Sensory responses elicited by subcortical high frequency electrical stimulation in man

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A radiofrequency current of 100 kHz sine wave was applied to therapeutic targets in the human brain and produced unpleasant sensory responses. Increasing the applied frequency to 250 kHz eliminated all these responses.

Key Words: subcortical electrical stimulation · conscious sensory responses · radiofrequency brain lesions

The use of radiofrequency current to produce therapeutic lesions has gained widespread acceptance in the course of human stereotaxic surgery. It is desirable to use the lowest frequency current that does not electrically stimulate neural tissue. Low frequency current minimizes the effects of lead and tissue shunt capacitance and allows a more reliable estimate of current actually delivered to the lesion site. To avoid discomfort to the patient, however, the frequency should be above that at which motor or sensory responses may be elicited. The results presented here form an approximate guideline for the lower frequency limit.

Patients being treated for dyskinesias and intractable pain had electrodes containing thermistor beads chronically implanted in suitable therapeutic targets (near the junctions between the ventral lateral and the posteroverentral lateral thalamic nuclei in patients with dyskinesias and in the medial lemniscus in patients with intractable pain). The surgical technique has been described elsewhere. Electrodes were stainless steel cylinders 1 mm in diameter and 3 or 5 mm long. Prior to lesion production, the targets were stimulated electrically with 1 msec square pulses repeated 60 times per sec with each succeeding pulse of alternate polarity. Current was increased in steps of 0.5 mA until the threshold for sensory or motor response was obtained. Following satisfactory stimulus responses, radiofrequency lesions were produced. Temperature at the electrode tip was monitored and slowly brought up to 62°C or 70°C at which point it was maintained for 30 sec to 2 min. In the past we have commonly used 2 MHz (megahertz) or 275 kHz (kilohertz). This paper deals with the sensory responses elicited when we lowered the frequency to 100 kHz. Frequently the patients reported that the 100 kHz radiofrequency current produced a severe unpleasant tingling or burning sensation. The sensation was similar in quality and site to that elicited by 60 pps (pulses per second) stimulation but tended to be much more intense and could not be tolerated by the patients. It was most apt to occur in those patients reporting sensations at 2 mA or below with 60 pps stimulation and began promptly with application of rf (radiofrequency) current.

However, during the period of current increase, if the current was held constant at any level, the sensation would disappear af-
ter some seconds as though the thermal lesion size had increased to inactivate the responding units at its periphery. We suggest that as the current is raised the lesion slowly expands to inactivate the newly responding units further from the electrodes. If at any time during formation of the lesion the current was turned off, the sensory response disappeared immediately while the brain temperature at the electrode tip fell much more slowly toward normal. The current necessary to produce sensory responses could produce a temperature change of less than 0.5°C as measured by our thermistor monitor. This together with the complete absence of sensory response to 275 kHz and 2MHz ruled out the possibility of thermal stimulation.

Due to the unpleasant nature of the reported responses, a survey was undertaken of the stimulus parameters necessary to elicit sensory response as the sine wave stimulation frequency was varied. For each frequency the current was increased until a response was reported or, in the absence of a response, until brain temperature at the electrode tip was increased by about 1°C. The sine wave bursts were kept short (of the order of 0.5 to 1 sec) to avoid significant heating. Results for two subjects are shown in Table 1 and Fig. 1. From our results it was concluded that 250 kHz would be the optimum compromise between patient comfort and undesirable current leakage along the electrode leads that occurs with higher radiofrequencies. This has proved to be the case; 225 lesions have now been made at 250 kHz without a single instance of sensory response.

The mechanism underlying the activation of sensory neural elements in and below the thalamus in man by high frequency current is not completely understood. By analogy with simpler preparations it is proposed that each cathodal half cycle produces a local re-

### TABLE 1

<table>
<thead>
<tr>
<th>Sine Wave Stimulus Frequency (kHz)</th>
<th>Subject A*</th>
<th>Subject B†</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Current (peak-to-peak) (mA)</td>
<td>Voltage (peak-to-peak) (volts)</td>
</tr>
<tr>
<td>0.1</td>
<td>0.4</td>
<td>0.4</td>
</tr>
<tr>
<td>1.0</td>
<td>0.4</td>
<td>0.4</td>
</tr>
<tr>
<td>10.0</td>
<td>2.0</td>
<td>1.2</td>
</tr>
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<td>50.0</td>
<td>15.0</td>
<td>6.0</td>
</tr>
<tr>
<td>100.0</td>
<td>44.0</td>
<td>18.0</td>
</tr>
<tr>
<td>125.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>150.0</td>
<td>72.0</td>
<td>26.0</td>
</tr>
<tr>
<td>200.0</td>
<td>72.0</td>
<td>26.0</td>
</tr>
</tbody>
</table>

* Diagnosis: spasmodic torticollis. Target: nucleus ventrointermedius externus (right). Electrode: 3 mm long (19-gauge stainless steel).
† Diagnosis: cerebral palsy. Target: nucleus ventrointermedius externus (left). Electrode: 5 mm long (19-gauge stainless steel).
sponse not cancelled by the succeeding anodal half cycle. The first small local response is insufficient to excite but, depending on its time course, it will partially sum with other local responses generated by later cathodal half-cycles until an impulse is set up. According to Gildemeister, for a 100 kHz stimulating current to be effective it is necessary that at least a few hundred cycles of current occur.

Brown and Brackett have shown that motor responses are obtained when stimulating subcortical structures in the cat with frequencies as high as 100 kHz. From 50 Hz to 25 kHz, they found the response to be smooth and definite. Above 25 kHz the responses from most areas consisted of quick transient jerks at the onset of the stimulus.

Other workers dealing with a variety of structures have reported stimulus responses to quite high frequencies. As the frequency is raised, the current required for excitation increases. Our evidence indicates that eventually I/R (I = current, R = resistance) heating and tissue destruction provide the upper frequency limit for excitation.

References

Fig. 1. Peak-to-peak voltage and current required for threshold sensory response plotted as a function of frequency.

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