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MODELLED TEMPERATURE CHARACTERISTICS OF HUMAN KNEE JOINT MENISCUS

Abstract. The aim of this study was investigates radiofrequency (RF) plasma temperatures around the active electrode of a bipolar arthroscopic RF resector and human knee meniscus tissue temperatures during RF resection. Knee arthroscopy knowing the optimal parameters for RF meniscus resection, such as resection temperature, mechanical stress on tissues, and process duration, is important. The parameters for RF tissue resection, such as RF plasma temperature, meniscus heating temperature, meniscus load, and resection process duration were determined by modelling the heating process of the knee joint meniscus using special COMSOL software.

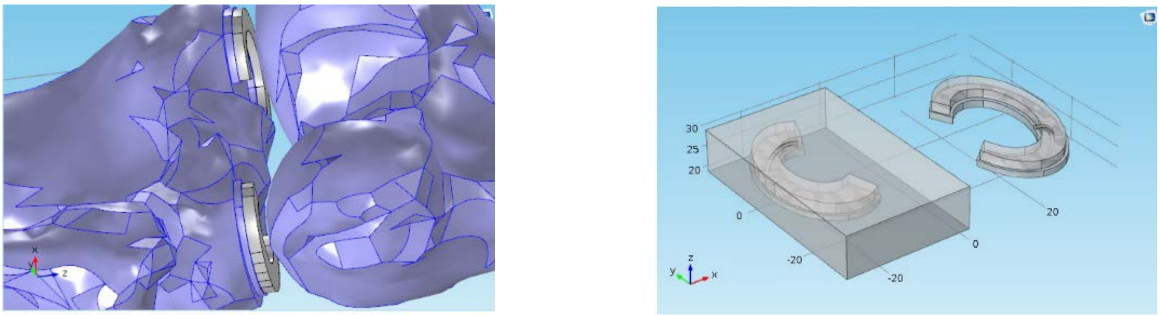
Keywords: arthroscopy; knee joint; meniscus resection; radiofrequency; temperature.

Introduction

Meniscal injury accounts for 75% of all knee injuries, with an incidence of 60…70 per 100,000 population and a prevalence of 12…14% [1]. Arthroscopic repair of a damaged meniscus is common in surgery, ranging from 10…20% [1, 2]. Mechanical resection has been the gold standard for treating knee injuries for years [3, 4]. In addition, special milling cutters and shavers are used in the mechanical resection process, which use a powered motor to reduce time loss when repeating resection cycles, increasing the mechanical stress on the meniscus tissue. This study aimed to determine the temperature parameters of RF plasma around the active electrode and the human knee joint meniscus tissue temperature during RF resection. In addition, it aimed to improve the RF resection technology, which can be successfully used to perform partial resection of the knee joint meniscus. In particular, it is necessary to experimentally determine the temperature indicators (characteristics or properties) of RF resection of the meniscus.

Materials and methods

The RF resection process model built in COMSOL Multiphysics 5.1 used a constant value for the force applied to the loop electrode, resection time, and electric potential on the electrode's surface. A mathematical model of a resection process involving a loop electrode immersed in the tissue of the knee joint meniscus during RF resection was built in COMSOL (Fig. 1).



a *b*

Fig. 1. The RF resection process model: (a) knee joint model with meniscus; (b) model of an electrode immersed in the meniscus tissue in a conductive liquid (0.9% NaCl)

Modelling the temperature distribution in a three-phase medium (electrode – meniscus and electrode – liquid) at a frequency of 100 kHz allowed us to study the non-stationary distribution of the temperature field during RF resection using an infrared thermograph and a pyrometer.

The physical parameters of the knee joint meniscus applied to the model in COMSOL Multiphysics were: thermal conductivity = 0.5 W/m·K; density = 30.9 kg/m^3; heat capacity = 60 J/kg·K; emissivity = 0.96 W/m^2.

Ten meniscus and RF plasma temperature measurements were made per experiment. The change in temperature of the isolated meniscus and nearby tissues in the centre of a loop electrode applied three times (inclusions) during HF resection with the Quantum 2 generator is shown in Figure 2.

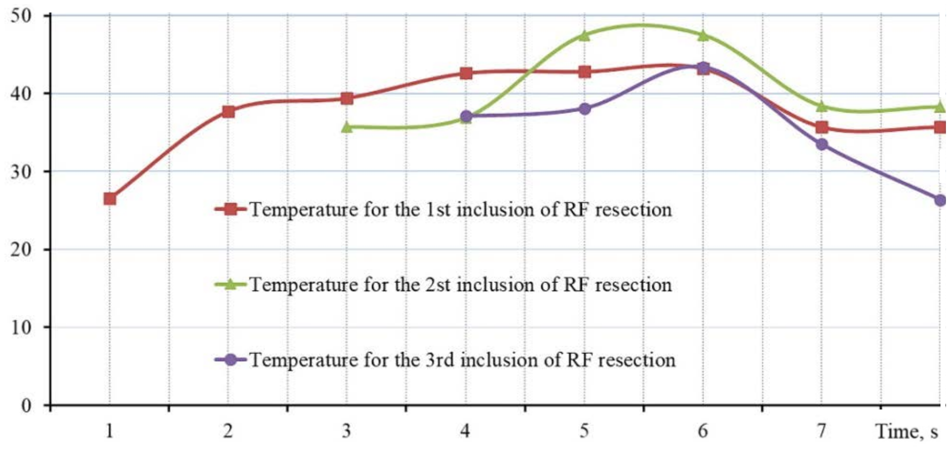


Fig. 2. Changing in temperature of the isolated meniscus and nearby tissues in the centre of the applied loop electrode: the first 8-second RF resection inclusion (*a*); the second 5-second RF resection inclusion (*b*); the third 3-second RF resection inclusion (*c*)

The temperature dispersion in time readings for each temperature measurement was ±1 °C, corresponding to an instrument error for temperature measurement of no more than ±2% in the range 0…90 °C.

Since the course of tissue thermal denaturation processes depends on temperature penetration deep into the tissue, this temperature value was determined by the RF resection simulation results in the COMSOL environment (Fig. 3).

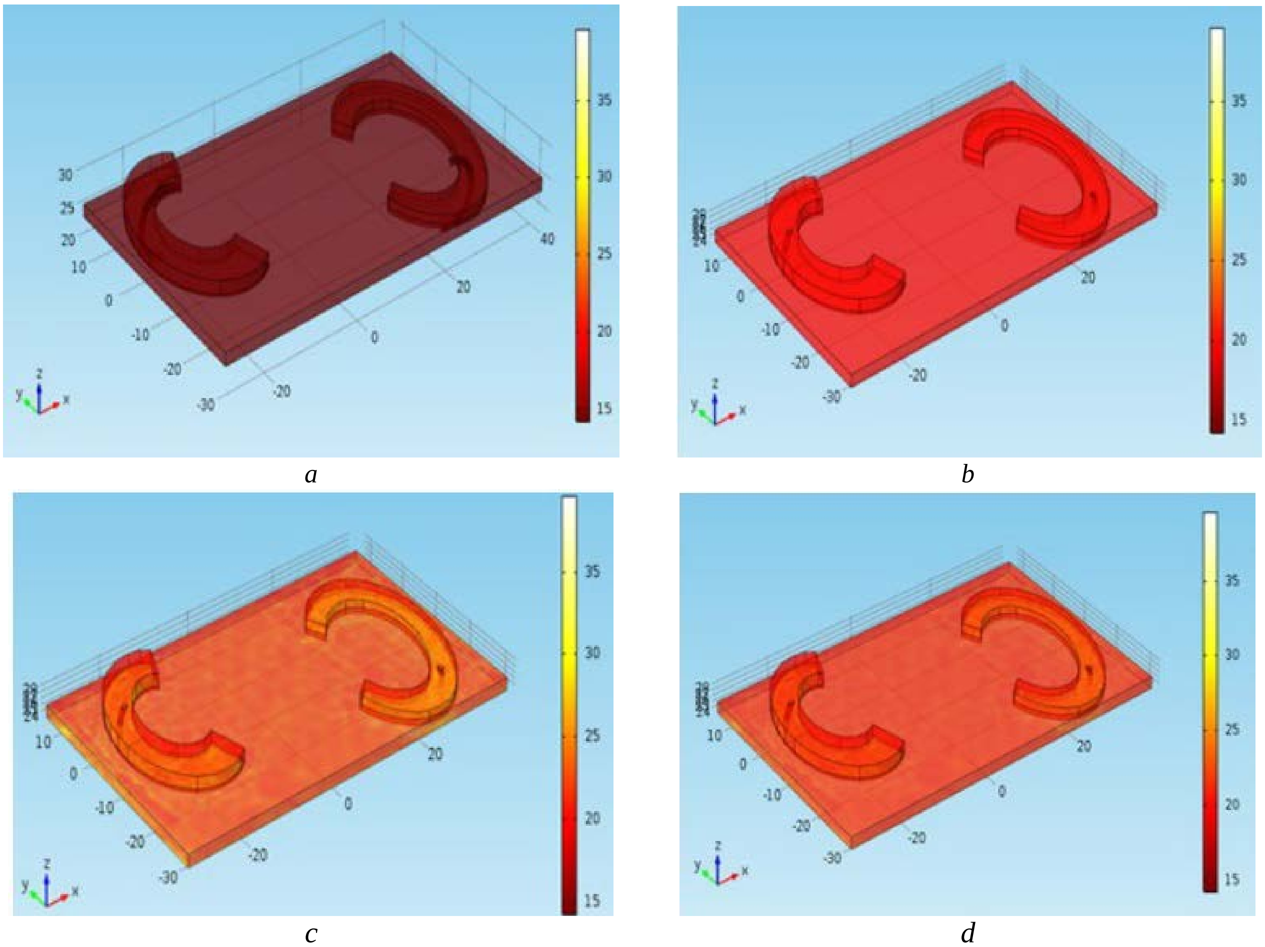


Fig. 3. COMSOL model of the temperature distribution in the meniscus: after 0.1 s at a conductive fluid temperature of +18 °C (*a*); after 0.3 s at a conductive fluid temperature of +20 °C (*b*); after 0.6 s at a conductive fluid temperature of +25 °C (*c*); after 0.9 s at a conductive fluid temperature of +30 °C (*d*)

The RF resection process simulation shows simultaneous and uniform heating of the knee joint meniscus and conductive fluid (0.9% NaCl) to 36°C. The simulation results in COMSOL agree with the experimental data obtained during the RF resection of an isolated meniscus (Fig/ 4).

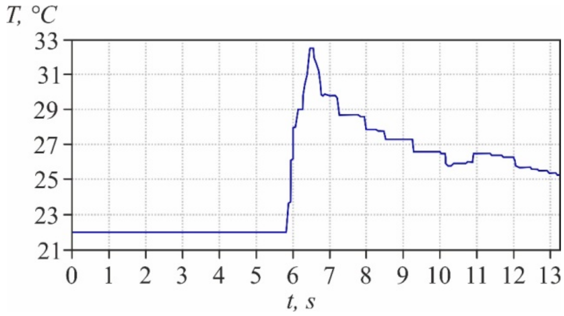


Fig. 4. Average temperature changes in the meniscus in the loop electrode's application area using conductive liquid (0.9% NaCl) in the experimental data (confidence interval = 1 °C; $p < 0.001$ for the data).

The optimal conditions for RF resection were determined based on the experimental and modelling data: (1) the meniscus's heating temperature during RF resection using a meniscus resector in a conductive fluid was 31…37 °C; (2) the meniscus's heating temperature when performing RF resection using a meniscus resector without a conductive fluid was 45…55 °C; (3) the temperature of the HF plasma was >37°C. Using these parameters for RF resection with the described arthroscopic instrument and a loop electrode will predictively improve the meniscal injury treatment results, confirmed by 10 clinical experiment results. Evidence supporting the efficacy of RF resection in treating meniscal injuries will be validated in future laboratory and clinical studies. The long-term postoperative effect of RF resection on the tissues surrounding the meniscus will be investigated in future studies.

Conclusions

The proposed RF resection technology can be used to perform partial resection of the knee joint meniscus. Studies have shown that mathematical modelling of the knee joint meniscus and conductive fluid heating processes due to a bipolar electrode through which an HF current passes closely aligns with experimental data. The optimal conditions for RF resection obtained from thermographic studies and modelling, such as the temperature of the knee joint meniscus and conductive fluid and resection process duration, can improve meniscus injury treatment result.

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