criterion. The macro MUP analysis algorithm is described below.

2.1. Step 1 Acquire macro MUP

The macro electrode was introduced perpendicular to the muscle fibre direction and 20–30 mm away from the end-plate zone. An epoch of 80 ms was acquired and the signal was averaged for 256 times as documented by Stalberg [1] and Stalberg and Fawcett [2]. The macro EMG signal was bandpass filtered at 8 Hz to 8 kHz. The signal was sampled at 2.5 kHz, giving a time resolution of \(400 \text{ ms} \) and the analogue to digital converter amplitude resolution was 10 bits. A sampling rate of 2.5 kHz, does not satisfy the Nyquist criterion for the filter bandwidth. This can give rise to potential errors due to aliasing of high frequency components. The combined effects of a large area recording electrode and signal averaging results in a signal with a relatively small proportion of aliased components which will not cause significant errors in the analysis methods used in this study. More specifically, the measures computed were amplitude, area, average power, duration and phases (see Steps 3 to 5). Consider the duration parameter which varies from 5 to 45 ms. Given that most of the potentials are biphasic, it can be assumed that their period varies from 5 to 45 ms, with their equivalent frequencies being 200 Hz to 22.2 Hz. Therefore, a sampling frequency of 2.5 kHz is well above the highest frequency required to be captured.

2.2. Step 2 Apply conventional baseline correction

From the total 80 ms acquired epoch, the first and last 5 ms were dropped to avoid artifacts. The baseline of the potential was firstly taken to be the average of the first and last 10 ms windows of the remaining 70 ms epoch. The baseline value was subtracted from the 50 ms macro MUP. The average value of the baseline beginning and ending 10 ms, ABB and ABE are given by

\[
\text{ABB} = \frac{\sum_{i=N_5}^{N_{15}-1} u_i}{N_{15} - N_5} \quad \text{and} \quad \text{ABE} = \frac{\sum_{i=N_{65}}^{N_{75}-1} u_i}{N_{75} - N_{65}}
\]  

where \( u_i \) is the magnitude of a sample in the macro MUP signal, and \( N_5, N_{15}, N_{65} \) and \( N_{75} \) are the sample numbers at 5, 15, 65, and 75 ms respectively. The average value of baseline, \( B \) is \((\text{ABB} + \text{ABE})/2\). The macro MUP conventional correction is described by

\[
x_i = u_i - B \quad i = N_{15}, N_{15} + 1, \ldots, N_{65} - 1
\]

2.3. Step 3 Compute amplitude and average power

2.3.1. Amplitude

Amplitude (amp) was defined as the difference between the minimum positive peak and the maximum negative peak.

2.3.2. Power

The power content of the macro MUP waveform was found by adding the square of each sample over the 50 ms epoch.

\[
\text{Power} = \sum_{i=N_{15}}^{N_{65}-1} x_i^2
\]

2.3.3. Average power

The average power (avpower) is the ratio of power and the total number of samples in the epoch, multiplied by the sampling interval, \( T \). It is measured in \( \mu\text{V}^2\text{ms} \).

\[
\text{Average Power} = T \frac{\text{Power}}{N_{65} - N_{15}}
\]

The average power has been multiplied by the sampling interval, measured in \( \mu\text{V}^2\text{ms} \).

2.4. Step 4 Compute power integral curve (PIC)

The cumulative power content of the \( n \)th sample of the macro MUP signal is given by

\[
\text{PC}_n = \sum_{i=N_{15}}^{n} x_i^2 \quad n = N_{15}, N_{15} + 1, \ldots, N_{65} - 1
\]

2.5. Step 4.1 Compute uncorrected duration measure

The uncorrected duration (udur) measure was worked out from the power integral curve of the macro
The 50% power point was determined. Working backwards and forwards the 5% and 95% power points were determined respectively. These points were assigned to be the “uncorrected beginning” and “uncorrected ending” points of the macro MUP. The difference between these two points, was defined to be the uncorrected macro MUP duration (dur) measure.

2.6. Step 5 Apply power integral curve correction

The power integral curve of the 70 ms conventionally corrected macro MUP (Eq. (2)) was determined as given by Eq. (5). Also, the average power content of the first and last 10 ms of the 70 ms conventionally corrected macro MUP was estimated. The macro MUP power integral curve was corrected by subtracting the cumulative average power content of the 10 ms windows from the conventionally corrected macro MUP power integral curve. The average power value of the baseline beginning and ending 10 ms, MUPBB and MUPBE are given by

$$\text{MMUPBB} = \frac{\sum_{i=N_{15}}^{N_{75}-1} x_i^2}{N_{15}-N_{5}}$$

$$\text{MMUPBE} = \frac{\sum_{i=N_{65}}^{N_{75}-1} x_i^2}{N_{75}-N_{65}}$$

(6)

The average power value of baseline is

$$\text{BP} = \frac{\text{MMUPBB} + \text{MMUPBE}}{2}.$$  

2.7. Step 5.1 Compute (corrected) duration measure bounded by 90% fraction of the total power

2.7.1. Duration

The duration (dur) measure was worked out from the corrected power integral curve of the macro MUP, as it is given in Eq. (7). The 50% power point was determined. Working backwards and forwards the 5% and 95% power points were determined respectively. These points were assigned to be the “beginning” and “ending” points of the macro MUP, $N_{DB}$ and $N_{DE}$ respectively. The difference between these two points, were defined to be the macro MUP duration measure.

2.8. Step 5.2 Compute area and phases bounded by the duration measure

2.8.1. Area

Area was computed as the sum of the rectified signal over the duration measure.

$$\text{Area} = T \sum_{i=N_{DB}}^{N_{DE}} |x_i|$$

(8)

2.8.2. Phases

Phases indicated the number of baseline crossings plus one. A phase criterion empirically determined was applied for each baseline crossing. A phase was counted if its power content was more than 10% of the power of the power integral corrected macro MUP. The number of phases was determined for the fraction of the macro MUP contained in the duration measure. Therefore, the parameters extracted from each macro MUP were the following: amplitude, area, average power, uncorrected duration, duration, and phases.

2.9. Step 6 plot the macro MUP and display its parameters

The macro MUP waveform and its parameters were displayed on the screen. Twenty macro MUPs per muscle were collected for each study and analyzed following the above algorithm.

How the above correction algorithm works is illustrated in the macro MUP of Fig. 1. The sweep is 80 ms and its peak to peak amplitude is 35 $\mu$V. Notice the abrupt beginning and ending parts of the macro MUP, as well as its complex shape. The macro MUP was firstly baseline corrected in the conventional way (Eqs. (1) and (2)). Then the power integral of the macro MUP was computed as is shown by the solid line in Fig. 1(b) (Eq. (5)). The cumulative average power contribution of the beginning and ending 10 ms windows was also plotted, shown by the hatched line of Fig. 1(b) (Eq. (6)). The difference between the power integral curve of the macro MUP (Eq. (5)) and the beginning and ending windows average power line (the slope of which is given by BP), gives the corrected macro MUP power integral curve (Fig. 1(c)). Once the macro MUP has been corrected, then the power related measures, i.e. duration, area bounded by duration and phases can be determined.

3. Results

Summary statistics of the macro MUP parameters amplitude, area, average power, uncorrected duration, duration and phases for each group studied are given in Table 1. The mean, median, standard deviation (S.D.), lower quartile ($Q_1$), upper quartile ($Q_3$), and the semi-interquartile range ($\text{SIQR} = (Q_3 - Q_1)/2$) are given for the NOR, MND, BMD and SMA groups.

The mean values of the macro MUP parameters for the MND, BMD and SMA groups are compared with
their respective mean NOR values. The $t$-test results for the above analysis are tabulated in Table 2. Also, correlation analysis was carried out in order to investigate the interrelations among the macro MUP parameters studied as given in Table 3. The parameters used were log amplitude, log area, log average power, uncorrected duration, duration and number of phases. Taking logarithms of the macro MUP parameters amplitude, area, and average power, transforms their frequency distribution closer to Gaussian. The amplitude is highly correlated to the area and the power of the macro MUP. The uncorrected duration measure is moderately correlated to amplitude. However, there is a low correlation between the amplitude and duration.

The macro MUP evaluation technique described by Stalberg and Fawcett [2] classifies a macro EMG study as normal or abnormal based on the amplitude parameter only. The percentage of correct classifications score (\%CCs) of this technique applied on the NOR, MND and BMD groups is 100, 89 and 21\% respectively. The overall \%CCs of this technique is 70\%. It can be easily concluded that the macro MUP amplitude feature alone is not in a position to differentiate between the normal and pathological motor unit. This is worst in the case of the BMD group. Other methods of data classification taking into consideration the macro MUP parameters amplitude, area, average power and duration like artificial neural networks (ANN) have to be investigated. These methods can classify a subject as belonging to either the NOR, or the MND, or the BMD, or the SMA group. ANN models using the supervised learning backpropagation algorithm [14] and the unsupervised learning self-organised feature maps algorithm [15,16] were developed to classify the macro EMG data presented in this study. Thirty of the subjects were used for training the models and 13 of the subjects for testing their diagnostic performance. The diagnostic performance of these models, i.e. \%CCs score for the NOR, MND, BMD, and SMA groups was 86, 100, 93, and 83\% respectively. The overall \%CCs of the ANN models was 90\%.

4. Discussion

4.1. Duration

The duration measure of the macro MUP has been one of the most difficult parameters to identify. This is due to the fact that the macro MUP waveform has no consistent shape or pattern. Also, it has not been documented in the literature how such a parameter could be measured and how it could be correlated physiologically. Given the above, an attempt has been made to identify such a measure. The most efficient way we came across was to relate the duration measure of the macro MUP with a certain fraction of the power content of the macro MUP waveform. After the conventional baseline correction algorithm was applied, the power content of the first and last 10 ms should have been zero, or very small. This would suggest no activity outside the central 50 ms waveform. However, this is not the case. Electrical activity is present and this could be attributed to asynchronous activity from other motor units whose territories overlap the recording volume of the macro electrode. Taking a typical motor unit territory for the biceps muscle of 5–10 mm [4,17,18] and typical fibre densities for the same muscle [3], at least 10–15 units can be expected to contribute to the macro MUP signal at full
Table 1
Macro MUP parameter statistics for the NOR, MND, BMD, and SMA groups

<table>
<thead>
<tr>
<th></th>
<th>amp μV</th>
<th>area μVms</th>
<th>avpower μV²ms</th>
<th>ucdur ms</th>
<th>dur ms</th>
<th>phases</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>NOR</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>171</td>
<td>601</td>
<td>444</td>
<td>19.8</td>
<td>17.1</td>
<td>3.0</td>
</tr>
<tr>
<td>Median</td>
<td>140</td>
<td>491</td>
<td>211</td>
<td>18.8</td>
<td>16.4</td>
<td>2.0</td>
</tr>
<tr>
<td>S.D.</td>
<td>122</td>
<td>379</td>
<td>654</td>
<td>8.0</td>
<td>7.0</td>
<td>0.6</td>
</tr>
<tr>
<td>Q₁</td>
<td>82</td>
<td>327</td>
<td>88</td>
<td>14.0</td>
<td>11.6</td>
<td>2.0</td>
</tr>
<tr>
<td>Q₃</td>
<td>200</td>
<td>778</td>
<td>429</td>
<td>25.2</td>
<td>21.2</td>
<td>3.0</td>
</tr>
<tr>
<td>SIQR</td>
<td>59</td>
<td>225</td>
<td>170</td>
<td>5.6</td>
<td>4.8</td>
<td>0.5</td>
</tr>
<tr>
<td><strong>MND</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>652</td>
<td>1720</td>
<td>5957</td>
<td>12.4</td>
<td>11.5</td>
<td>2.2</td>
</tr>
<tr>
<td>Median</td>
<td>429</td>
<td>1331</td>
<td>1719</td>
<td>11.6</td>
<td>10.8</td>
<td>2.0</td>
</tr>
<tr>
<td>S.D.</td>
<td>570</td>
<td>1367</td>
<td>11440</td>
<td>5.2</td>
<td>4.7</td>
<td>0.6</td>
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<tr>
<td>Q₁</td>
<td>285</td>
<td>752</td>
<td>673</td>
<td>9.6</td>
<td>8.8</td>
<td>2.0</td>
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<td>Q₃</td>
<td>834</td>
<td>2257</td>
<td>5618</td>
<td>13.6</td>
<td>13.2</td>
<td>3.0</td>
</tr>
<tr>
<td>SIQR</td>
<td>224</td>
<td>1252</td>
<td>2472</td>
<td>2.0</td>
<td>2.2</td>
<td>0.5</td>
</tr>
<tr>
<td><strong>BMD</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>88</td>
<td>334</td>
<td>111</td>
<td>23.2</td>
<td>16.8</td>
<td>2.3</td>
</tr>
<tr>
<td>Median</td>
<td>77</td>
<td>288</td>
<td>143</td>
<td>22.0</td>
<td>16.0</td>
<td>2.0</td>
</tr>
<tr>
<td>S.D.</td>
<td>57</td>
<td>206</td>
<td>62</td>
<td>9.2</td>
<td>8.6</td>
<td>0.6</td>
</tr>
<tr>
<td>Q₁</td>
<td>51</td>
<td>190</td>
<td>29</td>
<td>16.0</td>
<td>10.8</td>
<td>2.0</td>
</tr>
<tr>
<td>Q₃</td>
<td>107</td>
<td>444</td>
<td>145</td>
<td>29.6</td>
<td>21.2</td>
<td>3.0</td>
</tr>
<tr>
<td>SIQR</td>
<td>28</td>
<td>126</td>
<td>58</td>
<td>6.8</td>
<td>5.2</td>
<td>0.5</td>
</tr>
<tr>
<td><strong>SMA</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>397</td>
<td>1347</td>
<td>4976</td>
<td>20.1</td>
<td>16.3</td>
<td>2.4</td>
</tr>
<tr>
<td>Median</td>
<td>191</td>
<td>730</td>
<td>393</td>
<td>18.0</td>
<td>15.2</td>
<td>2.0</td>
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<tr>
<td>S.D.</td>
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<td>1744</td>
<td>16581</td>
<td>8.4</td>
<td>7.0</td>
<td>0.6</td>
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<tr>
<td>Q₁</td>
<td>99</td>
<td>3331</td>
<td>97</td>
<td>14.4</td>
<td>11.6</td>
<td>2.0</td>
</tr>
<tr>
<td>Q₃</td>
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<td>1667</td>
<td>2120</td>
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<td>20.4</td>
<td>3.0</td>
</tr>
<tr>
<td>SIQR</td>
<td>168</td>
<td>668</td>
<td>1011</td>
<td>5.4</td>
<td>4.4</td>
<td>0.5</td>
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</table>

Table 2
_t_-test results of the macro MUP parameters*

<table>
<thead>
<tr>
<th></th>
<th>NOR–MND*</th>
<th>NOR–BMD*</th>
<th>NOR–SMA*</th>
</tr>
</thead>
<tbody>
<tr>
<td>log amp</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>log area</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>log avpower</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>ucdur</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>dur</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>phases</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>

* *Significantly different at _P_<0.05.

Table 3
Correlation analysis of the macro MUP parameters for all subjects*

<table>
<thead>
<tr>
<th></th>
<th>log amp</th>
<th>log area</th>
<th>log avpower</th>
<th>ucdur</th>
<th>dur</th>
<th>phases</th>
</tr>
</thead>
<tbody>
<tr>
<td>log amp</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>log area</td>
<td>0.95</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>log avpower</td>
<td>0.98</td>
<td>0.97</td>
<td>1.00</td>
<td></td>
<td></td>
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<tr>
<td>ucdur</td>
<td>0.63</td>
<td>0.45</td>
<td>0.56</td>
<td>1.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>dur</td>
<td>0.25</td>
<td>0.17</td>
<td>0.26</td>
<td>0.25</td>
<td>1.00</td>
<td></td>
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<tr>
<td>phases</td>
<td>0.06*</td>
<td>0.05*</td>
<td>0.09*</td>
<td>0.09</td>
<td>0.42</td>
<td>1.00</td>
</tr>
</tbody>
</table>

* *No correlation was observed at level of significance.

Recruitment. Macro EMG studies are usually performed at between 10% and 40% of full recruitment giving an average contribution of five asynchronous units generating baseline noise. Thus applying a correction procedure in addition to the conventional one was considered necessary to allow for a less erroneous duration measure.

It has been empirically determined that the power fraction which seems to give satisfactory results for the duration measure is 90% of the total power. The statistics for the uncorrected duration and the corrected duration measures are tabulated in Table 1. It is shown that the macro MUP corrected duration is considerably shorter for the MND patients, being 11.5 ms, compared...
with 17.1 ms (mean values) of the normal group. However, the corrected duration of the macro MUPs recorded from the BMD and the SMA groups are not significantly different (at the $P<0.05$ level) from the normal group, as it is shown in the $t$-test results of Table 2. An important observation is that, if the duration correction algorithm had not been applied, then the uncorrected duration measure between the NOR group and the BMD group would have been significantly different ($P<0.05$). So an uncorrected duration measure would have given false findings.

For the uncorrected duration measure it should be mentioned that there is no significant difference between the normal and the SMA group ($P<0.05$). The mean values of the uncorrected duration measure for the BMD and SMA groups are 23.2 ms and 20.1 ms respectively. So, without correcting this measure, the conclusion could have been inferred that the BMD and the SMA groups give macro MUPs with slightly longer durations than the normal group.

4.2. Univariate analysis

The frequency distribution of the amplitude macro MUPs is not Gaussian, so the median value is used. Usually the median value of 20 macro MUPs is compared with the reference material published by Stalberg and Fawcett [2]. The amplitude results for each macro MUP study can also be compared with the lower and upper limits given by Stalberg and Fawcett [2]. A study is NOR only if two macro MUPs have an amplitude that is out of the given range. All of the subjects in the NOR group investigated can be classified correctly based on this criterion. For the MND group, all of the subjects can be classified as abnormal, apart from one subject whose macro MUPs drop within the normal limits. For the BMD group, only three patients out of the 14 examined can be classified as abnormal. For the SMA group, it can be observed that there is no pattern related to the macro MUP amplitude distribution between each subject, with which this disease can be easily identified. Four patients of this disease had macro MUP amplitudes within the normal range. Also four patients were classified as abnormal having macro MUPs towards a higher amplitude, whereas for two more patients the reverse was true.

Table 2 tabulates the $t$-test results for the main parameters. The log amplitude, log area and log average power are significantly different at the $P<0.05$ level for the NOR-MND, NOR-BMD, and NOR-SMA groups. Examining either of these parameters might give an indication as to whether a study is normal or abnormal. However, no definite conclusion regarding the pathology of the disease can be inferred, i.e this method is not specific. The duration measure, can only be used to differentiate between the NOR and the MND group. This measure is not significantly different ($P<0.05$) when the BMD group was examined against the NOR one. The same observation applies for the SMA group. If the uncorrected duration measure was used for differentiating between the NOR and the BMD group, an erroneous conclusion would have been drawn that these groups are significantly different ($P<0.05$).

The phases measure, is not significantly different ($P<0.05$) between the NOR group and the other three groups examined. The number of phases was measured within the duration limits. Even if this measure was determined for the whole 50 ms macro MUP waveform, there would not be any difference. This is due to the fact that only 5% of power was left unexamined on either side of the macro MUP, whereas the phase threshold criterion applied was twice this value, being 10% of the macro MUP power.

4.3. Correlation analysis

The high correlation between amplitude and area obtained has already been documented by Stalberg and Fawcett [2]. A high correlation between the power measure and both the amplitude and area measures was expected. The good correlation between the amplitude and the uncorrected duration, dropped considerably from $-0.63$ to $-0.25$ following correction of the duration measure. Thus, the absence of the correction technique on the duration would lead to the false conclusion that there is good correlation between the amplitude and duration. Also it should be stated that the amplitude-duration interrelation is negative. This means that for high amplitude macro MUPs a short duration is expected, whereas for low amplitude macro MUPs a long duration is expected. A similar finding is shown in a small number of surface macro MUPs in the paper by Stashuk [12]. Although the number phases measure was defined to be a certain fraction of the power, there is no strong correlation between phases and duration. The correlation coefficient obtained was 0.42 indicating that the higher the duration, the higher the number of phases. This finding is important, considering the phase threshold criterion applied, counting a phase only if its power content exceeds 10% of the total macro MUP power.

5. Conclusions

For the macro MUP, the definition of amplitude and or slope criteria for the duration measure are not applicable due to the non consistent shape of the macro MUP waveform beginning and ending. An attempt has been made to correct the macro MUP waveform based on the power content of the preceding and ending 10 ms windows of the macro MUP acquired epoch. Following this correction step, the power related “duration” of the macro MUP has been defined and measured. The dur-
ation measure can be questioned from the point of view that the determination of the boundaries of the duration is a difficult task. In essence the power related duration method provides an estimation technique of signal-base-
line approaching a limit. In view of baseline noise contributing to the total power of the whole sweep it can be expected that the fractional contribution of baseline noise power to total power will be greater for a small potential. Furthermore, there is no physiological interpretation of this measure with the motor unit structure as is the case with the concentric needle recorded MUP duration. It has been found that high amplitude and power macro MUPs give shorter macro MUP duration than macro MUPs with normal amplitude. In contrast, in low amplitude macro MUPs there was a tendency towards a higher duration measure, as compared with the duration of the normal amplitude macro MUPs.

The $t$-test results indicate that the log amplitude, log area and log average power are significantly different between the NOR and the MND, BMD, and SMA groups whereas for the duration measure, there is no significant difference between the NOR and the BMD and SMA groups. For the phases measure, no significant difference was obtained between the NOR and the three disease groups. The number of phases as it has been defined, seems to carry no useful information to differentiate between the normal and the abnormal macro MUP. Correlation analysis showed a high correlation between the log amplitude, log average power and log area parameters, and no correlation of these measures with duration and phases. So, even though the duration measure has the above mentioned limitations, it can be stated that it provides another way of looking at the macro MUP waveform.

There are a number of confounding factors for which allowance cannot be made and which have a significant impact upon the efficiency of the analytical procedures. The most important of these is the dependency upon the initial clinical classification of the patients into the four groups. Recent developments in molecular biology have allowed the precise identification of a number of types of muscular dystrophy using genetic analysis [19]. Therefore, it is possible that misclassification of the patients might have occurred which could give rise to the inconsistencies outlined above.

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References