Stereotactic Radiofrequency Lesion Making

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Abstract. The physical principles of radiofrequency (RF) lesion making in stereotactic neurosurgery are summarized. Empirical data are given on the relationship between lesion size and lesioning parameters. Currently accepted ranges of lesioning parameters for selected stereotactic procedures are discussed. Advanced RF lesion electrode designs are described which improve the capabilities to reach and confirm targets.

Background to Radiofrequency Lesion Making

Of the many techniques which have been applied for localized therapeutic destruction of nervous tissue, the radiofrequency (RF) lesion method has emerged as the most effective and widely used. The reasons for the success of this method are the following: (a) excellent circumscription of the lesion volume; (b) excellent control of the lesion process using temperature monitoring to quantify the lesion size, prevent boiling, charring, and sticking, as well as to produce differential destruction of neural tissue; (c) excellent target localization using stimulation, impedance monitoring, and recording, and (d) versatility of RF electrode configurations to optimize lesion size and adapt to intracranial, spinal, and peripheral nerve lesioning.

The Principles of the RF Lesion

The principle of RF heating is illustrated in figure 1. The RF voltage produced by the generator is impressed between the exposed tip of the "active" electrode. The RF current is observed in the surrounding tissues to produce the lesion pattern. The RF current density is given by $j = \frac{E}{\rho}$, where $E$ is the RF voltage across the electrode-tissue interface, which produces a current density $j$. The temperature distribution is computed using the tissue conductivities and the geometry of the electrode and lesion pattern. The RF lesion pattern is designed to produce a lesion of desired shape and size.

Figure 2 illustrates the RF lesion pattern on the shoulder of an animal, which shows the RF current density distribution, the applied RF voltage, and the RF temperature distribution. The RF lesion pattern is shown to be highly controllable and reproducible, allowing precise control of lesion size and shape.

"Active" electrode designs include the "active" lesion electrode, which is designed to produce a lesion pattern with uniform depth and diameter. The "active" lesion electrode is typically a cylindrical electrode with a small exposed tip, allowing precise control of lesion size and shape.

The RF lesion pattern is characterized by a high temperature rise at the exposed tip of the electrode, followed by a rapid decrease in temperature as the distance from the electrode increases. The RF lesion pattern is typically characterized by a temperature rise of 44-45°C, which is sufficient to destroy neural tissue. The RF lesion pattern is designed to produce a lesion of desired shape and size.

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the 'active' lesion electrode and the dispersive electrode (i.e., a gel-pad on the shoulder), which causes an electric field pattern (E lines) to form between the electrodes, which in turn drives the ions in the tissue electrolytes back and forth at the RF. It is this ionic current density $j = \sigma E$ which produces molecular friction and thus tissue heating at the rate given by $j^2/\sigma$, where $\sigma$ is the tissue conductivity. The equilibrium temperature distribution near the active electrode depends on the E field pattern, $\sigma$, the tissue thermal conductivity, and heat convection from blood flow. It can be calculated theoretically for simplified assumptions to predict the isotherm patterns near the tip (dashed lines in fig. 1). Within the 44–45°C isotherm and at higher temperatures, brain tissue is permanently killed, and this defines the lesion volume [1].

Figure 2 illustrates schematically temperature distributions versus distance from the electrode tip for two tip temperatures T1 and T2. The 44–45°C radius increases with tip temperature up to a maximum when the tip reaches 100°C, the boiling point. Thus by monitoring the tip temperature, one can gauge the lesion size as well as avoid the dangerous 100°C limit. Factors which most strongly determine lesion size are the tip dimensions and the tip temperature. Of much less importance are tissue resistance, thermal conductivity, or lesion current and voltage. Also, lesion size reaches equilibrium for a given tip temperature in 30–60 s. The most consistent lesion sizes are achieved by letting the lesion come to equilibrium for a given tip temperature in the range of 0–30 s, rather than increasing the size by increasing the lesion time.
Empirically Determined Lesion Parameters

With these guidelines, empirical data on RF lesion size versus tip size and temperature from human stereotaxy are useful. Though such clinical data are rare, figure 3 shows some gathered from several stereotactic neurosurgeons. Changes in lesion size may occur within weeks after surgery, so the sizes in figure 3 are probably lower limits. Figure 4 shows examples of two of these lesions [2, 3]. Note that in the case of the cingulum lesions, some spread of the lesion toward the ventricle is seen, possibly indicating a lower impedance pathway through the CSF. No marked differential spread to the white matter is noted, as has been discussed in the literature. Some preferential heating of either gray or white matter is expected depending on the relative position of the electrode in each. Recently, we have studied this question for lesions in animals, and shall report on it elsewhere.

Figure 5 shows the range of parameters used by several stereotactic surgeons who have considerable experience with the respective procedures. For thalamotomies, this suggests some variation in lesion sizes produced. The 1.6-mm tip diameter by 5- to 7-mm length seems a bit large. We recommend a 1.1- to 1.6-mm tip diameter and 4- to 5-mm tip length as a norm. The cingulotomy and hypophysectomy parameters...
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Using: Radionics Type TM Electrodes

<table>
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<th>PROC.</th>
<th>ELECTRODE TIP</th>
<th>TEMP (°C)</th>
<th>TIME (SEC)</th>
<th>P/M TIME</th>
<th>LESION SIZE A (MM)</th>
<th>LESION SIZE B (MM)</th>
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<td>5</td>
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<td>2 YR</td>
<td>3</td>
<td>7</td>
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<td></td>
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<td>4</td>
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<tr>
<td>CINGUL</td>
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<td>5 M</td>
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Fig. 3. Post mortem lesion sizes versus heating parameters.

Fig. 4. RF lesions in the thalamus and cingulum.
are probably less critical. Some surgeons prefer side outlet-tipped electrodes for these procedures to achieve larger, axially asymmetric lesion volumes. The recent technical advance of fine gauge cordotomy thermocouple electrodes brings all the advantages of safety and control to lesion making in the small structures of the cord.

It is notable here that there are unpredictable variables which can affect lesion size and shape. Low impedance CSF cisterns can draw heat away from neighboring tissues, and large blood vessels can carry heat away, cooling tissue nearby. Overall, however, consistency of results from RF lesioning in the brain using accepted parameters has been excellent.


**Fig. 6. Improved electrode design.**

**Improved Electrode Designs**

We are presently developing RF electrodes which, with a single insertion tract, will permit the recording, stimulating, and lesion making both on and off electrode axis. At the top of figure 6, a simple recording/stimulating ring is located proximal to the lesion tip of a conventional straight electrode. Below that is an universal stereotactic electrode system comprising an universal insulated cannula and many electrode and biopsy devices which can be passed through it. For example, either a straight or off-axis stimulating and recording probe (lower figure) may be used to probe the brain for neural targets, tumors, and so on. Then, a RF probe may be inserted to create a lesion precisely at the point of interest. The off-axis lesion probe may have an insulated surface except for the very tip, in which a thermal sensor is located for precise lesion control. Such systems should greatly expand the possibilities in stereotaxy while posing minimal intrusion into the brain.
References

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