Effect of Simulated Shoulder Thermal Capsulorrhaphy Using Radiofrequency Energy on Glenohumeral Fluid Temperature

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Purpose: To determine joint fluid temperatures at different time intervals during treatment with radiofrequency energy (RFE) applied in intermittent and continuous treatment manners under flow or no-flow conditions using a simulated shoulder joint model. **Type of Study:** In vitro measurement of simulated joint fluid temperature during RFE treatment. **Methods:** A custom-built jig with a chamber (volume size, 25 mL) was used to mimic the adult human shoulder. Three RFE systems: Vulcan EAS plus TAC-S probe (Smith & Nephew Endoscopy, Andover, MA); VAPR II plus End-Effect Electrode (Mitek, Westwood, MA); and ArthroCare 2000 plus TurboVac 90° probe (ArthroCare, Sunnyvale, CA) were tested in the chamber with saline solution initially set at 23°C. Each RFE probe was applied in a paintbrush pattern on the capsular tissue in the chamber and a fluoroptic thermometry probe was placed 1 cm above the RFE treatment probe to record the fluid temperature. Both intermittent and the continuous treatment manners were tested under flow and no-flow conditions. For each probe/manner/flow combination, 6 bovine capsular tissue specimens were tested (n = 6). All data were recorded using a HyperTerminal software program (Hilgraeve Inc, Monroe, MI) into a personal computer. **Results:** When using intermittent and continuous treatment manners with flow, all recorded chamber fluid temperatures for all tested RFE probes at each time interval were below 40°C. Under no-flow conditions, with intermittent treatment, the ArthroCare probe caused joint fluid temperatures to exceed 50°C after 70 seconds of RFE treatment. With the continuous treatment, the ArthroCare caused chamber fluid temperatures to exceed 65°C after 2 minutes of treatment. The highest mean recorded chamber fluid temperature was caused by ArthroCare probe, which reached 80°C at 3 minutes. For all probes, continuous treatment caused significantly higher chamber fluid temperatures than intermittent treatment. **Conclusions:** The results of this study indicate that using flow during thermal capsulorrhaphy could lower joint fluid temperature to prevent heated joint fluid from killing chondrocytes of articular cartilage, and the intermittent treatment manner caused lower fluid temperature compared with continuous treatment within the RFE-treated shoulder joint. **Clinical Relevance:** Articular cartilage of the humeral head may suffer potential thermal injury from heating of joint fluid during RFE thermal capsulorrhaphy. **Key Words:** Radiofrequency energy—Shoulder—Temperature—Chondrocytes—Capsulorrhaphy.

Thermal capsulorrhaphy was introduced as a treatment for the capsuloligamentous component of shoulder instability in the early 1990s.[1-3] The use of radiofrequency energy (RFE) within the shoulder has led to a greater understanding of the risks, benefits, and possible complications associated with these de-

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0749-8063/05/2105-4128$30.00/0
doi:10.1016/j.arthro.2005.02.013

vices. There have been reports of axillary nerves injuries, adhesive capsulitis, capsular necrosis, and recurrent instability following RFE application in the shoulder.[4,5] In addition, a single case was reported recently in which bipolar RFE (bRFE) was used for thermal shrinkage of the anterior structure of the shoulder joint; a focal chondral defect of the humeral head subsequently developed and was treated with autologous chondrocyte implantation.[6]

For thermal shoulder capsulorrhaphy, the percentage of tissue shrinkage is time- and temperature-dependent.[7] The optimal RFE treatment time for thermal capsulorrhaphy has not been determined and has usually depended on surgeons' judgments. The clinically used temperature range for thermal shrinkage of collagen has been reported to be between 65°C and 75°C.[8] Chondrocytes in articular cartilage begin to die at 45°C, 50% of chondrocytes are dead at 55°C, and all chondrocytes are dead at 65°C.[9-13]

The purpose of this study was to determine glenohumeral fluid temperatures at progressive time intervals in a simulated shoulder thermal capsulorrhaphy model, evaluating monopolar RFE (mRFE) and bRFE, intermittent or continuous treatments, and flow or no-flow conditions. We hypothesize that glenohumeral fluid temperatures in excess of 65°C will occur under certain of these conditions.

METHODS

A custom-built ablative fixture jig (Fig 1) with a 25-mL chamber made from polycarbonate was used to mimic the adult human shoulder. The polycarbonate material was chosen for its transparence, electrical resistance, heat resistance, and dimensional stability under varying environmental conditions. The 25-mL volume of the chamber approximates the normal volume of the shoulder.[14,15] Three RFE systems were tested in 0.9% saline solution at an initial temperature of 23°C: the Vulcan EAS system coupled with a TAC-S probe at 75°C/40 W/coagulation mode (Smith & Nephew Endoscopy, Andover, MA); the VAPR II System coupled with an End-Effect Electrode at V2-60 W/coagulation mode (Mitek, Westwood, MA); and the ArthroCare 2000 System coupled with TurboVac 90° probe at a default setting/coagulation mode (ArthroCare, Sunnyvale, CA). Fresh bovine lateral knee joint capsule ($2.0 \times 1.0 \times 0.5$ cm^3) was used for each test. Each RFE probe was applied in a paintbrush pattern on the capsular tissue. For each test, a new probe was used.

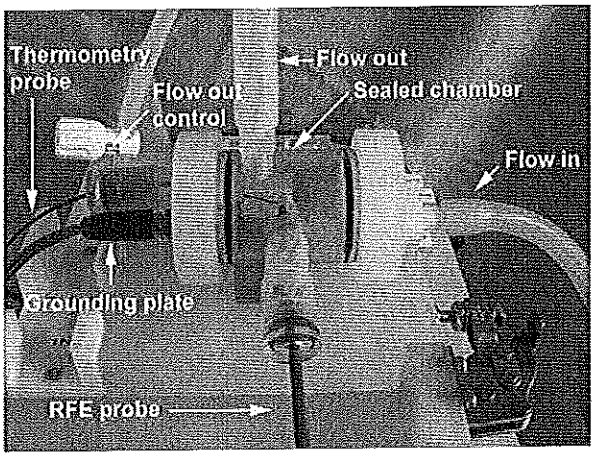

FIGURE 1. Experimental set-up for measurement of glenohumeral fluid temperature during simulated shoulder thermal capsulorrhaphy using RFE.

Each RFE device was tested using 2 manners of treatment, intermittent and continuous application. For the intermittent treatment, 1 treatment cycle included RFE on for 10 seconds and then off for 5 seconds, which was repeated 5 times. For the continuous treatment, each RFE probe was continuously activated for 3 minutes. Both the intermittent and the continuous treatments were tested under both flow and no-flow conditions. The flow rate was set at 200 mL/minute using a fluid pump. For each probe/manner/flow combination, 6 capsular tissue specimens were tested ($n = 6$).

A Luxtron 790 fluoroptic thermometry system/SFF-2 probe (Luxtron, Santa Clara, CA) was used to determine the fluid temperature in the chamber. The thermometry probe was placed 1 cm above the RFE treatment probe to record the chamber fluid temperature (based on a pilot study performed in our laboratory, chamber fluid temperatures recorded above the RFE treatment probe were higher than the temperatures recorded next to or below the RFE treatment probe). After a 15-minute warming-up period, the fluoroptic thermometer probe was then calibrated with a sealed precision bath at 23°C. The fluoroptic system's default setup was used to gather temperature data (sample/measurement = 8, measure 4 times/second, measurement update time = continuous). For the RFE intermittent treatment, chamber fluid temperatures were measured at 10 seconds, 25 seconds, 40 seconds, 55 seconds, and 70 seconds (each recorded time point at the end of RFE 10 seconds on treatment), and 30 seconds after RFE shut off. For the continuous treatment, chamber fluid temperatures were measured at

30 seconds, 1 minute, 2 minutes, and 3 minutes after RFE activation, and 30 seconds after RFE shut off.

Analysis of variance (ANOVA) was used to compare the effect of RFE probe type, time, treatment manner (intermittent, continuous), and flow condition (flow, no-flow) on the chamber fluid temperature. When ANOVA showed a significant difference for a specific parameter, Duncan's multiple-range tests were used to identify these differences; $P < .05$ was considered significant.

RESULTS

For intermittent treatment with flow, there were no significant differences in the mean chamber fluid temperatures at each recorded time interval among tested RFE probes ($P > .05$). For all tested probes, mean recorded fluid temperatures at each time interval in intermittent treatment with flow were below 40°C.

For intermittent treatment without flow, the ArthroCare probe resulted in higher mean chamber fluid temperatures than 1 or both of the other probes at all time intervals (Fig 2) ($P < .05$). In addition, the Mitek probe resulted in significantly higher temperatures than the Vulcan probe at 55-second and 70-second intervals ($P < .05$) (Fig 2). For the ArthroCare probe, mean recorded temperatures reached 46°C and 52°C at 55 seconds and 70 seconds, respectively. For the Vulcan and Mitek probes, mean recorded temperatures were below 45°C at all time intervals (Fig 2).

For continuous treatment with flow, the Vulcan probe resulted in a higher mean fluid temperature than the ArthroCare probe at the 1 minute interval ($P < .05$), however, the mean recorded fluid temperatures for all 3 tested probes were below 40°C at all time intervals.

For continuous treatment without flow, both ArthroCare and Mitek RFE probes caused significantly higher mean chamber fluid temperatures than the Vulcan probe at all recorded time intervals except for the Mitek probe at RFE on at 1 minute interval (Fig 3) ($P < .05$). The ArthroCare probe resulted in significantly higher mean chamber fluid temperatures than Mitek probe at all time intervals (Fig 3). The ArthroCare probe caused the mean chamber fluid temperatures to exceed 65°C after 2 minutes. The highest mean recorded chamber fluid temperatures caused by Mitek and ArthroCare probes reached to 52°C and 80°C at 3 minutes, respectively. After RFE probes were shut off for 30 seconds, the mean recorded chamber fluid temperature still remained above 75°C for the ArthroCare probe (Fig 3). Overall, using RFE in an intermittent treatment manner caused significantly lower chamber fluid temperature than the continuous treatment manner ($P < .05$).

DISCUSSION

The results of this study show that fluid flow and intermittent application of RFE resulted in lower fluid temperature measurements during thermal capsulorrhaphy in the model tested. A potential injury that has not been reported is injury of the articular cartilage within the joint secondary to heating of the joint fluid during RFE applications in the shoulder, because chondrocyte death begins to occur at a range of 45°C to 55°C.[10,12,13] In addition, RFE may be used for multiple applications in a single joint, including both

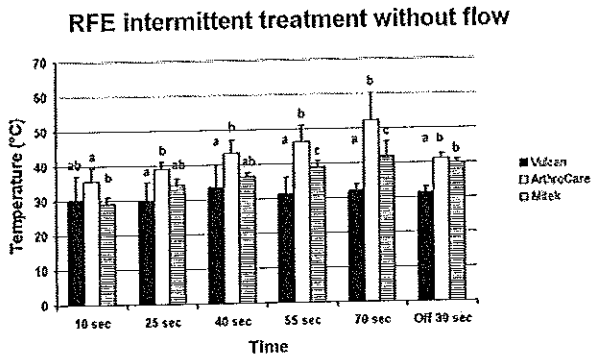

FIGURE 2. Chamber fluid temperatures (mean ± SD) at different recorded time intervals for tested RFE probes using intermittent treatment without flow. Means with different letters are significantly different from each other ($P < .05$).

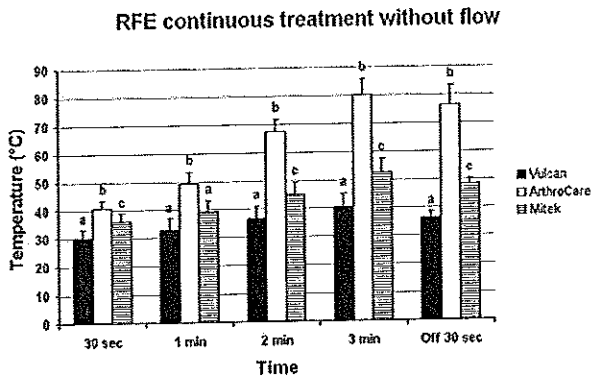

FIGURE 3. Chamber fluid temperatures (mean ± SD) at different recorded time intervals for tested RFE probes using continuous treatment without flow. Means with different letters are significantly different from each other ($P < .05$).

shrinkage and ablative procedures. There is the potential that the glenohumeral fluid may be heated over the threshold temperature of chondrocyte death, thereby causing thermal damage to the articular cartilage.

Tissue responds to heat by contracting and reducing the joint space, and surgeons rely on visual and tactile feedback to determine when to stop the thermal treatment. Collagen and its response to heat appear to differ among individuals with certain capsular tissue types, and some patients may respond more quickly to thermal energy than others.[4]

Currently, there are 2 basic RFE systems available for clinical application, mRFE and bRFE. During mRFE heating, current passes from the probe through the patient to the grounding plate. The mRFE system most commonly used in clinical application (Vulcan EAS RFE generator) is a temperature-controlled device. The mRFE system uses delivered power to control the tissue temperature reflected by a thermocouple within the mRFE probe tip.[5,16] At the beginning of treatment, the RFE generator delivers full preset power to cause tissue heating. The thermocouple within the mRFE probe tip is subsequently heated, reaching the preset temperature relatively quickly.[16] After reaching the preset temperature, the mRFE algorithm reduces the power to prevent tissue/probe-tip temperature from continuing to increase and then uses bursts of power output to maintain the tissue temperature near the preset temperature.[16] This may result in the mRFE generator delivering mean powers that are significantly less than preset powers to maintain the preset temperatures.

During bRFE application, current passes from the probe through the irrigation fluid and back through the probe. Therefore, the tissue effects with bRFE result from thermal and ionic modification of the tissue. These devices produce uniform and direct power output or a variable amplitude sinusoidal waveform while the bRFE probes are activated. No thermocouples are embedded in the probe tips to monitor and adjust the temperature at the interface between the probe tip and treated tissue.

Thermal (RFE) treatment of soft tissue has been increasingly used as an arthroscopic stabilization technique to enhance joint stability,[6] especially in the shoulder, although the safety and efficacy of this technique have come into question.[5,17] Compared with the laser thermal treatment, RFE has the potential advantages of being relatively inexpensive, temperature-controlled, and easy to use arthroscopically.[18,19]

Fluid flow resulted in temperatures of less than 40°C under all circumstances evaluated using our model. When performing RFE thermal capsulorrhaphy using the ArthroCare RFE device without flow, the chamber fluid temperatures reached to 52°C in intermittent treatments at 70 seconds and exceeded 65°C in continuous treatment after 2 minutes. The highest mean chamber fluid temperature reached 80°C for the ArthroCare RFE probe. Even after RFE shut down at 30 seconds, the mean chamber fluid temperatures remained above 70°C for the ArthroCare probe. Based on previous studies,[12,20] fluid temperatures higher than 45°C to 55°C typically start to kill chondrocytes.

The arthroscopic pressure-driven flow system is designed to inflate joint space under a certain pressure during the RFE thermal treatments. To maintain the appropriate fluid solution pressure in the treated joint, the flow-out rate is adjusted less than the flow-in rate. The bRFE device, especially for the ArthroCare generator coupled with the TurboVac probe, should be used cautiously in the pressure-driven flow systems when it is applied in a continuous treatment manner.

Several limitations of this study warrant discussion. First, the tested RFE probes were moved horizontally across the tissue when they were applied in a paintbrush pattern; therefore, the distance between the RFE probe and thermometry probe was variable, ranging from 1 to 2 cm. Second, the results from this in vitro study may not reflect the real joint fluid temperature in the in vivo condition. Third, the flow rates less than the 200 mL/minute and other different intermittent time cycles may be sufficient to prevent joint fluid temperatures from exceeding 45°C to 55°C in a clinical situation and require further investigation. Fourth, the RFE generators coupled with different kinds of probes at different settings could yield different results compared with this study in both experimental and clinical situations. Fifth, because the fluid temperature recorded by fluoroptic thermometry probe is 1 cm away from activated RFE probe, whether the cartilage of the humeral head within this distance experiences the same temperature and suffers thermal injury needs further investigation.

Our hypothesis that glenohumeral fluid temperatures in excess of 65°C would occur during RFE treatment was proven for only one treatment condition: the ArthroCare probe applied in continuous treatment without flow after 2 minutes. Clinically, surgeons performing shoulder thermal capsulorrhaphy using RFE should consider the effects of RFE system/probe/setting/mode, fluid flow versus no-flow, and technique of application of thermal energy (intermittent *v* continuous application) on glenohumeral fluid

temperature. The results of this study show that RFE applied in an intermittent manner with flow is a reliable method for maintaining safer intra-articular temperatures during RFE thermal capsulorrhaphy of the shoulder joint. Future research is required to determine whether elevated shoulder glenohumeral fluid temperature results in shoulder chondrocyte necrosis in vivo and, if so, to determine whether this cell death has clinical significance.

Acknowledgments: The authors thank Eric F. Dahlinger for his consultation with this study. Equipment used in this study was provided by Smith & Nephew, Endoscopy, Andover, MA.

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