Factors Influencing Intra-Articular Fluid Temperature Profiles with Radiofrequency Ablation

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Factors Influencing Intra-Articular Fluid Temperature Profiles with Radiofrequency Ablation

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Background: Radiofrequency ablation devices are being used increasingly in arthroscopic surgery. However, there are concerns that excessive temperatures may damage the articular cartilage. The purpose of this study was to investigate the temperature profiles that occur within the glenohumeral space with the use of one commercially available radiofrequency ablation probe.

Methods: Ten fresh-frozen human cadaver shoulder specimens were used. Intra-articular temperatures were measured at different time intervals over a two-minute period at a distance of 1, 3, 5, and 10 mm away from the probe. The radiofrequency probe was activated throughout the range of machine power settings, and irrigation fluid flow was varied (no flow, a flow at 60 mm Hg without suction, and a flow at 60 mm Hg with suction).

Results: Temperatures deleterious to articular cartilage chondrocytes (i.e., those in excess of 50°C) were seen with an increased duration of application, a decreased distance between the thermometer and the probe, and a decreased irrigation fluid flow rate. The highest recorded irrigation fluid temperature reached >80°C after two minutes in a no-flow setting. The flow rate was found to be the most significant predictor of intra-articular temperature profiles. The various machine power settings had no apparent influence on temperature, meaning that higher probe settings are not necessarily associated with higher temperature profiles.

Conclusions and Clinical Relevance: These results demonstrate the importance of the management of the irrigation fluid flow rate across the joint during arthroscopic procedures that involve radiofrequency ablation. Even short intervals of limited flow could lead to supraphysiological temperature profiles and potentially to cartilage damage.

Radiofrequency ablation devices are being used increasingly in arthroscopic surgery to precisely remove soft tissue as well as to simultaneously cut and coagulate vascular tissue[1-3]. The use of a radiofrequency device can increase the joint fluid temperature during those procedures, depending on a number of variables, including the volume of fluid in the joint, the duration of the use of a radiofrequency device, and the flow rates of irrigation fluid through the joint[1,2]. If these variables are not properly controlled during the arthroscopic procedure, the heated irrigation fluid can lead to a variety of complications such as nerve injury, capsular tissue damage, and chondrolysis[1-6]. Horstman and McLaughlin[7] noted capsular tissue changes at temperatures of >65°C and chondrocyte damage at temperatures as low as 45°C. Voss et al.[8] determined the critical temperature that reduces chondrocyte viability, and they evaluated the ability of chondrocytes to recover after exposure to certain temperatures for a period of time. They concluded there was a sharp increase in the death of chondrocytes between 50°C and 55°C. Therefore, fluid temperatures as low as 45°C may have deleterious effects on chondrocytes and soft-tissue cells.

Previous studies have used a custom-built chamber in an attempt to mimic a shoulder model rather than using cadaver shoulders[9]. Others have used a cadaver shoulder model but looked only at a single probe setting without varying irrigation fluid flow rates[10]; however, there is limited research regarding the use of radiofrequency devices that measures temperatures at varying flow rates, with varying probe settings in a cadaver shoulder model. Our goals were to investigate the temperature profile that occurs within the glenohumeral joint space during

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the use of a radiofrequency ablation probe, to identify safe guidelines, and to improve procedure and device designs to decrease the number of complications due to irrigation fluid heating.

The purpose of this study was to evaluate factors influencing glenohumeral joint temperatures during arthroscopy. Our hypothesis was that irrigation fluid flow through the joint, the distance from the probe, ablation time, and probe setting all have an effect on joint fluid temperature.

Materials and Methods

Ten fresh-frozen human cadaver shoulder specimens were used. The donors had a mean age of seventy-six years (range, forty-three to ninety-eight years) at the time of death. All soft tissues around the shoulder were preserved. Each shoulder was thawed to room temperature for forty-eight hours prior to the experimental procedures. Standard posterior and anterior shoulder arthroscopy portals were established. The arthroscope with irrigation inflow was placed in the posterior portal. Soft-tissue ablation was performed with use of a bipolar radiofrequency device (Super TurboVac; ArthroCare, Sunnyvale, California). The radiofrequency device was placed in the joint through the anterior portal. A transrotator cuff portal was established, and a temperature probe was placed through it (Fig. 1). The temperature probes were calibrated with a saline solution bath and two separate thermometers between each experiment. Continuous temperature output from the probes was measured on a multichannel fiberoptic thermometer unit (Luxtron FOT Lab Kit; LumaSense Technologies, Santa Clara, California). This kit utilizes fluoroptic technology (FOT) for the measurement of temperature by exciting a phosphorescent sensor attached to the end of a fiberoptic probe[1,10]. The fluoroptic technology instruments are well suited for measuring temperatures in the harsh environments often encountered during research, which may include high voltage and strong radiofrequency emissions[10]. The fluoroptic technology system is calibrated with an accuracy of ±0.5°C, and is simultaneously recorded on a computer with use of TrueTemp computer software (Luxtron; LumaSense Technologies). Four thermometer probes (Luxtron; LumaSense Technologies) were placed into the joint at a distance of 1, 3, 5, and 10 mm away from the radiofrequency probe (Fig. 2). Temperatures were measured at zero, five, ten, twenty, thirty, forty, fifty, sixty, ninety, and 120 seconds of ablation time. The radiofrequency probe setting was varied at 1, 3, 5, 7, and 9, which correspond to voltage settings of 100, 150, 200, 250, and 300 V, respectively. The voltage at each controller set point is fixed, and the thermal effect output is based on the voltage setting. The glenohumeral joint irrigation fluid flow was varied from no-flow (both the radiofrequency suction was off and the inflow was off), to a moderate-flow (radiofrequency suction was off, but the inflow pressure was 60 mm Hg), and to a high-flow setting (inflow pressure of 60 mm Hg, with the radiofrequency device suction on). Arthroscopy was performed with pump inflow of normal saline solution at room temperature (17° to 19°C, verified by thermometer). Between

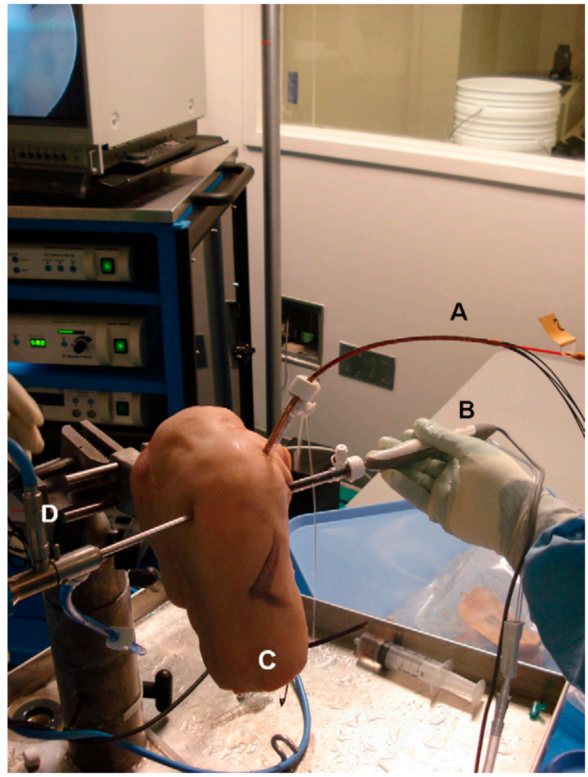

Fig. 1
The laboratory setup used for this study, showing the fluoroptic thermometer probes in the transrotator cuff portal (A), the radiofrequency device in the rotator interval portal (B), the cadaveric shoulder in the beach-chair position (C), and the arthroscope in the posterior portal (D).

each test, the temperature of the joint was allowed to return to baseline, and the joint was irrigated copiously with saline solution at room temperature. The average temperature of the ten shoulders was calculated at each setting and time point and was recorded on a graph. A temperature of >50°C was defined as deleterious for the purpose of analysis. In order to minimize any variance, we maintained the same distance (approximately 8 mm) between the arthroscope and the radiofrequency probe tip at all times. We purposely kept the arthroscope focused and centered on the radiofrequency probe tip as would occur during a surgical procedure.

Statistical Analysis

Comparisons between groups and temperatures were performed with use of one-way analysis of variance. A generalized estimating equation (GEE) strategy was used to determine the effects of four variables on the risk of a temperature of ≥50°C: group designation (no flow and no suction, inflow pressure of 60 mm Hg with no suction, and inflow pressure of 60 mm Hg with suction), radiofrequency probe setting (1, 3, 5, 7, and 9), distance of the radiofrequency probe to the thermometer (1, 3, 5, and 10 mm), and time of ablation (zero, five, ten, twenty,

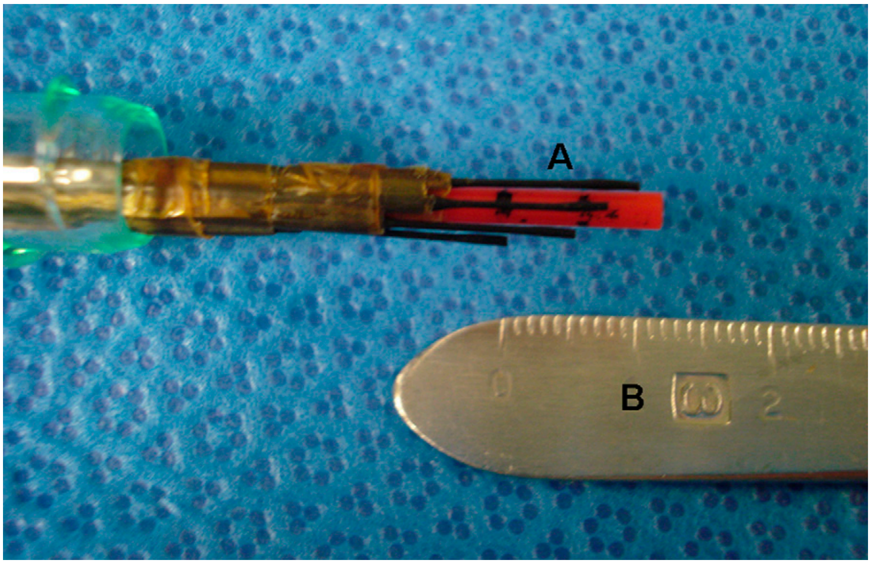

Fig. 2

Four fluoroptic probes (A) are set 1, 3, 5, and 10 mm away from the tip of the radiofrequency device and are taped at a 1, 3, 5, and 10-mm distance from the tip of a plastic straw, next to a scalpel (B) showing the millimeter gradations.

thirty, forty, fifty, sixty, ninety, and 120 seconds). A binary response cutoff temperature of 50°C that was chosen as the dependent outcome of interest allowed for a logistic regression model to be fit with a binomial distribution and with the shoulder treated as the within-subject factor; the group, as a factor; and probe setting, distance, and time of ablation, as covariates in the multivariable generalized estimating equations model[11]. An independent working correlation structure was used to handle the repeated measurements over time on the same shoulder (correlated data within subjects) with fit of the model judged with use of the quasi-likelihood criterion, and significance assessed by the Wald chi-square test[12]. A two-tailed value of $p < 0.05$ was considered significant.

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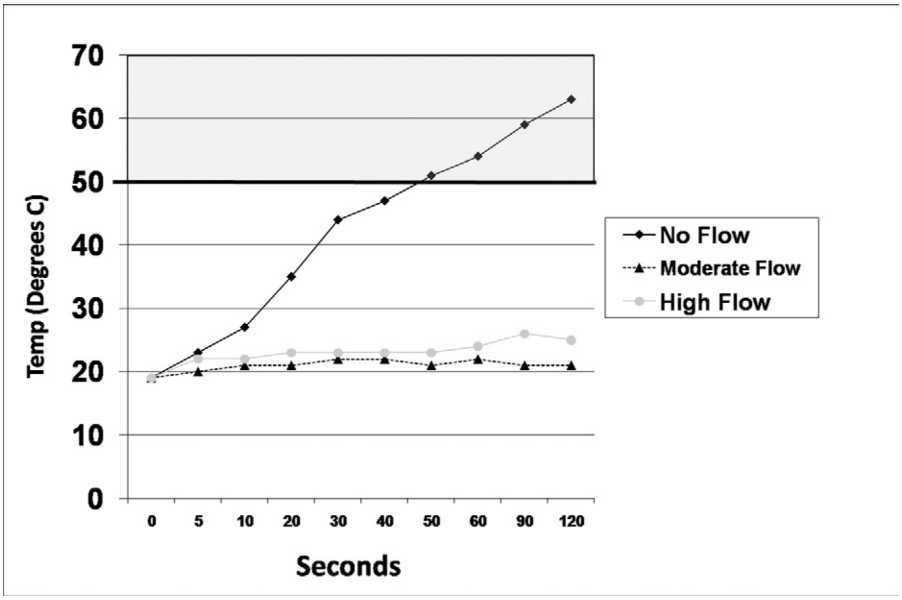

Fig. 3

Temperature profiles at a radiofrequency probe setting of 7 in the no-flow, moderate-flow, and high-flow conditions at a distance of 5 mm.

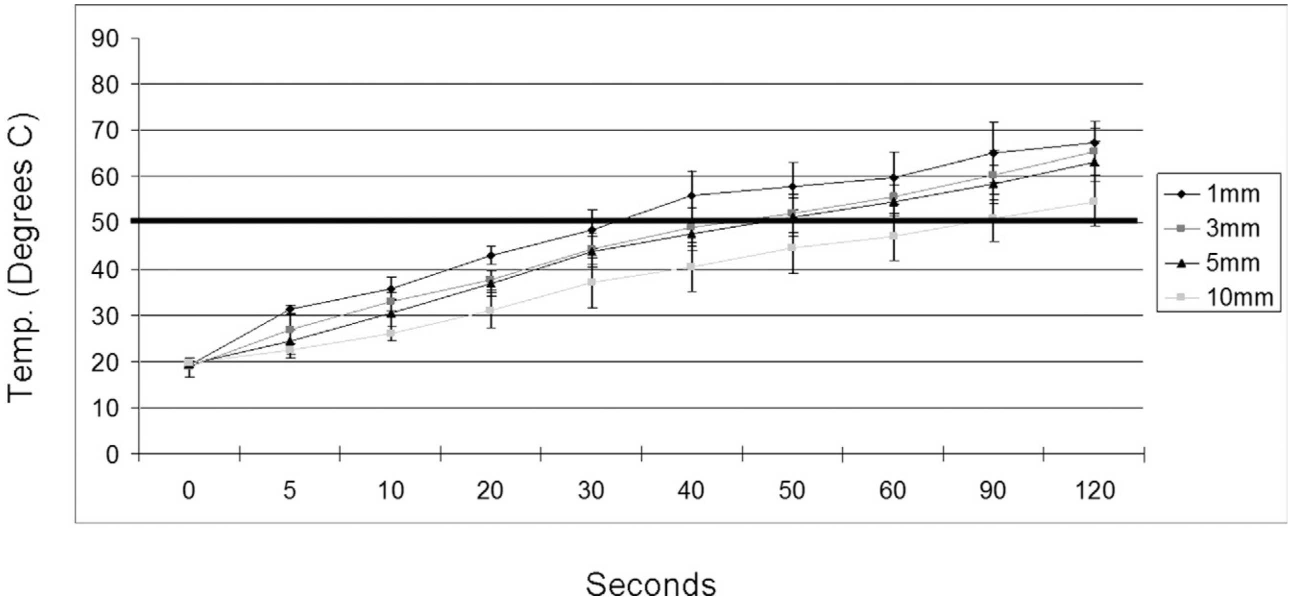

Fig. 4

Temperature profiles (mean and standard deviation) for the radiofrequency probe with no suction and no flow averaged over all probe settings.

Results

Comparing the data at a standard probe setting of 7 and a 5-mm distance from the radiofrequency probe, we found no significant difference in temperature at each time point between the moderate-flow state (flow and no suction) and the high-flow state (flow and suction) ($p > 0.05$). Both had significantly lower temperatures than the no-flow state (no flow and no suction), with a difference up to 47°C (Fig. 3).

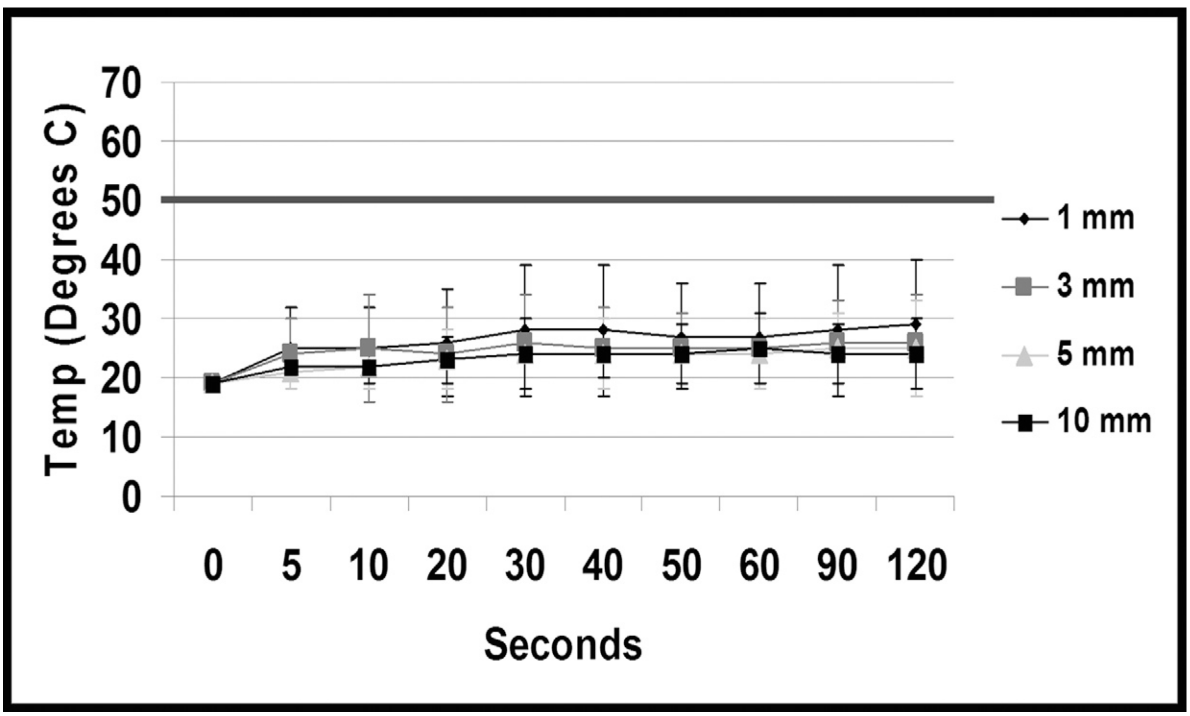

Fig. 5

Temperature profiles (mean and standard deviation) for the radiofrequency probe with flow but no suction averaged over all probe settings.

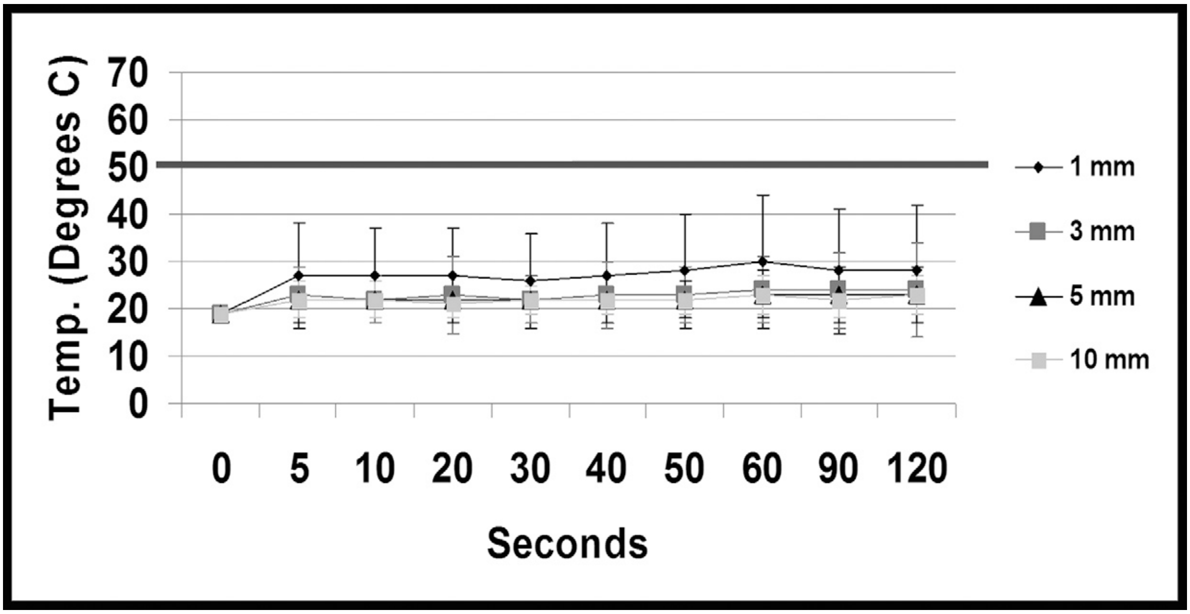

Fig. 6

Temperature profiles (mean and standard deviation) for the radiofrequency probe with suction and flow averaged over all probe settings.

In settings of no flow, temperatures of >50°C occurred in 12% of the cases after only five seconds, and 22% of the cases after ten seconds, reaching a threshold high enough to cause thermal damage to chondrocytes. With temperatures averaged over all probe settings, temperatures increased as the distance between the radiofrequency probe and the thermometer decreased and the time periods increased (Figs. 4, 5, and 6).

We further evaluated the data as a binary set of numbers with a cutoff point of 50°C, where there is likely to be an increased risk of thermal necrosis. With regard to the risk of a very high temperature (i.e., a temperature of ≥50°C), we found that the estimated probability is 32% (95% confidence interval, 20% to 44%) for the no-flow state (no flow and no suction). This finding was independent of the other variables. This increased risk in the no-flow group was significantly higher than in the groups with moderate flow (flow and no suction) or high flow (flow and suction) ($p < 0.0001$), and the probability of reaching 50°C was 1% (95% confidence interval, 0% to 2%) for both the moderate-flow and the high-flow groups. The radiofrequency ablation probe setting did not significantly affect temperature ($p = 0.99$) (Figs. 4, 5, and 6). The highest recorded fluid temperature exceeded 80°C at two minutes in a no-flow setting.

Discussion

Radiofrequency ablation has been used commonly in orthopaedic surgery over the last few years[1,2]. Most of the devices use electromagnetic energy to shrink, coagulate, and ablate tissue[1,2]. The device (Super TurboVac; ArthroCare) used in the present study is bipolar. The ground is located on the probe, and energy is localized in a plasma layer at the tip of the probe. With continuous flow of the arthroscopic irrigation fluid, the thermal energy is controlled and dissipated[10]. Several studies have examined the complications related to the use of thermal energy for tissue shrinkage in the shoulder[5-7,13-17]. Axillary nerve thermal injury and capsular disintegration appear to be common concerns during thermal capsular shrinkage procedures[9,18]. These types of complications appear to be due to the transmission of too much thermal energy to the adjacent tissues[5,6,13,14]. However, reports of thermal energy-induced axillary neuropathies are rare[6,16], and most spontaneously resolve. Certainly, of all of the potential complications, glenohumeral chondrolysis is one of the most serious[19,20].

While there are no precise data on specific temperatures that would be deleterious to chondrocytes and soft-tissue cells, previous studies have provided important insight[1,8]. Edwards et al. compared cartilage matrix temperatures during thermal chondroplasty by using monopolar and bipolar radiofrequency devices and concluded that, even with the differences among the devices, temperatures of >70°C generated by the radiofrequency energy are high enough to kill articular cartilage chondrocytes[1]. Voss et al. determined the critical temperature that reduces chondrocyte viability and evaluated the ability of chondrocytes to recover after exposure to certain temperatures for a period of time[8]. They concluded there was a sharp increase in the death of chondrocytes between 50°C and 55°C. Horstman and McLaughlin noted capsular tissue changes at temperatures of >65°C and chondrocyte damage at temperatures as low as 45°C[7]. Petty et al. stated that thermal and/or radiofrequency energy can cause chondrocyte cell death, and they reported on the cases of three patients who had rapid glenohumeral chondrolysis following shoulder arthroscopy[14]. Two of the three cases involved the use of thermal energy within the glenohumeral joint. The authors concluded that a substantial increase in the temperature of arthroscopic irrigation fluid could lead to thermal tissue necrosis, and that this could be a potential etiology of diffuse chondrocyte death. Jerosch and Aldawoudy considered chondrolysis the most important complication that may occur following arthroscopy when radiofrequency devices were used[19].

Previous investigations have studied temperature profiles in various shoulder models. McKeon et al. showed that, in a cadaver shoulder model with a constant irrigation flow rate through the joint and with a single probe setting, temperature profiles did not reach physiologically deleterious levels[10]. Lu et al. used a custom-built jig with a chamber to mimic the adult human shoulder and found that, when intermittent and continuous treatment modes with flow were used, all recorded chamber fluid temperatures for the three tested radiofrequency probes at each time interval were <40°C[9]. The three radiofrequency systems used were Vulcan EAS and TAC-S probe (Smith and Nephew Endoscopy, Andover, Massachusetts), VAPR II and End-Effect Electrode (Mitek, Westwood, Massachusetts), and ArthroCare 2000 and TurboVac 90° probe (ArthroCare). Under no-flow conditions, intermittent treatment with the radiofrequency probe caused joint fluid temperatures to exceed 50°C after seventy seconds. With continuous radiofrequency probe treatment, the chamber fluid temperatures exceeded 65°C after two minutes of treatment, and the highest mean recorded chamber fluid temperature reached 80°C at three minutes[9]. In a recent study in a cadaver shoulder model, with a Mitek VAPR 3 radiofrequency system (DePuy Mitek, Raynham, Massachusetts) and variable flow rates through the joint, Good et al. showed that intra-articular fluid temperatures of >45°C were obtained in all flow settings[17]. They also noted that the time needed to cool the joint down to a safe temperature was substantially longer in no-flow states compared with 50% flow and 100% flow states. They concluded that use of a thermal probe during arthroscopy can cause joint temperature elevations high enough to cause chondrocyte death; however, they did not comment on what could be done by the surgeon to increase the margin of safety.

Our results demonstrate that each of the following three factors has an effect on temperature: the duration of application, distance from application, and flow rate, with the flow rate being the most important factor. As the distance from the tip of the radiofrequency probe increases, the risk of reaching temperatures high enough to cause thermal damage to chondrocytes decreases. Furthermore, as the duration of application increases, the risk of thermally induced damage increases. It is important clinically to understand this fact as scenarios often arise in the surgical setting where fluid flow becomes decreased. The suction on the radiofrequency probe can occasionally become obstructed or the irrigation fluid supply is depleted. As a no-flow or limited-flow scenario occurs, it is important to realize that after only five seconds of ablation, temperatures of >50°C can be reached.

A limitation of this study is that the cadaver specimens were studied at room temperature rather than at actual body temperature. If anything, this experimental design is a best-case scenario, given that the temperature of the testing system started below body temperature and thus more heat would be required to reach fluid temperatures of >50°C. Thus, it is plausible that, if the shoulder specimens were at body temperature, the effect could have been worse. We attempted to simulate clinical conditions and used saline solution at room temperature as our arthroscopy irrigation medium. Furthermore, temperatures were measured on a continuous basis with fluoroptic thermometer probes. We observed additionally, during preliminary testing, that the distance of the arthroscope from the radiofrequency probe, and the direction in which the arthroscope was pointing, could influence the temperature profiles. Since inflow for the arthroscopy came through the arthroscope, we concluded that temperature profiles could be altered substantially if the arthroscope was pointed away from the probe. Therefore, in order to minimize any variance, we maintained the same distance (approximately 8 mm) between the tip of the arthroscope and the tip of the radiofrequency probe at all times. We purposely kept the arthroscope focused and centered on the probe as would occur during a surgical procedure. Finally, normal blood flow in living tissue may act as a heat sink to reduce intra-articular temperatures, and this fact was not controlled for since we used cadaver specimens.

These results are only valid for one type of bipolar radiofrequency device in a specific joint, the shoulder. Monopolar devices or other brands of radiofrequency devices may exhibit different intra-articular temperature profiles. In the recent study by Good et al., similarly elevated temperature profiles were noted for the Mitek VAPR 3 radiofrequency system (DePuy Mitek)[17].

These results demonstrated a safe thermal level for most recommended parameters of use of the ArthroCare radiofrequency device in the shoulder. We found that temperatures of >50°C could be achieved when no irrigation fluid flowed. Flow appeared to be the major determinant of the intra-articular temperature profiles we measured. The lowest temperature profiles were seen in a high-flow scenario with the probe suction activated, thus maximizing the flow. In order to maintain temperatures at physiological levels and to avoid excessive heating, irrigation fluid flow rates must be carefully managed. We also observed that the probe power setting had no significant influence on temperature. This finding suggests that, with this device, higher probe power settings are not necessarily associated with higher temperature profiles. Finally, as the distance from the radiofrequency probe tip increases, the risk of reaching temperatures high enough to cause thermal damage to chondrocytes decreases, and as the duration of ablation increases, the risk of inducing thermal damage increases.

On the basis of these data, we offer four recommendations for the use of radiofrequency ablation: (1) make certain that there is always adequate irrigation fluid flowing through the joint; (2) use the radiofrequency device in short time intervals to minimize heating of the surrounding fluid and allow adequate time between ablations for the fluid to cool down; (3) make sure the suction on the radiofrequency probe is working properly to maximize flow; and (4) maintain the arthroscope focused on the radiofrequency device while it is in use, whether it has an inflow or outflow cannula, to further maximize the irrigation fluid flow through the joint. ■

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