The optimal recording electrode configuration for compound sensory action potentials

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SUMMARY There is no uniformity in the published literature from different laboratories on the optimal electrode configuration for recording nerve action potentials, and a number of standard texts omit any reference to the effects that interelectrode distance and electrode orientation can have on the shape, amplitude and latency of nerve action potentials. The sensory action potential from the digital nerves of the index finger was recorded at wrist and elbow using bipolar electrodes with the "active" electrode over the median nerve and the "reference" placed 4 cm laterally or proximally along the nerve using interelectrode distances of 4, 3 and 2 cm. These potentials were compared with that recorded using a remote reference on the ipsilateral shoulder, the assumption being that this configuration eliminated the contribution of the reference electrode to the compound nerve action potential. With different electrode configurations, there were significant differences in the shape of the potential, the latencies to onset and peak and the rising- and falling-phase amplitudes. The shorter the distance between the electrodes the greater the distortions. Overall, the distortions were least with the 4 cm interelectrode separation, particularly for short conduction distances.

Although there has been much debate in the evoked potential literature about the optimal recording montages for somatosensory evoked potentials, relatively few studies have considered recording parameters for nerve action potentials.1-4 Relevant chapters in many standard references do not discuss electrode configuration5-10 (however see ref. 11), and there appears to be no unanimity on usage between different laboratories. For example, recent publications have used or recommended the following interelectrode distances: 4 cm for antidromic and 2 cm for orthodromic recordings;12 1 cm for antidromic and 3 cm for orthodromic recordings,13 2 cm for antidromic recordings,14 2-3 cm,15,16 3 cm for orthodromic recordings17 and 3-5 cm for orthodromic recordings.18 Furthermore, while most authorities measure latencies to the onset of the negative phase of the compound action potential, others quote latencies to the negative peak (for example refs 12, 19, 20-22); some measure the amplitude of the negative phase, but others quote peak-to-peak amplitudes (such as in refs 22, 23).

The implication in diagnostic studies is always that the recorded action potential reflects activity seen at the "active" electrode. This assumption is reasonable only if the contribution of the "reference" electrode is negligible, an unlikely assumption with a bipolar recording, no matter what the electrode orientation. The present study was undertaken to quantify the effects of different "reference" electrode positions on orthodromic nerve action potentials. Although a number of other studies have documented differences in the shape and amplitude of compound sensory action potentials with different longitudinal interelectrode distances1 3 and with longitudinally and transversely orientated references,24 no previous study has attempted to compare these potentials with that which would be recorded if a true monopolar derivation were possible.

Methods

The study was performed on six healthy volunteers with no past history of neuromuscular disease, each of whom gave informed consent to the procedures. The orthodromic sen-
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Each trace is reconstructed at the wrist using the wrist potential recorded at the conventional active site. The optimal configuration was lateral and proximal to the conventional active site and was situated along the shoulder. The wrist potential was recorded from the conventional site using the remote reference.

At the wrist or, in separate experiments, at the elbow, the compound sensory action potential was recorded simultaneously from five sites using a remote reference at the ipsilateral shoulder. The bandwidth for each recording channel was 0.3–5 kHz. Routinely 256 responses were averaged using a sampling rate of 50 kHz. The first recording electrode was situated along the course of the median nerve at the wrist, 2 cm proximal to the distal crease (conventional active site). The other electrodes were placed 4 cm lateral and 2 cm, 3 cm and 4 cm proximal to this conventional site. Bipolar recordings with 4 cm, 3 cm and 2 cm interelectrode distances were reconstructed by subtracting the waveform recorded by the relevant electrode from that recorded at the conventional site (see figs 1 and 3). A similar procedure was used to reconstruct the potential seen with a reference 4 cm lateral to the conventional site (see fig 2). The reconstructed potentials were then compared with that recorded from the conventional site using the shoulder reference (see fourth traces in figs 1 and 2). In control experiments it was confirmed that, as must be the "reconstructed" potentials were identical to those recorded using bipolar inputs.

The latency, amplitude and duration of the recorded and reconstructed potentials were measured. Latencies were measured to the peak of the first positive deflection or, if this was absent, to the onset of the negative deflection (onset latency) and to the peak of the subsequent negative deflection (peak latency). Amplitudes were measured peak-to-peak for both the rising and falling phases of the potential. Duration was determined by measuring the time between the peak of the first positive deflection to the peak of the second positive deflection. On some occasions, particularly at the elbow, a second positive peak could not be defined, and the point at which the potential returned to the baseline was used. The above-mentioned parameters for the reconstructed potentials were expressed as a percentage of the values for that subject for the potential recorded from the conventional site using the remote reference on the shoulder. The significance of differences from these control values was assessed using a paired t test.

**Results**

The potential recorded at the wrist or elbow against a remote reference on the shoulder is considered in this study to reflect the activity seen by the "active" electrode and, in bipolar derivations, deviations from this to represent unwanted distortions due to the "reference" electrode. This assumes that there are no significant "far-field" contributions to the recorded activity within the relevant time interval,24 an

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**Fig 1** Comparison between potentials recorded with a remote reference and with 4 cm bipolar electrodes. Trace (A): potential recorded from the conventional active site at the wrist using a remote reference. Trace (B): potential recorded by an electrode 4 cm proximal to the conventional active site using a remote reference. Trace (A–B): 4 cm bipolar reconstructed by subtracting trace B from trace A. Fourth trace: superimposition of the first and third traces. Each trace is the average of 256 sweeps. Vertical scale: 10 µV/div; Horizontal scale: 0.5 ms/div.

**Fig 2** Comparison between potentials recorded with a remote reference and a lateral reference. Trace (A): potential recorded from the conventional site at the wrist using a remote reference. Trace (B): potential recorded by an electrode 4 cm lateral to the conventional site using a remote reference. Trace (A–B): laterally referred potential reconstructed by subtracting trace B from trace A. Fourth trace: superimposition of traces (A) and (A–B). Each trace is the average of 256 sweeps. Vertical scale: 10 µV/div; Horizontal scale: 0.5 ms/div.
assumption that is probably valid for orthodromic recordings at the wrist, but may be debated for recordings at the elbow. As it happened, the compound nerve action potentials proved to be clean potentials not obviously contaminated by "far-field" activity, and this factor will not be considered further.

**Compound nerve action potential at the wrist** All reference electrodes saw a significant neural volley (figs 1–3), on average 31%, 41%, 59% and 75% of that seen by the "active" electrode for the lateral, 4 cm, 3 cm and 2 cm references, respectively. As a result there were significant distortions of shape, latency and amplitude in the bipolar recordings. The distortions of shape are illustrated in figs 1–3 and are identical to those documented by Andersen. The latency data are summarised in table 1, and the amplitude data in the table 2.

There were no significant deviations from the

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**Table 2** Rising- and falling-phase amplitudes

<table>
<thead>
<tr>
<th>Reference</th>
<th>Mean (SD)</th>
<th>p</th>
<th></th>
<th>Mean (SD)</th>
<th>p</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Lateral</td>
<td>76% (4%)</td>
<td>&lt;0.001</td>
<td>65% (7%)</td>
<td>&lt;0.001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 cm</td>
<td>84% (11%)</td>
<td>&lt;0.001</td>
<td>119% (12%)</td>
<td>&lt;0.001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 cm</td>
<td>97% (9%)</td>
<td>&lt;0.001</td>
<td>136% (12%)</td>
<td>&lt;0.001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 cm</td>
<td>101% (7%)</td>
<td>&lt;0.001</td>
<td>138% (12%)</td>
<td>&lt;0.001</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

"true" latencies with the 4 cm configuration. With the lateral reference, latencies to onset were significantly longer (p < 0.005) than the "true" value, but with the 2 cm and 3 cm montages they were significantly shorter (p < 0.02 and 0.01 respectively). With these two montages, latencies measured to the negative peak of the potential were more severely affected than those to onset. Rising-phase amplitudes were less distorted than falling-phase amplitudes and, again, the least amplitude distortion occurred with the 4 cm montage. With each recording montage, the duration of the potential deviated significantly from the "true" duration (p < 0.001 for each montage; see table 1).

**Compound nerve action potential at the elbow**. In three subjects, recordings were made at the elbow to model the effects of greater dispersion of the neural volley, as would occur with a long conduction distance or with pathological dispersion over a short conduction distance. The recorded potentials were biphasic with the remote and lateral references, but triphasic with the 3 cm and 4 cm references. Latencies to onset were longer than the "true" value (101-1%) with the lateral reference, shorter (98-5%) with the 3 cm reference and similar (99-4%) with 4 cm reference. Rising-phase amplitudes were smaller than the "true" value: 88% with the lateral references, 82% with the 4 cm reference, 68% for the 3 cm reference. The duration of the potential was 79-6% of the "true" value with the lateral reference but only 40-3% and 36-7% with the 4 cm and 3 cm references, respectively.

**Discussion**

This study has demonstrated significant contributions of the reference electrode with all four recording montages, the degree of distortion of the "true" neural volley being least with electrodes 4 cm apart, orien-
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