Simulation on Temperature Field of Radiofrequency Lesions System Based on Finite Element Method

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Abstract. This paper mainly describes the way to get the volume model of damaged region according to the simulation on temperature field of radiofrequency ablation lesion system in curing Parkinson’s disease based on finite element method. This volume model reflects, to some degree, the shape and size of the damaged tissue during the treatment with all tendencies in different time or core temperature. By using Pennes equation as heat conduction equation of radiofrequency ablation of biological tissue, the author obtains the temperature distribution field of biological tissue in the method of finite element for solving equations. In order to establish damage models at temperature points of 60°C, 65°C, 70°C, 75°C, 80°C, 85°C and 90°C while the time points are 30s, 60s, 90s and 120s, Parkinson's disease model of nuclei is reduced to uniform, infinite model with RF pin at the origin. Theoretical simulations of these models are displayed, focusing on a variety of conditions about the effective lesion size on horizontal and vertical. The results show the binary complete quadratic non-linear joint temperature–time models of the maximum damage diameter and maximum height. The models can comprehensively reflect the degeneration of target tissue caused by radio frequency temperature and duration. This lay the foundation for accurately monitor of clinical RF treatment of Parkinson's disease in the future.

1. Introduction
Parkinson’s disease (PD) [1] is one of the most common degenerative diseases in the general population, especially in the old people. This disease affects the patient's motor function and life skills seriously in China at present as the result of an increasing trend of incidence rate year by year. According to the literatures that published during the last two years, drug control method and neuronal ablation [2, 3] method are widely used for the treatment of Parkinson’s disease at present. The method, which is widely used for neuronal ablation today, of removing the ablated brain section [4] from living body in order to measure the size of damaged region, is insufficiently studied on the information of damaged region and affection of surrounded brain tissue.

This paper mainly describes the way to get the volume model of damaged region according to the simulation on temperature field of radiofrequency ablation lesion system in curing Parkinson’s disease based on finite element method. This volume model reflects, to some degree, the shape and size of the damaged tissue during the treatment with all tendencies in different time or core temperature.

2. RF ablation Technology
Radiofrequency (RF) [5] with highly concentrated current is a kind of electromagnetic wave at the frequency between 50 kHz and 2000 kHz. The friction caused by the high frequency among the ions heats up the tissue in organisms to make it dissolved or gasified. RF ablation means ablating the target tissue with RF instruments. The RF generator generates high frequency current which arrives at the damage probe to form a current loop with another probe parked on the surface of skin. Powerfully and highly thermal, current from the sharp point of probe kills nerve cells and fibers by heating the tissue while the tissue gives a feedback thermal to the probe. We get the temperature of sharp point of probe with RF generator in order to deduce the temperature distribution of damaged area. Probe diameter, length, tissue parameters and other circumstance affect the range of damaged area, especially the duration and temperature of operation.

RF ablation, which has been broadly applied in clinical medicine as a result of rapid development of electronics, is a rising technology during the last ten years. High frequency bistouries, RF ablation instruments, heat treatment instruments for prostate and so on are advanced medical installations in recent years. As is repeatable, lightly hurt, easily controlled, short time treatment, little side-effect, little syndrome, RF ablation is more and more widely used in clinical medicine, such as treatment of cardiac arrhythmia, pain, prostatoplasia, tumor of brain, lung, liver, kidney, pancreas, galactophore and matrix[6, 7].

RF ablation heat treatment instruments used domestic mainly contains Leksell of temperature-controlled, Radionics RFG-3C, ASA-601[8] produced in Anke limited company of high technique in Shenzhen.

3. Finite element method

The first step of Finite Element Method (FEM) [9] is to divide the whole solve field into limited small conjoint fields that are defined as finite elements. We get an imprecisely solution by respectively getting the solution of each finite element. The solution is imprecisely because of the predigestion of the question. FEM become an effective method to analytics as a result of highly precision, adaptability to different shapes.

Radically, FEM distinguishes from other methods of solving boundary problems by confining the similarity in much smaller fields. Dr. Clough, who firstly gave a definition to FEM early in 1960s, vividly described that “FEM = Rayleigh Ritz + partial function”, that is FEM is localized by Rayleigh Ritz [10]. Unlike Rayleigh Ritz, which solves the question in whole field, FEM defines the function in ordinary shapes which is much more advanced than other methods.

4. Heat transfer model in biological tissue

Pennes equation [11] is the most widely used thermal conductive model in biomedical circle. This model simplifies the process of thermal conduction in organism tissues with the formulation following:

$$\rho c \frac{\partial T}{\partial t} = \nabla \cdot (k \nabla T) + W_b C_b (T_a - T) + q_m + q_r \tag{1}$$

Table 1 listed the parameters and their physical significance. In this simulation, $q_m$ and $q_r$ are ignored while normal temperature in vivo tissue is selected.

| Table 1. Parameters and their physical significance |
|---------------------------------------------------|
| Parameter | Physical significance |
| $T$ | normal temperature of tissue |
| $\rho$ | density of tissue |
| $c$ | specific heat of tissue |
| $k$ | heat exchange rate of tissue |
| $W_b$ | filling rate of blood |
| $C_b$ | specific heat of blood |
| $T_a$ | normal temperature of arterial blood |
The assumptions of Pennes are listed as follows:
(1) Tissue where capillary vessels (the diameter is between 0.005 mm and 0.015 mm) are existed is the major situation that exchange between vessels and tissue occurs;
(2) Blood at the temperature of $T_a$ will achieve a balance to tissue around vessel immediately while feeding in the capillary vessel bed and then feeds back to the vein at the temperature of $T$;
(3) The heat exchange between blood and tissue can be simulated by a scalar heat quantity, of which the size has direct ratio with filling rate of blood and temperature margin of arterial blood and tissue.

5. Simulation of temperature distribution in RF Ablation

5.1 Tissue model
The RF system selected to damage tissue is Leksell RF instrument produced in Sweden, which is an intact system specially used in nerve exciting, solid beamed damage, ache treatment and bipolar electro coagulating. The frequency of Leksell, which is higher than any other congeners, insures that the increasing speed of temperature can be $5 \, ^\circ C/s$. This could cut down the pain and operation time.

As is shown is figure 1, simulation of temperature distribution [12] in RF ablation setting out in this paper supposes the PD’s model to be an even, infinite sphere with the probe tip (0.5mm, -1mm) around the centre (0, 0). The diameter of the sphere is 20mm while the probe is 1mm with 2mm exposed.

The fuscous part in the centre in figure 1 is the exposed part of the probe, of which the temperature curve is showed in figure 2. The temperature of the probe increase at the speed of $5 \, ^\circ C/s$ from normal temperature($25 \, ^\circ C$) to damage temperature($70 \, ^\circ C$) linearly and then keep constant at the latter one.

Equation (1) is chosen to be the simulate formula while mice tissue is chosen to be the organism. Thermal parameters [13, 14] are listed in table 2.

| $\rho$ (kg/m$^3$) | $c$ (J/kg $\cdot ^\circ C$) | $k$ (w/m $\cdot ^\circ C$) | $T$ ($^\circ C$) | $h$ (w/m$^2$ $\cdot ^\circ C$) |
|------------------|-----------------|-----------------|-------------|-----------------|
| tissue           | 1090            | 3400            | 0.54        | 25              | 4.33            |

5.2 Simulation results
Figure 3 shows the result of finite element simulation.

![Result of finite element simulation](image)

**Figure 3.** Result of finite element simulation

Dark rectangular portion in figure 3 is the exposed part of the probe. Probe temperature rises as figure 2 describes. A tissue temperature distribution is formed in consequence of the rise in temperature. Temperature distribution of RF ablation presented to half of the elliptical according to the effective picture. The unit of colour bar is Kelvin.

### 5.2.1 Temperature distribution at constant temperature

The simulation establishes damage models at temperature points of 60°C, 65°C, 70°C, 75°C, 80°C, 85°C and 90°C while the time points are 30s, 60s, 90s and 120s. Take the case of the simulation results at four different time points while the temperature is constant, for example, 70°C.

![Temperature distribution at constant temperature](image)
Figure 4. Results of temperature distribution at 70 degree centigrade

While heating the probe to 70°C for 20 seconds, a small oval is formed surrounding as the temperature distribution. This oval becomes larger while the damage time increases at constant temperature. We can deduce that the volume of damage area is increased with damage time while the temperature is constant.

5.2.2 Temperature distribution at constant time
Figure 5 shows different distributions at different temperatures(30°C, 60°C, 90°C, 120°C) while time is constant(60s).

Figure 5. Results of temperature distribution at 60 degree centigrade

While heating the probe to 60°C for 60 seconds, a small oval is appeared as the temperature distribution. This oval becomes larger while the damage temperature increases in constant time. We can draw a conclusion that the volume of damage area is increased with damage temperature while the time is constant.

5.3 Analysis
Through data analysis of maximum radial direction length and maximum longitudinal length, we could draw the temperature curves in figure 6:
Figure 6. Temperature curves

The maximum radial direction temperature holding time of curves shown in figure 6(a) are respectively 4 seconds, 6 seconds, 8 seconds, 10 seconds, 20 seconds, 40 seconds, 60 seconds while the maximum height of curves is shown in figure 6(b) with the same temperature holding time. According to the irreversible change of clinical RF ablation while temperature rises up to 45°C [15], we are mainly concerned about the irreversible data. Through analyzing the simulated data, we could get the volume of damaged area. Figure 7 shows the volume data comparison of simulation and mice radio frequency experiment. Chart (a) is the trend comparison when the time maintains at 30 seconds and the temperature changes from 60 centigrade to 90 centigrade. Similarly, chart (b) is the same comparison when the time maintains at 60 seconds with the same range of temperature while the maintained time of chart (c), (d) is 90 second and 120 second.

Figure 7. Volume data comparison of simulation and mice experiment
Figure 8(a) shows the three dimensional plot of the simulated volume result at different time and different temperature while figure 8 (b) shows the finally model according to fitting algorithm. Figure 8(c) shows the three dimensional plot of the volume result in mice experiment at different time and different temperature while figure 8 (d) shows the finally model according to fitting algorithm.

![Figure 8](image)

**Figure 8.** Time-temperature distribution of effective damage volume

The top value of color bar means the maximum value of volume in the simulation while the bottom means the minimum.

We can draw a conclusion that the simulation on temperature field of RF lesions system based on FEM has the same effect with mice experiment and could comprehensively reflect the denaturation of damaged tissue.

6. Conclusions
As an easy, fast and effective method, FEM referenced in this paper is widely used to simulate the temperature distribution in biological tissue optics domain. During the research, the author draws several conclusions as followings:

- The damage area presented to be a smaller oval
- While the centre temperature is constant, the volume of damaged area is increased with holding time.
- While the holding time is constant, the volume of damaged area is increased with centre temperature.
- Simulation on temperature field of RF lesions system based on FEM has the same effect with mice experiment and could comprehensively reflect the denaturation of damaged tissue.
The nonlinear model, which can synthetically reflect denaturation of target brain tissue, is developed to describe foregoing conclusions that can make sense to the dosage theory.

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