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# Electrical properties of extracted rat liver tissue

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**Abstract.** We attempted to investigate the process of ischemia-induced disturbances in the rat liver, employing the electrical bio-impedance technique. The electrical bio-impedance was measured continuously over 6 h by the 4-electrode method, at various incubation temperatures, in six liver samples extracted from male Wistar rats. The electrical properties of biological tissues can be expressed in terms of three parameters: extracellular resistance (Re), intracellular resistance (Ri) and cell membrane capacitance (Cm). These three parameters were calculated from the measured values of the electrical impedance by the curve-fitting technique, using a computer program. The Re value increased rapidly after the rat livers were extracted, and then decreased slowly. The Re value reached a peak after about 13 min at 36 °C, and then decreased slowly, becoming constant after 3 h. There was a negative correlation between the Tmax of Re (the time when Re reached a maximum) and the incubation temperature ($R = -0.973$, $P < 0.001$). The Ri value decreased once in the early stage after extraction, followed by almost no change and then an increase after 4 h at 36 °C. The Cm showed a similar pattern of change to the Re value, and a negative correlation was also found between the Tmax of Cm and the incubation temperature ($R = -0.969$, $P < 0.001$). The increases in the Re and Cm values, and the decrease in the Ri value for quite long periods after the blood flow has stopped, suggest an increase in the resistance of extracellular fluid due to a decrease in its volume, an increase in cell membrane capacitance due to cell swelling, and a decrease in cellular fluid resistance due to an increase in its volume. The time when the Cm value decreases rapidly after an initial gradual decrease after the peak corresponds well with the time when the Ri value begins to increase, from which it is estimated that cell lysis proceeds and that the flow of extracellular fluid into the cell begins at this time. The findings of this study suggest the possibility of estimating the changes in liver tissue or the tissue structure due to ischemia.

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**Key words:** Electrical impedance – Rat liver – Ischemia – Time course – Incubation temperature

## Introduction

It is generally known that the liver is an organ that is susceptible to damage due to ischemia, and interruption of the blood flow to liver is often a problem in liver transplantation or hepatectomy. There have been many experimental studies of the tolerance time of the liver for ischemia, and it is said to be 20–60 min at ambient temperature [6, 7, 10–12, 15, 16]. The degree of hepatic damage can be determined by biochemical examination, by electron microscopic observation of frozen tissue specimens [2, 8], or by the NMR method [4, 17]. On the other hand, it is generally known that the electrical properties of biological tissues differ significantly, depending on their structure, and various studies have been based on this fact [13, 20–24]. We have previously reported the possibility of clinical application of differences in the electrical impedance of breast tumors and pulmonary masses [18, 19].

In this study, the electrical impedances of extracted rat livers at different incubation temperatures were measured, and the change in the tissue structure due to ischemia was evaluated [14].

## Materials and methods

### *Experimental procedure*

Male Wistar rats, each around 200 g in weight, were used as the experimental subjects. After injecting 0.1 ml (100 U) of heparin into the tail vein of the rat under ether anesthesia and performing laparotomy, more than a 1 cm length of liver tissue was removed, using a biopsy drill of 4 mm inner diameter. A drill biopsy apparatus for breast tumors (Nipro, Tokyo, Japan) was employed as the biopsy drill. This apparatus is composed of an output section that is equipped with a biopsy needle and the mechanism controlling rotation speed, and a motor section that has a lead wire. The biopsy needle is attached to the motor section, and the boring of tissue is carried out by rotating the needle. The biopsy needle is made of stainless steel; it is a cylindrical tube with a length of 45 mm, an outside diameter of 4.5 mm, and an inside diameter of 4 mm, and the tip is sharpened to a knife-edge shape. The biopsy needle was placed gently perpendicular to the surface of the liver and stabbed and inserted into the liver tissue at a rotation speed of 200 rev/min, under a flow of chilled physiological saline solution. When the needle had been rotated for 2–3 s and gently pulled out, a piece of tissue of cylindrical shape was retained in the biopsy needle. The sample tissue was then inserted into a measuring cell of 4 mm inner diameter. After both ends were plugged with current electrodes of 4 mm diameter, two voltage electrodes of 2 mm diameter were inserted into the center of the sample to a depth of 0.5 mm. Measurements were then made.

The impedance was measured by the four-electrode method, using the sine wave response method. The distance between the two central electrodes was 4.5 mm, and the potential difference across them was measured, thereby eliminating the influence of electrode impedance. There was no gap between the sample tissue and the cell wall, and leakage of current could be neglected.

Stainless steel was used for the current and voltage electrodes. A constant current (50 μA), the frequency of which was varied from 300 Hz to 200 kHz, was applied through the current electrodes. The electrode area was 12.56 $mm^2$, and the maximum current density was 0.39 $mA/cm^2$, which is within the linear range of the electrical properties of biological tissues (1 $mA/cm^2$ or less). Six specimens, incubated at 2 °C, 20 °C, 25 °C, 30 °C and 36 °C, were measured continuously for 6 h. In order to keep the measurement temperature constant, the measuring cell was enclosed in a water bath, with the water circulating at a constant temperature (Fig. 1).