ABSTRACT: The aim of this study was to estimate normal jitter in voluntarily activated extensor digitorum communis (EDC) and orbicularis oculi (OOc) muscles using a disposable concentric needle electrode (CNE). The EDC of 67 normal subjects (22 males and 45 females, mean age 35.5 ± 10.2 years) and the OOc of 50 normal subjects (13 males and 37 females, mean age 37.9 ± 9.6 years) were studied. Jitter values were expressed as the mean consecutive difference (MCD) of 20 potential pairs. The mean MCD for EDC was 23.6 ± 3.1 μs (upper 95% confidence limit [CL]: 29.7 μs). The mean MCD of all potential pairs (n = 1340) was 23.5 ± 7.3 μs (95% CL: 38.2 μs). The mean MCD for the 18th highest value was 31.4 ± 4.9 μs (95% CL: 41.2 μs). The mean MCD for OOc was 24.7 ± 3.1 μs (95% CL: 31.0 μs). The mean MCD of all potential pairs (n = 1000) was 24.7 ± 7.1 μs (95% CL: 39.0 μs). The mean MCD for the 18th highest value was 32.7 ± 4.1 μs (95% CL: 40.9 μs). Our reported CNE jitter values obtained during voluntary activation represent the largest series currently available. The suggested practical limit in the EDC for mean MCD was 30 μs and for outliers was 42 μs, and in the OOc for mean MCD was 31 μs and 41 μs for outliers. The present study confirms that CNE can be used to assess jitter values, although certain precautions must be taken. 


REFERENCE JITTER VALUES FOR CONCENTRIC NEEDLE ELECTRODES IN VOLUNTARILY ACTIVATED EXTENSOR DIGITORUM COMMUNIS AND ORBICULARIS OCULI MUSCLES

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Single-fiber electromyography (SFEMG) was developed in the early 1960s by Stålberg and Ekstedt.6,8,14,20 The SFEMG electrode (SFE), which is a needle electrode with a small recording surface (25-μm diameter) exposed on the side of the electrode 3 mm from the tip,6 allows for the recording of one or more single-fiber action potentials (SFAPs) from a given motor unit. Neuromuscular jitter represents the variation in time intervals between pairs of SFAPs in voluntary SFEMG (v-SFEMG) or the time between axonal microstimulation and SFAPs in stimulated SFEMG.17,21 Using the SFE, normal jitter values for the extensor digitorum communis (EDC) and orbicularis oculi (OOc) have been established.1,2,4,10,19 The jitter measurement is accepted as the most sensitive electrophysiological test for diagnosing myasthenia gravis,3,9,14–16 and it has become an integral part of the evaluation of these patients.

In recent years, the use of SFE has raised concerns regarding the risk of transmission of infectious agents, such as prion diseases.3,16 Therefore, the use of disposable concentric needle electrodes (CNEs) has been addressed in some studies.3,9,11,12,16 Due to the differences in the electrodes, the low-frequency filter should typically be increased to 500 Hz to 1–2 kHz, to suppress activity from distant muscle fibers.3,11,12,16

The aim of this study was to estimate normal jitter in voluntarily activated EDC (67 subjects) and OOc (50 subjects) muscles in a Brazilian population, using CNE recording.

Abbreviations: CNE, concentric needle electrode; EDC, extensor digitorum communis; MCD, mean consecutive difference; MIPI, mean interpotential interval; MSD, mean sorted difference; MUP, motor unit potential; OOc, orbicularis oculi; SFAP, single-fiber action potential; SFE, single-fiber electrode; SFEMG, single-fiber electromyography; v-SFEMG, voluntary single-fiber electromyography

Key words: concentric needle electrode; extensor digitorum communis; jitter; orbicularis oculi; single-fiber electromyography

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Methods

Subjects. From April 2006 to September 2007, 117 healthy subjects were studied using CNE for quantitative jitter analysis. The EDC subset included 67 subjects, 22 men and 45 women, with a mean age of 35.5 ± 10.2 years (range 19–55 years). The OOc group included 50 subjects, 13 men and 37 women, with a mean age of 37.9 ± 9.6 years (range 20–61 years). None had symptoms of a medical condition, including neuromuscular disease, and none had been taking medication that could interfere with the study. Screening nerve conduction studies and electromyography were not done.

Recording. For all studies, a portable Keypoint electromyograph (Medtronic, Skovlunde, Denmark) with SFEMG software with peak interval measurement was used for recording and analysis. CNE analyses for jitter studies were done by the first investigator (J.A.K.) in Brazil, after a training period at the Department of Clinical Neurophysiology, University Hospital, Uppsala, Sweden; the second investigator (E.S.) saw many of the digital recordings. We planned the project and did the initial cases together to check the combined technical settings before the first data were collected for the project. No recordings were discarded after the study was finished. Cancellation was made during the recording itself, as is routine. The recordings were not blinded.

Voluntary SFEMG was performed with a CNE with a diameter of 0.30 mm and a recording area of 0.019 mm² (Medtronic). A recording of two or more time-locked spiky components from the same motor unit was performed during minimal voluntary contraction of the EDC and OOc muscles. A maximum of three needle insertions were performed, with either a few different recording sites of various depths in the EDC muscle or at various angles in the OOc muscle from 1 cm lateral to the lateral canthus. The jitter values of 20 different pairs were calculated for each subject. For jitter analysis, both the examiner and the Keypoint software selected individual potentials (spikes) with minimal summation of many components; that is, with a distinct and dominating spike of short rise-time (most below 300 µs) without notches and a well-defined peak. A criterion using rise-time makes no sense if measured from largest positive to largest negative spike if the signal is complex. It is more important that the spike chosen for measurement has a fast rise-time without notches or shoulders, and a constant shape in consecutive discharges, as in SFEMG. The amplitude should exceed 100 µV. At present, a more exact definition cannot be given, which is also a weakness of CNE recordings. The computer software has a built-in “peak” criterion. If the computer fails to define a peak in enough traces (e.g., >30%), the peak is probably very poorly defined mathematically. The spike components used for analysis had a clear separation (>150 µs) with no or minimal merging of one signal onto the other. Nonetheless, the triggering potential was often a compound signal composed of more than one spike, whereas the other signal (occurring after or, occasionally, before the trigger) was sharper and uniform in consecutive discharges. Measurements were made between software-extrapolated negative peaks. Examples of CNE jitter recordings from EDC, and also some pitfalls, are shown in Figure 1.

For each jitter analysis, a minimum of 50–100 consecutive traces were recorded. The filter setting range was 1–10 kHz. The mean value of mean consecutive difference (MCD) and the mean sorted data difference (MSD) were calculated. If the MCD/MSD ratio was >1.25, the MSD value was used instead of the MCD value as the jitter value in v-SFEMG. The Keypoint software also calculated the mean interpotential interval (MIPI) between the triggering and the measured spike. Fiber density was not considered in CNE studies.

The study was approved by the Faculdade de Medicina de Sào José do Rio Preto ethics committee, and informed consent was obtained from each subject.

Results

The mean jitter and its standard deviation were analyzed according to a previously used method; that is, a calculation of the mean MCD of at least 20 SFAP pairs for v-SFEMG. In addition, the mean jitter for the entire subject population was calculated. Furthermore, a practical definition of abnormality includes the assessment of individual outlier values. Two of 20 recordings were allowed to be outside of the calculated limits. Therefore, the 18th highest value was taken from each set of 20 recordings. The 95% upper confidence limit of the 18th value was calculated to define the outlier limit. There was no correlation with age in these data (p > 0.5). The two-sample t test between gender and MCD revealed P values of 0.762 and 0.949 for EDC and OOc, respectively. There were no recordings with impulse blocking. Signal amplitude was typically 100–1500 µV.

Voluntary SFEMG for the Extensor Digitorum Communis.

The mean of the 67 v-SFEMG MCD values in each subject was 23.6 ± 3.1 µs (range 17–31 µs). The upper 95% confidence limit was 29.7 µs. The mean of all
1340 MCD values was 23.5 ± 7.3 μs (range 9–57 μs). The upper 95% confidence limit was 38.2 μs. In all cases MCD was used. The outlier limit, 18th highest out of 20 recordings for each subject (10% of the values may be outside the limit) was 31.4 ± 4.9 μs, with an upper 95% confidence limit of 41.2 μs. The mean value of MIPI values was 786 ± 180 μs (range 530–1412 μs). In isolated pairs, only 0.3% (7 pairs) were longer than 4 ms, up to 4.7 ms. These were excluded from the jitter analysis.

**Voluntary SFEMG for the Orbicularis Oculi.** The mean of the 50 v-SFEMG MCD values from each subject was 24.7 ± 3.1 μs (range 18–32 μs). The upper 95% confidence limit was 31.0 μs. The mean of all 1000 MCD values was 24.7 ± 7.1 μs (range 10–45 μs). The upper 95% confidence limit was 39.0 μs. In all cases MCD was used. The outlier limit was 32.7 ± 4.1 μs, with a 95% confidence limit of 40.9 μs. The mean value of MIPI values was 927 ± 212 μs (range 555–1425 μs).

For all data, the upper limit of the MCD, SFAP pairs, and 18th highest value for 95% confidence limits are shown in Tables 1 and 2 and Figures 2 and 3.

**DISCUSSION**

If electrodes other than the SFE are used in studies of neuromuscular jitter, a new definition of accept-

![FIGURE 1. Concentric needle electrode recordings for jitter measurements (peaks) in extensor digitorum communis muscle: (A) normal jitter with well-defined and clearly separated spikes; (B) second peak, distinct and separated from the first by more than 150 μs, and therefore accepted. This riding effect would lead to a false abnormal jitter value with use of the level trigger (not shown). (C) Long total rise-time (> 30 μs) and clear summation on first peak; only second and third peaks with short rise-time (<300 μs) were accepted. (D) The software found only an exceptional (<70% of traces) peak on the first component due to slow rise-time (>300 μs), and therefore it was excluded. Jitter findings from 100 discharges are given, but only 5 discharges are shown.](image-url)

| Table 1. Concentric needle electrode jitter: values in voluntary EDC (age 35.5 ± 10.2 years). |
|---------------------------------|-----------------|------------------|-----------------|
|                                | MCD per study   | Individual pairs | 18th MCD value  |
| n                               | 67              | 1340             | 67              |
| v-SFEMG (μs)                    | 23.6            | 23.5             | 31.4            | 786          |
| SD (μs)                         | 3.1             | 7.3              | 4.9             | 180          |
| Range (μs)                      | 7–31            | 9–57             | 22–44           | 530–412      |
| 95% (μs)                        | 29.7            | 38.2             | 41.2            |
| Practical limit (μs)            | 30              | 42               |

v-SFEMG, voluntary single fiber electromyography; EDC, extensor digitorum communis; MCD, mean consecutive difference; MIPI, mean interpotential interval.
able signals must be formulated and new reference values must be obtained. In two earlier studies on the Brazilian population,\textsuperscript{11,12} preliminary calculations of jitter values in control subjects, both for voluntary and for stimulated CNE jitter studies in the EDC muscle, were made. In this study we have extended these data and included the orbicularis oculi muscle.

Our initial concern was the suitability of signals recorded with CNE in the study of neuromuscular transmission. A larger electrode records a compound signal (motor unit potential, MUP) from a number of muscle fibers adjacent to the electrode. Such a summation is usually detected visually as a complexity of the signal and a shape variability, called jiggle,\textsuperscript{18} from one discharge to the other in the form of changing rise-time, moving notches and varying peak amplitude. The jiggle is generated by jitter in each of the SFAPs that participate in the MUP. Our simulations have shown that the summed jitter is less than the jitter of individual components.\textsuperscript{20}

Developing a reliable method to express the jitter of components representing individual SFAP in the MUP was an aim of this study. The first approach was to enhance visual assessment of the variability by signal filtering, a method called the “blanket principle.”\textsuperscript{13} For quantitative assessment of overall MUP variability, an early attempt was “jiggle analysis,”\textsuperscript{20} a method that has not been fully tested in the clinic. Next, the blanket principle needed to be further developed to fit quantitative analysis.

The first step was to determine if it was possible, with proper filtering, to extract the contribution from just one muscle fiber. Our unpublished simulation studies have shown that, for SFAPs with little temporal dispersion, the answer is no. When the high-pass filter is increased from 5 Hz (normal EMG routine) to 500 Hz (SFEMG), and further to 1–2 kHz, the slow components are suppressed and the amplitude reduced. For the highest filter values, extra peak components may appear as artifacts, but, in general, individual SFAPs cannot be extracted. Some MUP have some outstanding individual components in amplitude or latency, such as late components, which can be found in reinnervation, myopathies, and sometimes in normal muscle. In such cases, jitter analysis will be performed between one part of the possibly complex filtered MUP and a component that may represent a SFAP.

Another factor is the size of the recording surface. Smaller electrodes give higher amplitudes due to less shunting effect of the electrical field.\textsuperscript{7} We recommend a CNE with the smallest possible recording surface. In this study we used a CNE with a recording surface of 0.019 mm\textsuperscript{2} as compared with the 0.070 mm\textsuperscript{2} of most conventional CNEs.
At present, the definition of acceptable signals may need more consideration, but in practical terms we have established general guidelines. For obtaining signals, a small CNE, as used in this study, with a recording surface of 0.019 mm² (facial needles), should be used. A high-pass filter setting of 1–2 kHz is recommended, and we used 1 kHz in this study. It may be easier to detect summation of SFAPs with 1 kHz than with 2 kHz, and the signal has higher amplitude. The spike signal used for measurement should have a fast rise-time and a constant shape without notches or irregularities on consecutive discharges, at least in the peak area. Visual inspection easily reveals summation and is better than a numerical expression of rise-time or duration. The computer software has a peak definition. If a given signal repeatedly fails to be accepted by the computer (intermittently accepted), the jitter values should usually be cancelled. For triggering, the most stable peak should be chosen. Different muscles have different motor unit topography and different MUP parameters. They may therefore be less optimal for CNE jitter analysis. EDC is good, and the facial muscles. They may therefore be less optimal for CNE jitter analysis. EDC is good, and the facial muscles.

### Table 3. Voluntary jitter values with various electrodes (values expressed in microseconds).

<table>
<thead>
<tr>
<th>Electrode</th>
<th>Muscle</th>
<th>Subjects</th>
<th>MCD per study</th>
<th>MCD per study 95%</th>
<th>Number of individual pairs</th>
<th>Individual pairs</th>
<th>Individual pairs 95%</th>
<th>Ref. no.</th>
</tr>
</thead>
<tbody>
<tr>
<td>SFE</td>
<td>EDC</td>
<td>Multicenter</td>
<td>36.0*</td>
<td>Multicenter</td>
<td>53.0*</td>
<td></td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>SFE</td>
<td>OOc</td>
<td>Multicenter</td>
<td>41.0*</td>
<td>Multicenter</td>
<td>55.0*</td>
<td></td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>Monopolar</td>
<td>EDC</td>
<td></td>
<td>22.4 ± 2.81</td>
<td>28.0</td>
<td>820</td>
<td>22.0 ± 5.61</td>
<td>33.2</td>
<td>5</td>
</tr>
<tr>
<td>Concentric</td>
<td>EDC</td>
<td>10</td>
<td>20.0</td>
<td>30.7 ± 3.7</td>
<td>453</td>
<td>30.6 ± 9.2</td>
<td>49.0</td>
<td>15</td>
</tr>
<tr>
<td>Concentric</td>
<td>OOc</td>
<td>20</td>
<td>29.1 ± 3.9</td>
<td>36.9</td>
<td>484</td>
<td>28.8 ± 10.5</td>
<td>49.8</td>
<td>15</td>
</tr>
<tr>
<td>Concentric</td>
<td>Frontalis</td>
<td>23</td>
<td>460</td>
<td>29.1 ± 12.0</td>
<td>53.1</td>
<td></td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Concentric</td>
<td>EDC</td>
<td>50</td>
<td>24.2 ± 2.81</td>
<td>29.8</td>
<td>1000</td>
<td>24.07 ± 7.31</td>
<td>38.7</td>
<td>10</td>
</tr>
<tr>
<td>Concentric</td>
<td>EDC</td>
<td>41</td>
<td>23.0 ± 2.81</td>
<td>28.6</td>
<td>820</td>
<td>22.9 ± 6.71</td>
<td>36.3</td>
<td>11</td>
</tr>
<tr>
<td>Concentric</td>
<td>OOc</td>
<td>67</td>
<td>23.6 ± 3.11</td>
<td>30.9</td>
<td>1340</td>
<td>23.5 ± 7.31</td>
<td>38.1</td>
<td>Present</td>
</tr>
<tr>
<td>Concentric</td>
<td>OOc</td>
<td>50</td>
<td>24.7 ± 3.11</td>
<td>30.9</td>
<td>1000</td>
<td>24.7 ± 7.11</td>
<td>38.9</td>
<td>Present</td>
</tr>
</tbody>
</table>

EDC, extensor digitorum communis; OOc, orbicularis oculi; MCD, mean consecutive difference; SFEMG: single-fiber electromyography.

*Age-dependent, 50 years.
†Not age-dependent.
that leads to different measurement points along the signals, or it is underestimated if the DC shift is so large that some signals move out of the measuring window.

In this study we also documented the MIPI value. For CNE it is the mean value in a study of the interval between the first and last spike in the recording. It is of the same magnitude as in SFEMG (usually <3.4 ms), and its usefulness will be tested in studies of abnormal muscles.

In conclusion, our study has established reference jitter values for CNE. These values are transferable between laboratories, provided the same or very similar techniques are used. With other measurements of jitter (amplitude level for start and stop of time measurements instead of peaks), attention must be paid to avoid merging signals. Separate reference values may be necessary for the two analysis techniques. A high-pass filter exceeding 1 kHz may result in problems in visually assessing signal shape properly. It gives lower amplitudes, notches are lost for the detection of summation, and it may also produce extra phases, which may be used erroneously during analysis. For analysis, the recording electrode should be adjusted to give the sharpest signals with a particular focus on constant peak shape in consecutive discharges. We recommend a filter setting of 1–10 kHz for high- and low-pass filters, respectively. We also recommend that the concentric electrode with the smallest possible recording surface be used for the acquisition of data. It should be noted that SFEMG fiber density cannot be obtained with the CNE.

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