RADIOFREQUENCY ENERGY-INDUCED HEATING OF BOVINE ARTICULAR CARTILAGE USING A TEMPERATURE-CONTROLLED, BIPOLAR RF ELECTRODE

Frank G. Shellock, Ph.D., FACSM
University of Southern California
and
Shellock R & D Services, Inc.
Los Angeles, California

INTRODUCTION

Radiofrequency (RF) energy-induced heating is believed to be useful therapy for cartilage lesions that do not penetrate subchondral bone (1, 2). During the thermal modification of articular cartilage, the goal is to debride and smooth damaged articular surface by applying heat (1, 2).

Chondrocytes are known to be thermal-sensitive, insofar as excessive temperatures may cause cellular death and promote the degeneration of articular cartilage (3). Therefore, it is imperative to determine and use the lowest possible settings of RF energy that will produce the desired effects (1-3). Similar to other studies conducted to characterize temperature changes for tissues treated using electrosurgical devices (4, 5), it is necessary to determine the thermal effects association with the delivery of various levels of RF power to articular cartilage (3). A given level of RF energy may then be selected that produces the appropriate result, while avoiding excessive heating during treatment of articular cartilage lesions. Therefore, the purpose of this *in vitro* study was to determine the temperature changes associated with the use of RF energy delivered at different settings to bovine articular cartilage using a temperature-controlled, bipolar RF electrode. These data will provide information to help guide the use of this electrosurgical equipment for thermal-assisted chondroplasty.

MATERIALS AND METHODS

Electrosurgical System and Bipolar RF Electrode. The electrosurgical device used in this investigation was the VAPR II System (DePuy Mitek Inc., Raynham, MA). A newly-developed, temperature-controlled, bipolar RF electrode (VAPR TC, DePuy Mitek Inc., Raynham, MA) was utilized to apply RF energy. The electrosurgical system was used to deliver RF power at various settings, as follows:
(1) 55°C, 20 W
(2) 65°C, 20 W
(3) 70°C, 20 W
(4) 70°C, 30 W

These settings were derived from pilot experiments conducted to identify levels that could produce the lowest threshold for the previously-described visual changes induced by heating articular cartilage.

Measurement of Temperature. Because of well-known limitations of conventional thermometry methods operating in an RF environment, a fluoroptic thermometry system (accuracy and resolution of measurements $\pm$0.1°C; Model 3100, Luxtron, Santa Clara, CA) was used to record the temperatures in this investigation. The non-metallic, electrically non-conducting thermometry probe (diameter, 0.5

mm) responds rapidly (response time, 0.25 sec.) to determine temperature transients typically not detectable by other means in an RF environment (3-5).

Tissue Samples and Experimental Protocol. Samples of bovine patellar cartilage were used in this investigation. The tissue sample was placed on a plastic holder, the fluoroptic thermometry probe was calibrated and placed in a fixed position on the surface of the articular cartilage, and this preparation was submerged in a bath of 0.9% NaCl solution maintained at room temperature. The temperature-controlled, bipolar RF electrode was positioned in direct contact with the surface of the articular cartilage, within 0.1 mm of the fluoroptic thermometry probe. This site is representative of the highest temperature that results from RF energy-induced heating of cartilage (5).

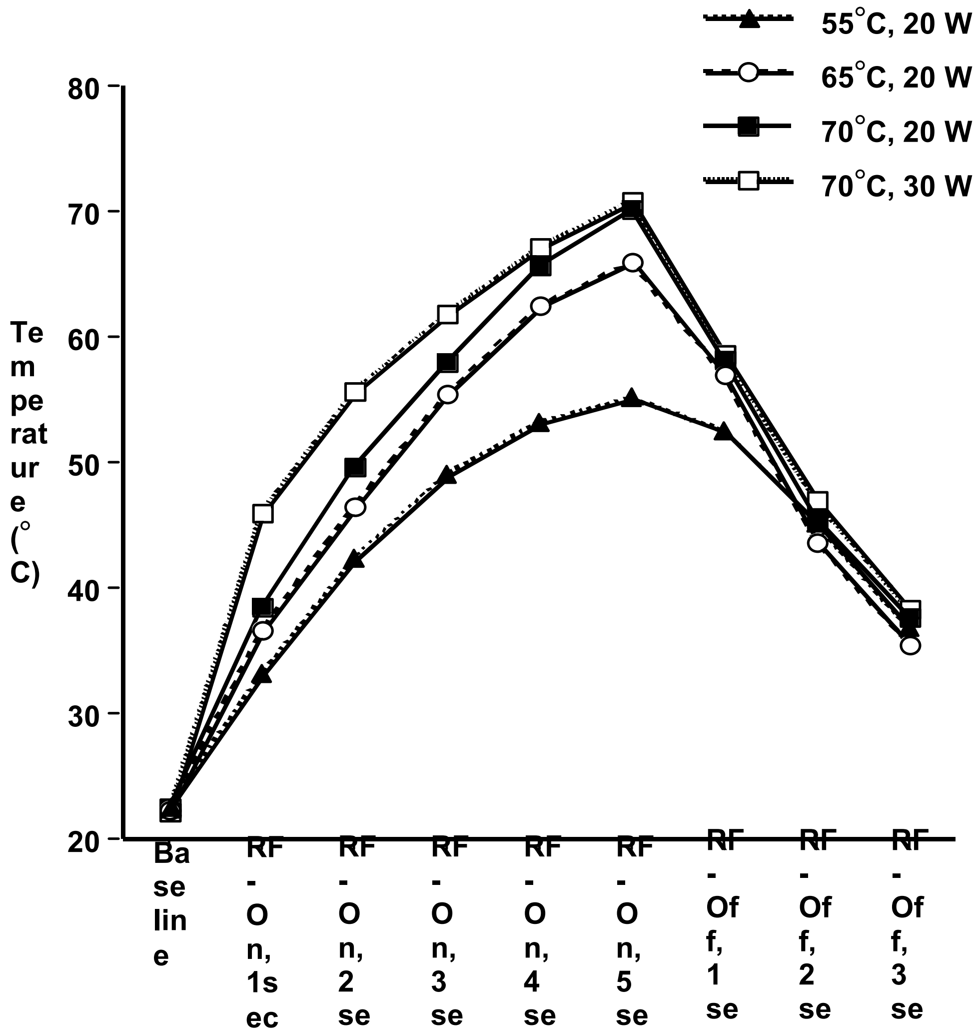
Temperatures were recorded at one second intervals for a baseline period of 5 seconds and during the delivery of RF energy for 5 seconds with the RF electrode applied in a stationary manner, and for a period of 3 seconds after the delivery of RF energy. This is different from how thermal-assisted chondroplasty is conducted whereby the RF electrode is applied in a moving, paint-brush manner. However, this investigation specifically intended to determine the temperature changes associated with extreme or worst case conditions for RF energy applied to cartilage. To obtain consistent results relative to a simulated *in vivo* use of the RF delivery system, the same investigator manually-controlled the contact pressure and orientation of the bipolar RF electrode to the articular cartilage tissue (3-5). Eight measurements were obtained for each RF delivery condition.

RESULTS

Baseline temperatures were stable (i.e., P –value, not significant) throughout the 5 sec. period that the eight separate recordings were obtained. Thus, these data were averaged and reported as mean values for each condition. Figure 1 shows a summary of the average temperatures recorded during application of the different levels of RF energy that were evaluated.

During the delivery of RF energy, the temperature measured on the cartilage surface reached the "set temperature" after 5 seconds for each setting that was evaluated. Notably, temperatures recorded on the cartilage surface did not exceed the set temperatures.

Figure 1. Graph showing temperature data for the temperature-controlled bipolar RF electrode (VAPR TC) delivering RF energy at various settings.


55°C, 20 W
65°C, 20 W
70°C, 20 W
70°C, 30 W
80
70
60
50
40
30
20
Te m pe rat ur e (° C)
Ba se lin e
RF - O n, 1s ec
RF - O n, 2 se
RF - O n, 3 se
RF - O n, 4 se
RF - O n, 5 se
RF - Of f, 1 se
RF - Of f, 2 se
RF - Of f, 3 se

DISCUSSION

Little research has been conducted to examine the various aspects of thermal assisted chondroplasty despite the great interest in this procedure. A laboratory study by Turner et al. (6) examined the use of a bipolar RF electrode for treatment of experimentally roughened cartilage (sheep model) compared to using the traditional shaver technique. The hypothesis was that RF energy-induced heating would be more tissue-specific than the shaving technique. The findings indicated that the bipolar RF electrode produced less severe histological changes, suggesting that this heating method of treating cartilage lesions may produce more acceptable, overall results compared to using a mechanical shaver. Notably, the report by Turner et al. (6) did not indicate the RF power setting used nor were the tissue temperatures evaluated.

Recently, Kaplan et al. (2) used a bipolar RF electrode-based electrosurgical system for thermal assisted chondroplasty and reported that the chondrocytes showed no appearance of damage in association with the application of thermal energy. Furthermore, there was a smoothing effect seen for the fibrillated cartilage. The combined data from these recent studies are encouraging and support the use of bipolar RF electrodes for thermal assisted chondroplasty.

The findings of this study characterized the temperature changes associated with the use of a newly-developed temperature-controlled, bipolar RF electrode applied to articular cartilage. Accordingly, this information may be used to select settings for the electrosurgical equipment to safely and effectively perform a thermal-assisted chondroplasty. The general recommendation for the use of RF power to treat damaged cartilage is that the lowest possible RF power setting should be utilized that produces a visual effect (1).

Similar to other orthopedic procedures using RF energy-induced heating of tissues (2), the delivery of RF energy for thermal-assisted chondroplasty is accomplished using visual observations. With the articular cartilage tissue temperatures characterized for an RF delivery system, the orthopedic surgeon selects the lowest, effective RF setting and relies on the visual cues to guide the application of the RF electrode, understanding that potential deleterious effects can occur. To prevent an iatrogenic cartilaginous injury, the application of RF energy-induced heating should be precisely directed towards damaged cartilage, avoiding areas that appear normal.

A recent study by Shellock (3) reported that the temperature-controlled monopolar RF electrode and RF generator poorly modulated the delivery of RF energy, resulting in temperatures that greatly exceeded the equipment's set temperature. However, this was clearly not the case for the temperature-controlled, bipolar RF electrode used in this investigation. The temperatures recorded at the RF electrode tip compared well to those recorded using the fluoroptic thermometry system (Unpublished observations, F.G. Shellock). Reasons for this good agreement between the set temperature and tissue temperature may be due to (1) the design of the RF electrode and (2) the control mechanism in the RF generator. The distal electrode has a relatively small mass and, therefore, transfers the temperature quickly to the thermistor within the electrode, permitting great accuracy for temperature measurements. The control mechanism in the RF generator system was specially-designed to be optimally "damped" to work with the RF electrode, thus preventing the development of inappropriate tissue temperatures.

This *in vitro* study was performed using bovine articular cartilage and a standardized experimental procedure. Differences between these conditions and the clinical situation will obviously have an effect on the tissue temperatures associated with a given level of RF energy utilized for thermal-assisted chondroplasty. Nevertheless, because this investigation used extreme conditions (e.g., stationary, direct contact delivery of RF energy for up to five seconds), the safety aspects of the findings have clinical relevance. That is, the highest average tissue temperatures for the various RF settings should not be exceeded in the clinical setting as long as the RF electrode is not applied in a stationary manner for a period of longer than 5 seconds.

Summary and Conclusions

This investigation determined temperature changes associated with RF energy delivered at different settings to bovine articular cartilage using a temperature-controlled bipolar RF electrode (VAPR TC). The findings indicated that the tissue temperatures were in close agreement with the equipment set temperatures. These data are specific to the particular RF delivery system (VAPR II), bipolar RF electrode (VAPR TC), and equipment settings that were used in this study.

REFERENCES

(1) Dillingham M, Arthroscopic electrothermal surgery of the knee. *Operative Techniques in Sports Medicine* 1998;6:154-156.

(2) Kaplan L, Uribe JW, Sasken, H, Markarian G. The acute effects of radiofrequency energy in articular cartilage: An in vitro study. *Arthroscopy* 2000;16:2-5.

(3) Shellock FG. RF energy-induced heating of bovine capsular tissue temperature changes produced by bipolar vs. monopolar RF electrodes. *Arthroscopy* (in press) 2000.

(4) Shellock FG, Shields CL. Temperature changes associated with radiofrequency energy-induced heating of bovine capsular tissue: evaluation of bipolar RF electrodes. *Arthroscopy* 2000;16:348-358.

(5) Shellock FG, Shields CL. Radiofrequency energy-induced heating of bovine articular cartilage using a bipolar RF electrode. *The American Journal of Sports Medicine* (in press)

(6) Turner AS, Tippett JW, Powers BE, et al. Radiofrequency (electrosurgical) ablation of articular cartilage: a study in sheep. *Arthroscopy* 1998;14:585-591.

[This research study was funded by an unrestricted grant from DePuy Mitek, Inc., a Johnson and Johnson Company, Raynham, MA]

For more information, call your DePuy Mitek representative at 1-800-382-4682 or visit us at www.mitek.com.
DePuy Mitek Inc., 325 Paramount Drive, Raynham, Massachusetts 02767