SCIENTIFIC ARTICLE

Effects of Radiofrequency Probe Application on Irrigation Fluid Temperature in the Wrist Joint

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Purpose Radiofrequency (RF) probes used in wrist arthroscopy may raise joint fluid temperature, increasing the risk of capsular and ligamentous damage. The purposes of the current study were to measure joint fluid temperature during wrist arthroscopy with the use of RF probes, and to determine whether using an outlet portal will reduce the maximum temperature.

Methods We performed wrist arthroscopy on 8 cadaveric arms. Ablation and coagulation cycles using RF probe were performed at documented locations within the joint. This was done for 60-second intervals on both the radial and ulnar side of the wrist, to mimic clinical practice. We used 4 fiberoptic phosphorescent probes to measure temperature (radial, ulnar, inflow-tube, and outflow-tube probes) and measured joint fluid temperature with and without outflow.

Results There was a significant difference between wrists with and without outflow when examining maximum ablation temperatures ($p < .002$). All specimens showed higher maximum and average ablation temperatures without outflow. Maximum joint temperatures, greater than 60°C, were observed in only no-outflow conditions.

Conclusions In performing RF ablation during wrist arthroscopy, the use of an outlet portal reduces the joint fluid temperature. Without an outlet portal, maximum temperatures can exceed desirable levels when using ablation; such temperatures have the potential to damage adjacent tissues. It is useful to maintain adequate outflow when using the radiofrequency probes during wrist arthroscopy. *(J Hand Surg 2009;34A:1832–1837. Copyright © 2009 by the American Society for Surgery of the Hand. All rights reserved.)*

Key words Ablation, fluid temperature, radiofrequency, wrist arthroscopy, outflow.

The use of electrosurgical (radiofrequency [RF]) devices in arthroscopic surgery has gained increasing popularity in recent years as a tool for resection, ablation, and coagulation.[1,2] RF is established as an adjunctive surgical tool used primarily for tissue ablation and thermal shrinkage in knee and shoulder arthroscopic surgery.[2–7]

The development of small joint RF probes has extended the use of RF in the wrist joint. RF probes are small and easily controlled, allowing simple access to the wrist joint. Triangular fibrocartilage complex (TFCC) debridement and scapholunate (SL) thermal shrinkage were the first applications of this technology to the wrist, and researchers have been engaged in clinical studies concerning these applications.[8–10] Thermal capsulorrhaphy for midcarpal instability has also been performed.[11]

Concerns have been raised over inadvertent increases in irrigation fluid temperature in the wrist dur-

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Received for publication September 30, 2008; accepted in revised form July 17, 2009.

In support of this research, one of the authors received grants or outside funding from Depuy/Mitek, Westwood, MA.

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0363-5023/09/34A10-0012$36.00/0
doi:10.1016/j.jhsa.2009.07.006

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ing RF probe application, resulting in thermal tissue damage, because complications such as tendon ruptures and skin burns have occurred as a result of thermal ablation.[12] Such issues have not been encountered in shoulder and knee joint arthroscopy. These 2 joints have a large volume, outflow is usually obtained through large cannulas, and the outflow is often facilitated by vacuum suction. Furthermore, RF probes are available for knee and shoulder arthroscopy with suction tubes attached. These factors lead to mass flow rates through the joint, which in turn lead to reduced temperature changes in the joint because of heat convection, resulting in average temperatures below 45°C.[13]

The wrist joint presents a different clinical scenario because of its small volume and restricted outflow (traditionally, gravity-assisted outflow through an 18-gauge needle is used in wrist arthroscopy). To date, there are no RF probes equipped with suction tubing available for small joint arthroscopy. This leads to concerns over possible thermal damage of tissues resulting from irrigation fluid overheating during RF probe application in the wrist. The fact that fluid accepts heat more quickly than solid tissue must be kept in mind when considering the implications of heat generation in a small joint. Thermal damage can occur secondary to denaturation of collagenous tissues or as a result of cell death. Collagen denatures at 65°C[14] but denaturation starts at about 40°C.[15] Cell death can occur at a much lower temperature, 45°C,[14] and depends on the duration of elevated temperatures. To encompass all possible cases, Good et al applied a damage threshold of 45°C in considering shoulder capsulorraphy.[16]

The irrigation fluid temperature resulting from RF probe application has not been well studied. We performed a cadaveric study of irrigation fluid temperature changes during RF probe application to the wrist joint. This study sought to clarify whether such temperature changes occur for RF probes use in the wrist, and, moreover, whether an outflow portal will reduce internal temperatures during wrist RF ablation.

MATERIALS AND METHODS

We prepared 8 cadaveric forearms with no musculoskeletal anomalies for arthroscopic surgery (Fig. 1). The forearms had been stored at –20°C and were thawed to room temperature immediately preceding usage. The arm was fixed proximally to the arthroscopy table and supported using tower distraction. A 50-N distraction force was applied using finger traps. The 3-4 portal was used for viewing, the 6U portal for outflow, and the 4-5 and 6R portals for instrumentation. Each specimen was maintained at room temperature (21°C). An arthroscopic pump supplied a constant intra-articular pressure of 50 mm Hg with an inflow rate of 80 mL/min. Outflow was achieved through an 18-gauge needle in the 6U portal. The outflow was gravity assisted and was unrestricted but was not otherwise controlled.

Wrist arthroscopy was performed using standard techniques on all 8 wrists. Temperatures were recorded using 4 fiberoptic phosphorescent sensors (Model 3100 Fluoroptic Thermometer; Luxtron Corp., Santa Clara, CA) at a rate of 4 measurements per second. To establish reference temperatures, we placed the 4 sensors in an ice bath until constant output values were reached. Two sensors were inserted 4 mm into the joint space: the radial temperature probe was inserted at the site of the 1,2 portal and the ulnar temperature probe at the 6U portal. One sensor was inserted into the outflow tube at the base of the 18-gauge needle outlet and 1 sensor was inserted into the inflow supply. Use of catheter insertion guides ensured that no fluid leaked from the joint space sensor insertion sites. Figure 1 shows the experimental setup without the outflow. For consistency, we collected the outlet portal data across all trials even when no outlet was used.

We performed ablation using an RF probe (VAPR 2.3 mm, side effect electrode; Depuy Mitek, Westwood, MA). The manufacturer's default energy settings were used: 60 W for ablation and 45 W for coagulation. New RF electrodes were used for each specimen and the same temperature probes were used for all specimens.

The RF probes were placed into the joint space and activated without tissue contact or outflow. The RF probe was first located 10 mm from the temperature sensor on the ulnar side. Ablation and coagulation cycles of 60 seconds were performed with at least 2 minutes between cycles. The initial temperature for each sensor for each test was monitored to ensure an initial reading equal to the room temperature of 21°C. This procedure was repeated with the RF probe 10 mm from the sensor on the radial side. The coagulation and ablation cycles were then repeated at the sites of the SL ligament and TFCC. Next, outflow was obtained by inserting an 18-gauge needle and the sequence was repeated.

We collected 3 trials of each probe setting and location, identified the peak value during each trial, and computed the average temperature at each sensor over all trials for each specimen, which in turn was also averaged to compute an overall average.

Three statistical tests were performed. A $2 \times 4 \times 2 \times 4 \times 2$ repeated-measures analysis of variance

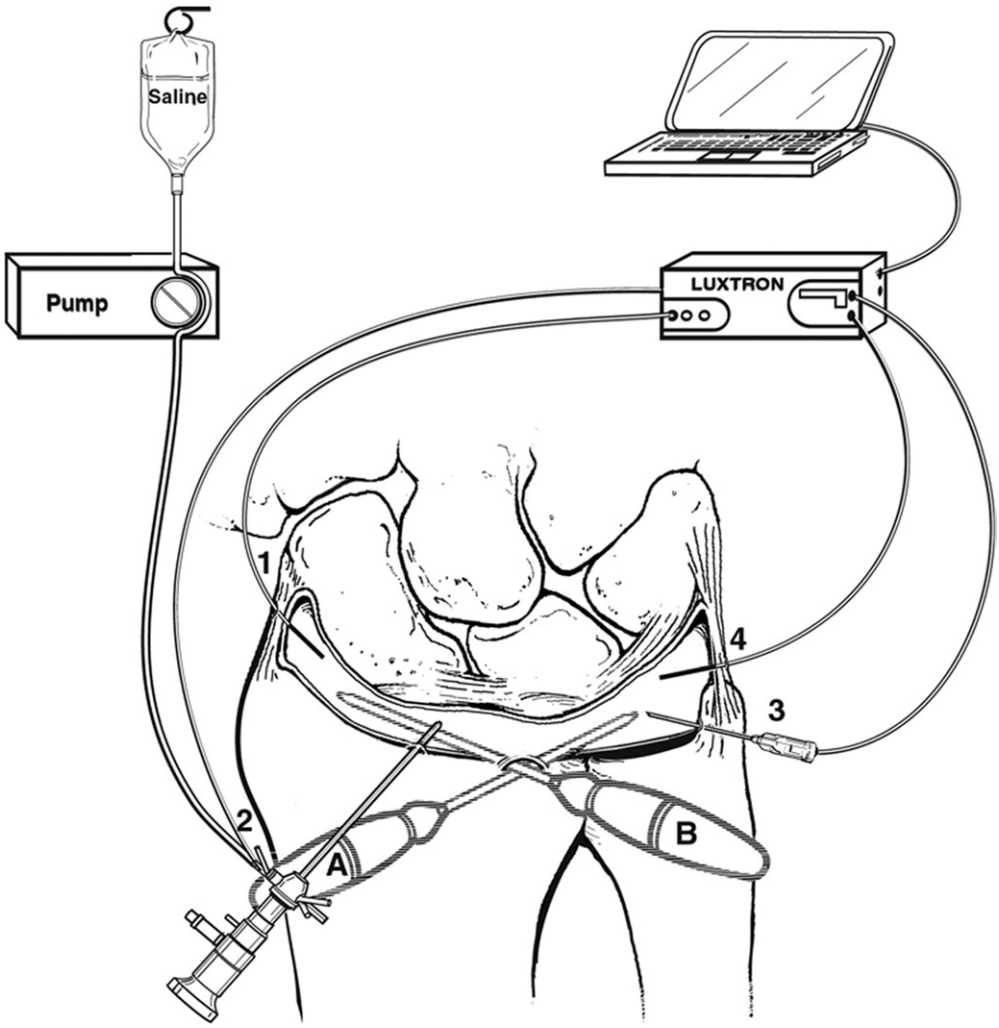

FIGURE 1: Experimental apparatus. 1–4, sensor locations; 3, outlet; A, B, probes at the ulnar and radial locations. A traction load of 50 N was applied.

(ANOVA) was performed for initial statistical analysis, where the independent variables were condition (without outflow or with outflow), location (ulnar, radial, SL, or TFCC), probe setting (coagulation or ablation), sensor location (inflow, radial, ulnar, or outflow), and temperature measure (average or peak). Given that local transient temperatures for the most severe probe setting were a primary concern, we also performed two $2 \times 4 \times 2$ repeated-measures ANOVAs to separate the peak ablation temperature from the average ablation temperature. The first $2 \times 4 \times 2$ ANOVA analyzed only maximum ablation temperatures for condition (with or without outflow), probe location (ulnar, radial, SL, or TFCC), and sensor location (radial or 6U). The second ANOVA used only the ablation temperatures averaged over the entire ablation time using the same $2 \times 4 \times 2$ design. Tukey's honest significant difference post hoc tests were then conducted on results for which more than 2 conditions could be compared when a statistically significant correlation was found.

RESULTS

Figure 2 shows a sample result for a set of three 60-second ulnar ablation trials. The inflow value for all trials remained constant at 21°C and the outflow temperature for this trial was constant, as expected, because the outlet portal was not inserted.

The statistical comparison between cases with outflow and without outflow was significant at $p < .002$ when examining maximum ablation temperatures alone in the $2 \times 4 \times 2$ ANOVA. Probe location ($p < .02$) and sensor location ($p < .02$) were also statistically significant. The maximum temperature during ablation frequently exceeded 60°C without outflow, but only 1 case during coagulation reached this temperature. Specifi-

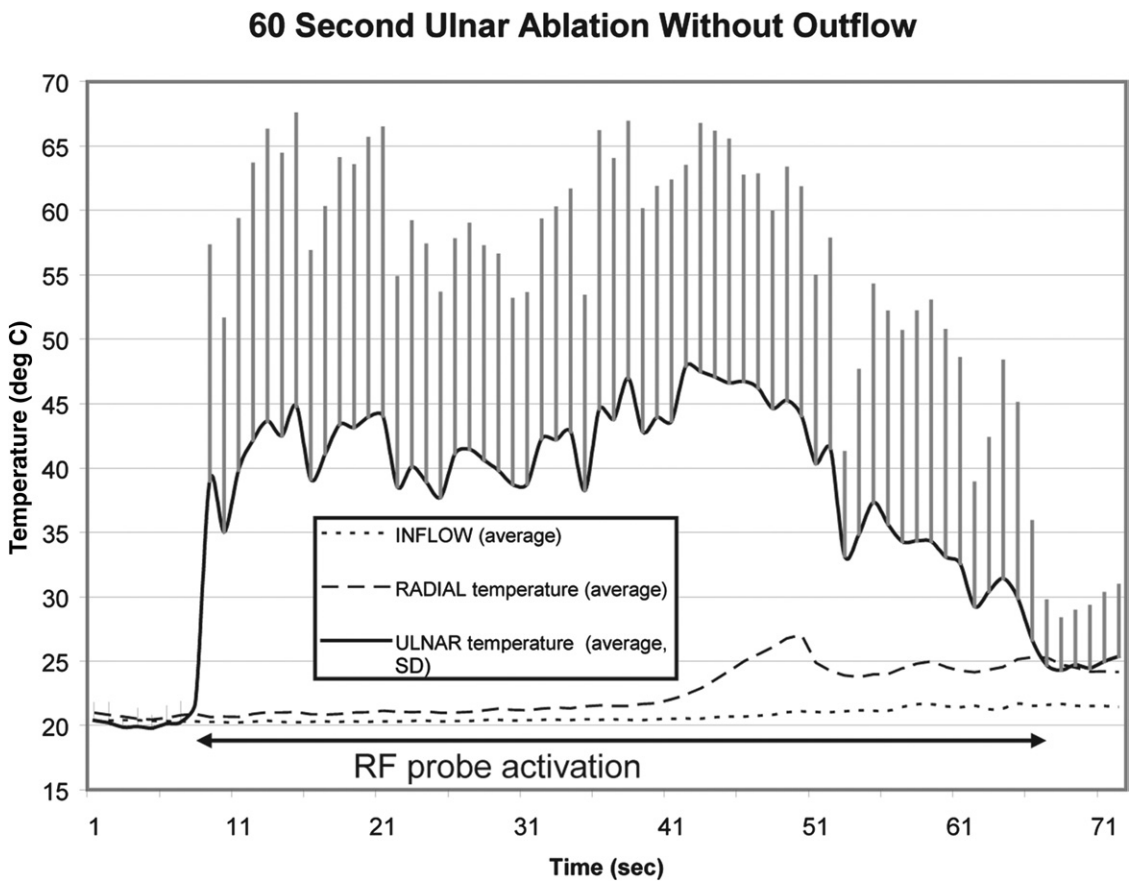

FIGURE 2: Sample temperature profile from 3 trials of 1 specimen.

TABLE 1. Average Maximum Temperatures (°C) During Ablation With and Without Outflow

	Radial Sensor Without Outflow	Radial Sensor With Outflow	6U Sensor Without Outflow	6U Sensor With Outflow
Ulnar ablation	30.1 (9.3) [21.8–44.9]	23.5 (4.3) [21.1–33.5]	61.2 (16.9) [36.5–89.2]	30.1 (6.7) [23.6–44.3]
Radial ablation	43.2 (21.2) [24.2–84.7]	28.1 (4.7) [22.2–35.4]	29.4 (6.8) [21.1–40.0]	26.4 (4.3) [21.0–35.2]
SL ablation	24.9 (2.3) [22.1–28.9]	23.8 (2.2) [21.4–28.4]	23.1 (1.9) [20.4–27.0]	23.3 (2.0) [21.2–26.9]
TFCC ablation	22.7 (2.2) [21.1–27.0]	22.0 (1.0) [21.0–23.6]	36.4 (17.7) [22.1–76.0]	29.6 (11.6) [23.0–54.8]

n = 8. Data are presented with SD in parentheses and range in brackets.

cally, the temperature at the 6U location exceeded 60°C during ablation without outflow in 4 of the 8 specimens, whereas the radial sensor exceeded this value in 2 of the specimens. In 1 other case, that of a 6U sensor during TFCC ablation, a temperature exceeded 60°C. The coagulation settings produced 1 instance of a maximum temperature above 60°C: the 6U portal sensor in 1 case of ulnar coagulation. No sensor temperatures in any case with outflow exceeded 60°C. Table 1 shows the average maximum temperatures in all 8 specimens, where *average maximum* refers to the average of the 8 maximum temperatures. Figure 3 displays the single highest peak temperature during ablation among all 8 specimens. The maximum temperatures occurred at the sensor locations closest to the ablation site. Temperatures were elevated at the other sensor location in the joint space but did not exceed 60°C. For example, the average peak temperature at the 6U sensor during ulnar ablation was 61.2°C, whereas the corresponding value at the radial sensor was 30.1°C.

The temperatures averaged over the entire time of ablation exceeded 60°C in the case of radial ablation

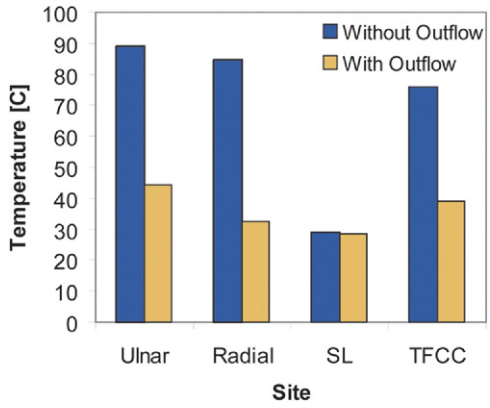

FIGURE 3: Peak temperatures during ablation across all specimens.

without outflow at the location of the radial sensor; several other results showed higher temperatures when no outflow was present. However, there was no statistical difference in average temperatures with and without outflow.

DISCUSSION

Radiofrequency probes work by creating a high-frequency alternating current between their tips. Heat is generated by friction of ions in the treated tissue as they try to follow this alternating current. When the temperature exceeds 100°C, water in the treated tissue is vaporized and ablation of the tissue occurs.[1,2] Temperatures around 60°C lead to collagen triple helix unwinding, reduction of the length of the molecule, and tissue shrinkage[3,4,6]; collagen damage begins at even lower temperatures.[17] In contrast to electrocautery, the RF probe itself is not heated but heat is generated in the tissue. The only known limitation to RF probe use is in patients with pacemakers or other implantable electronic devices, but clinical experience regarding their application to the wrist has been limited.

The application of RF in shoulder arthroscopy has been studied extensively.[2–4,6,7] Optimal temperatures between 65°C and 75°C were found to result in maximal tissue shrinkage without thermal necrosis.[3,7,18,19] Sporadic complications included capsule destruction, nerve injuries, and cartilage damage that sometimes led to massive chondrolysis.[20,21]

Radiofrequency probe application to the wrist is becoming increasingly popular. Mechanical debridement with a full-radius resector is difficult at times in the wrist joint because of its small volume and often leads to bleeding with associated diminished visualization. Thermal ablation of the tissue is more thorough and rapid, while providing immediate hemostasis. In addition, there is less likelihood of iatrogenic injury to the adjacent cartilage that can be encountered with larger mechanical debridement.[8] However, we are unaware of meaningful experimental or clinical data to determine whether temperatures during the procedures reach levels that may inadvertently damage adjacent tissues. Pell and Uhl[12] reported that among 47 patients who underwent wrist arthroscopy with thermal ablation, 4 sustained serious complications; thus there was a 9% complication rate. The complications included tendon ruptures and a full-thickness skin burn. These authors concluded that the minimal amount of soft tissue between the wrist capsule and the surrounding skin, tendons, and neurovascular structures places these structures at risk when using thermal ablation in wrist arthroscopy. During ablation, damage is most likely to occur to cartilaginous structures, but large nerves also cross the wrist. Like all tissue, thermal nerve injuries are a function of both temperature and duration. However, damage to nerve tissue can occur at temperatures of 55°C for 1 second,[22] indicating that ablation could also lead to nerve damage with inappropriate positioning of the probe.

In the current study, the presence of an outlet portal reduced the likelihood of the fluid reaching damaging peak temperatures and also reduced the average temperatures. This study investigated the scenario of inadvertent RF probe activation without tissue contact in the wrist, which represents the maximum possible thermal energy delivery to the irrigation fluid. Tissue debridement will probably absorb energy and decrease the thermal energy delivery to the irrigation fluid.

The increase in temperature should be considered in relation to the experimental conditions. First, the baseline temperature for the current study was 21°C instead of body temperature. The amount of energy input to the joint was not a function of the temperature in the joint, although the increase in temperature was a function of the amount of energy added. The heat capacity of the tissue over the small range of temperatures in this study can be considered to be constant, so that the temperature rise would be independent of the original temperature. If one adds this difference to all the temperature increases to estimate the *in vivo* case, many more instances of potentially damaging high temperature may have occurred. Thus, the results may be considered conservative for the possible onset of denaturation, and more so for cell death. The second experimental condition with a potential to alter the results was the lack of concurrent vascular perfusion. Vascular transfer of heat, if present, could certainly alter the temperature profile, especially in the case of the average. However, blood flow may not be a major factor if a tourniquet is used

during surgery. Perfusion should have a major effect only on the average temperature. A relatively constant perfusion would change the average by convecting heat away but would not act quickly enough to change the circumstances leading to a peak temperature. These circumstances could be the development of hot gaseous bubbles or localized fluid flow.

The net effect of the baseline temperature and perfusion together would be less substantial to the differences caused by the peak temperature. If both *in vitro* experimental conditions are considered either together or separately, the peak temperature changes could reach damaging levels. That is, the change in baseline temperature would affect both the average and the peak. The amount of heat added would be the same and the change in peak temperature would be the same, assuming that the heat capacity of the tissue is constant.

The irrigation fluid temperature quickly returned to baseline values after RF probe deactivation. Therefore, there would be merit in intermittent RF probe activation for a few seconds at a time, as is practiced by some surgeons to protect the joint from overheating. Although the heat conduction in the tissue reduced the temperatures quickly, the conductivity of the tissue did not impede transient temperatures from exceeding 60°C.

Several possible independent variables were omitted in the experimental method. The use of a different-size outlet portal may have altered the results, and only 1 flow rate was studied. Furthermore, the use of chilled water was not considered and the actual amount of flow through the outlet portal was not measured. The volume of fluid in the joint was also not quantified. This omission could have introduced variability and may have altered the results. Finally, only 1 portal location was considered. Tissue contact was not included in the study so that multiple trials could be performed, and because the specimens were also for later use in anatomical studies that required tissue integrity. Further work could consider these additional issues.

The use of an outlet portal with RF ablation reduces the temperature. Without an outlet portal, maximum temperatures can exceed desirable levels when using ablation. These high temperatures are in regions close to the ablation site. Temperatures at other locations may not exceed 60°C but can also be elevated.

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