



Analysis of parameters influencing intraarticular temperature during radiofrequency use in shoulder arthroscopy

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Abstract

Purpose The aim of this study was to analyze the influence of several factors on the temperature in the work chamber during shoulder arthroscopy procedures in order to identify danger zones when using radiofrequency.

Methods Intraarticular temperature was measured intraoperatively using system with special probe that directly measured the temperature in 22 patients. Data collection was prospective. The main parameters studied were the measurement of the temperature depending on: localization of the procedure (glenohumeral or subacromial), the use of coagulation or ablation, the number of portals, the pressure of the arthropump, the time of use, the blood pressure and the temperature of the operating room.

Results Ninety-three recordings were made. No complications were identified. Addition of a portal reduces the average elevation of 3.8 °C ($p < 0.05$). Ambient temperature above 19.15 °C with two portals leads to an average increase of 13.3 °C ($p < 0.05$). Increasing the pressure of the arthropump of 10 mmHg increases the temperature of 0.8 °C ($p < 0.05$). No significant difference was found on the change in blood pressure, location and mode of use.

Conclusions These results show the interest of controlling these factors when performing shoulder arthroscopy procedure. This study identifies situations of high joint risk when using radiofrequency and thus to prevent secondary complications such as burns and massive chondrolyses.

Keywords Arthroscopy · Shoulder · Radiofrequency · Temperature · Complications

Introduction

Shoulder arthroscopies procedure has become very common [1]. Radiofrequency devices are frequently used for this procedure in soft tissues management. Several publications in the literature [2–5] report the risk of complications following thermal ablation during arthroscopy [6, 7]. These devices cause an increase in the joint fluid temperature [8] and can thus potentially cause skin burns, nerve and capsular

damage [5] and extensive chondrolysis [4, 9]. The burns observed were due to poor management of the irrigation fluid and non-respect of the manufacturers' instructions [8]. Reported causes were insufficient circulation of intraarticular fluid (aspiration tube blockage) and cases with electrodes including a cannula drain; the cannula was not connected to the operating block aspiration system [10]. Irreversible damage to the capsular tissue and chondrocyte occurred at temperatures as low as 45 °C [11, 12]. These complications appear to be due to the transmission of an excess of thermal energy in the adjacent tissues [13, 14].

Intraarticular temperature increases depend on several factors, notably the power level and activation of the radiofrequency electrode along with the duration of activation, number of activations and duration of the break between two activations. In addition to variables relating directly to the material used, the volume of fluid in the joint, the rates of fluid irrigation through the joint, as well as the position of the temperature sensor relative to the electrode, should also be considered. In vitro studies are somewhat limiting

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in this context and do not necessarily correspond well to the real-life conditions of an arthroscopic procedure. A review of the literature [15–18] shows that temperature increases in the shoulder joint space do not reach levels considered dangerous for the surrounding tissues if irrigation is sufficient [19]. To our knowledge, there are very few studies analyzing the variation in these parameters during an arthroscopic procedure in in vivo model [20].

The aim of this study was to analyze the influence of several factors on the temperature in the work chamber during shoulder arthroscopy procedures in order to identify danger zones when using radiofrequency.

Materials and methods

Patients

A single-surgeon, single-center prospective observational study was performed. All patients signed informed consent for their data collection. The single inclusion criterion was for patients undergoing a shoulder arthroscopy using radiofrequency at the time of the study. Patients were in beach chair position. Exclusion criteria were patients undergoing a shoulder arthroscopy with a wider portal (> 1 cm), patient refusal of data use or non-availability of a radiofrequency system.

Surgical procedure

All surgeries were performed by the same surgeon at the same center using the same materials for each procedure. A 30° arthroscope with irrigation tube connected to a one-way-flow arthropump (Conmed®) was used. Irrigation was performed with 3-l bags containing normal saline (0.9% NaCl). A bipolar radiofrequency generator (Quantum™ 2, Smith & Nephew™) was used with a bipolar electrode (Ambient Super TurboVac™ 90, Smith & Nephew™).

Classic entry approaches for shoulder arthroscopy were used. The arthroscope was placed in the posterior portal at the soft point. Additional portals were used according to the operator's requirements and the surgical indication. Standard practices were implemented, including intermittent use of radiofrequency. The generator warned the operator when the temperature reached beyond 40 °C. Aspiration via the probe was connected to the operating room aspiration system all the time and at maximum intensity.

Study parameters and data collection

Temperature rise of the irrigation fluid was the main parameter under study. Other many parameters were collected for the primary objective with a systematic specific data

collection protocol for each surgery. Measurement of the intraarticular temperature was carried out using the electrode (Smith & Nephew™) which has a sensor at 1 cm of its extremity. The measurement of temperature is therefore reliable in a sphere of 1 cm in diameter at the tip of the electrode. Operator read out the value of different parameters during the surgery. Assisting nurse completed a pre-filled data collection page. For each use of the radiofrequency device, temperature of irrigation fluid was measured at time zero and at completion. Flow of the irrigation fluid is varied by modifying the entry pressure on the arthropump, according to each operator's needs. Irrigation was with a saline solution at room temperature, and as a consequence room temperature was one of the study parameters. Room temperature was measured directly through the sensors of the hospital. The glenohumeral and subacromial working chambers were considered separately. The arterial pressure and the number of portals, as well as the parameters used for the generator including the operating mode "cut" or "coagulation," were collected. Data for all of these parameters were recorded for each radiofrequency application, with the primary data point being the intraarticular temperature.

Statistical analyses

Statistical analyses were performed by a statistician from the Public Health Laboratory of the University. Data collected were validated and entered in an Excel table (Excel 2016 Microsoft, Redmond, WA, US), and statistical analyses were performed using SPSS (IBM®, Armonk, US). A mixed model was used to determine any associations between the variable "temperature increase" (which is the main outcome measured) and the potential impacting factors over time. Univariate and multivariate analyses were carried out. The dependency of the observations for a given individual over time (manipulation) was modeled using a compound symmetry covariance structure, which assumes that two observations performed for a given individual at two different time points are constant.

Results

A total of 22 consecutive patients undergoing a shoulder arthroscopy were included. Patients' characteristics are shown in Table 1. This inclusion allowed to realize 93 recordings of each use of the electrode in order to carry out the statistical analyses. No complications in relation to increasing the temperature of irrigation fluid were identified.

Descriptive statistics

Results of descriptive analyses are shown in Table 2.

Univariate analyses

The results of the univariate analyses are presented in Table 3. Intraarticular temperature of the irrigation fluid measured with the probe was used as the comparative parameter. Only the number of portals and room temperature were significantly related to intraarticular temperature increase. This indicates that if a portal is added during the course of a surgery, the intraarticular temperature increases drop by a mean of 2.8 °C.

Multivariate analyses

The results of the multivariate analyses are presented in Table 4. Significant parameters from the univariate analysis were used for multivariate analysis. The multivariate analysis demonstrated that the addition of a portal allowed a mean reduction of 3.2 °C in intraarticular temperature increase, while an additional 10 mmHg of pressure with the arthropump led to a temperature increase of approximately 0.8 °C. Room temperature increase of 0.5 °C allows a mean augmentation of 1.6 °C in intraarticular temperature.

Significant parameters derived from the multivariate model were used to develop a CART decisional tree (Fig. 1; Classification and Regression Tree), to

Table 1 Characteristics of the study population

Population	Sex (%)	Age (years)	Indication (%)
<i>n</i> = 22	Male	59	Shoulder rotator cuff injury
	Female	41	Acromioclavicular separation
		Mean	1/4 clavicular distal fracture
		Min–Max	Calcification
		SD	

Table 2 Results of descriptive analyses for radiofrequency ablation parameters (*N* = 22)

	Mean	SD	Minimum	Maximum
Duration of use (s)	10.42	2.94	5	30
Start temperature (°C)	23.11	2.58	16	34
End temperature (°C)	31.59	6.11	23	45
Temperature variation (°C)	8.48	5.4	2	23
Arthropump pressure (mmHg)	50.61	8.71	35	70
Number of portals	2.53	0.61	2	4
Room temperature (°C)	18.98	1.25	17	22
Duration of surgery (min)	61.82	12.48	40	80
Subacromial liters consumed (l)	7.59	3.03	3	12
Glenohumeral liters consumed (l)	2.36	2.5	0	9
Systolic arterial BP (mmHg)	97	15.08	74	130
RF generator operating mode	Coagulation 62%	Cut 38%		

BP = blood pressure; RF radiofrequency; s = seconds; °C = degrees Celsius; min = minutes; l = liters; mmHg = millimeter of mercury

Table 3 Results of univariate analysis for changes in intraarticular temperature (*N* = 22)

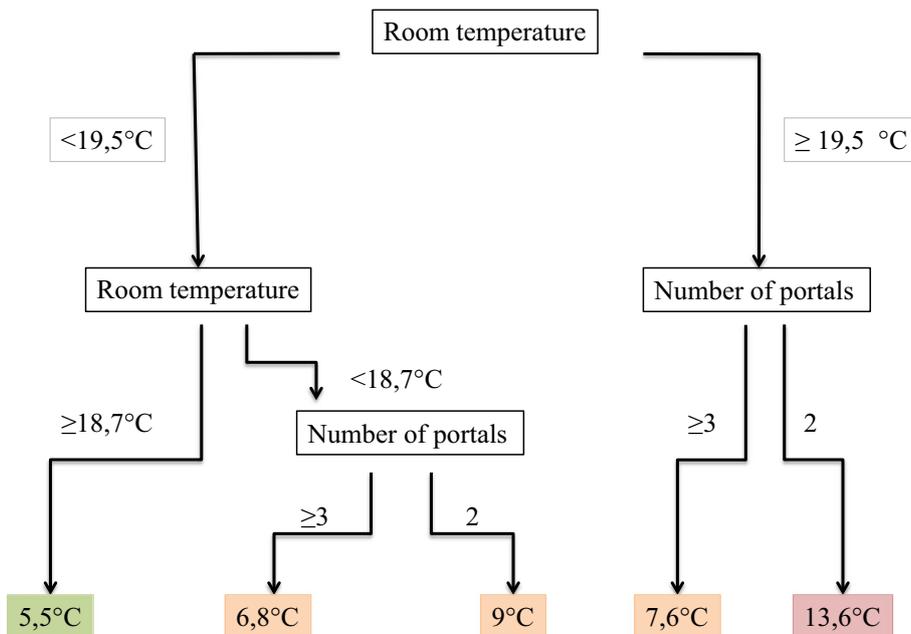
Parameters	Estimation	SE	Significance (<i>p</i> value)	95% confidence interval	
				Lower limit	Upper limit
Activation time	−0.238066	0.236154	0.317	−0.71	0.233868
Arthropump pressure	0.081842	0.0835	0.334	−0.087648	0.251332
Number of portals	−2.805395	1.052497	0.01	−4.908097	−0.702694
Room temperature	1.708974	0.625752	0.016	0.373793	3.044156
Systolic blood pressure	0.05071	0.047789	0.296	−0.046271	0.147692
Location of surgery	0.83449	1.567532	0.596	−2.297105	3.966084
Operating mode	0.929684	1.321468	0.485	−1.718536	3.577904

Significant parameters are shown in bold

Table 4 Results of the multivariate analysis for changes in intraarticular temperature ($N=22$)

Parameters	Estimation	SE	Significance (p value)	95% confidence interval	
				Lower limit	Upper limit
Activation time	-0.157284	0.225858	0.489	-0.609703	0.295136
Operating mode	0.909166	1.205374	0.454	-1.507922	3.326254
Location of surgery	-0.691019	1.708308	0.687	-4.111109	2.72907
Room temperature	1.60725	0.586287	0.022	0.286968	2.927532
Arthropump pressure	0.185217	0.088019	0.046	0.003877	0.366556
Number of portals	-3.264489	1.099218	0.005	-5.470984	-1.057995

Significant parameters are shown in bold

Fig. 1 Classification and regression tree

characterize the conditions leading to low, moderate or high intraarticular temperature increases. The general principal behind this approach is a repeat method which builds an individual class as homogeneously as possible by asking a series of binary questions (yes/no) on individual attributes. Interpreting the resulting decisional tree is relatively intuitive; by operating a series of dichotomies derived from the tree root (located at the top of the graphic), each individual group can be characterized. The tree indicates that we can predict three types of temperature rise depending on the number of portals and the room temperature (Fig. 1). The addition of a portal allows a considerable reduction in temperature in settings with temperature increases. However, arthropump pressure must remain low in all cases. It is also important to keep in mind that there is no significant influence of the surgical location (i.e., glenohumeral versus subacromial) during use, or the choice of coagulation versus cut operating mode.

Discussion

The principal finding of this study was the identification of different profiles of significant temperature increases according to the room temperature, the number of portals, and the chamber pressure regulated. Other important findings were the absence of a significant difference in terms of the subacromial versus glenohumeral location of the surgery, as well as of the choice of coagulation versus ablation operating mode.

In our study, the addition of a portal in a shoulder arthroscopy allowed a mean reduction of 3.2 °C in intraarticular temperature increase during arthroscopy. If the pressure of the arthropump, and thus in the working chamber, is increased by 10 mmHg, we can expect to see a mean increase of 0.8 °C in temperature. This result is due to a simple rule of physics that when the pressure of an object increases, the temperature increases proportionally

as the number and extent of molecular shocks—which are sources of heat—also increase. We also demonstrated that controlling the temperature in the operating room has a major impact on intraarticular temperature; the ambient temperature very probably influences the temperature of the incoming flow. However, we did not check this because we did not measure the temperature of the incoming flow.

Other studies have reported the influence of various parameters with radiofrequency ablation on temperature during shoulder arthroscopy. Lu et al. used an experimental chamber and demonstrated that when intermittent and continuous radiofrequency ablation with irrigation was performed, fluid temperatures for the three radiofrequencies applications were always $< 40\text{ }^{\circ}\text{C}$ [16]. Without flow, the temperature rose to $> 50\text{ }^{\circ}\text{C}$ after 70 s. With continuous use, the temperature of the chamber fluid rose to more than $65\text{ }^{\circ}\text{C}$ after 2 min, and reached $80\text{ }^{\circ}\text{C}$ after 3 min, thus demonstrating the critical role of irrigation. Good et al. studied variable flow across the joint in cadaveric shoulder joint models [21]. The authors reported intraarticular temperatures $> 45\text{ }^{\circ}\text{C}$ for all flow parameters. They also found that the time to cool the joint to normal ranges was substantially longer without irrigation compared to a 50% or 100% flow. Their conclusions related to the irrigation flow and the risk of chondrocyte damage—however, they did not discuss what the surgeon could do to improve the security margin under these conditions. In a similar study, Zoric et al. identified three factors with a major impact on temperature—duration of the application, distance of the application and the flow [17]. They concluded that the flow had the most impact and that in a setting where the flow was limited or stopped altogether, it was important to be aware that after only 5 s of ablation, temperatures could reach more than $50\text{ }^{\circ}\text{C}$. McKeon et al. demonstrated that during subacromial decompression with a constant irrigation flow and a single regulating probe, the temperature and temperature increase in each profile did not reach physiologically harmful levels [19]. These results are coherent with ours where we used a constant flow to drain the shoulder.

In vivo studies are rare, and their value lies in the fact that they can measure basal physiological temperatures of the patient as well as blood flow. Only four in vivo studies have been published—all of which are in line with our results. Davies et al. performed continuous temperature measurement in the subacromial space during surgery with intermittent use of a monopolar electrode, with mean maximum temperatures of $27.8\text{ }^{\circ}\text{C}$ [22]. Barker et al. used the Coblation[®] system undergoing a subacromial bursectomy [23]. The temperature peak was on average $32\text{ }^{\circ}\text{C}$ with a mean increase of $9.8\text{ }^{\circ}\text{C}$ and reported that the most influential factor on the subacromial temperature was the temperature of the irrigation fluid. Use of a fluid heated to body temperature rapidly resulted in temperatures of

$45\text{ }^{\circ}\text{C}$ and should not be permitted. This is in accordance with importance of the room temperatures demonstrated in our study. In a study using the Coblation[®] system, Ghostine et al. reported temperatures reaching $50\text{ }^{\circ}\text{C}$ in 12% of their recordings during continuous use of the probes for a minute, with four different levels of aspiration and three different powers [24]. They concluded that even with the new bipolar probes, the temperature can easily reach values superior to $45\text{ }^{\circ}\text{C}$, and also highlighted the importance of good irrigation. Very recently, Hyunh et al. evaluated the temperature using two separate probes, with the Coblation[®] system and a thermal probe recording for 60 s at 10-s intervals [20]. The authors used only two portals. There were no significant differences between the two probes for the first 40 s. The temperatures did not rise above $28\text{ }^{\circ}\text{C}$, even after 60 s of continuous use. These results differ from those of our study, where temperatures beyond $40\text{ }^{\circ}\text{C}$ were reported with intermittent use of radiofrequency. These differences are likely to be due to differences in temperature measurement methods. We measured the temperature 1 cm away from the end of the probe, whereas in the study by Hyunh et al. the thermal probe was located further away. It is widely agreed that a deleterious effect of the temperature on chondrocytes occurs from $45\text{ }^{\circ}\text{C}$, with 100% cellular lysis at $65\text{ }^{\circ}\text{C}$ [16, 25–27]. To avoid any such damage, we had an audible alarm set at $40\text{ }^{\circ}\text{C}$.

The study was associated with a number of limitations. Firstly, the intraarticular temperature measurements could not be applied to the entire volume of irrigation fluid. The sensor was on the dorsal side of the probe, 1 cm from the end. Measurements did not reflect the exact temperature at greater distances from the electrode. We could thus only be sure that the temperatures measured concern a 1-cm sphere around this measurement point. This includes the temperature at the point of contact with the tissues, a clinically relevant feature. Nonetheless, various studies including cadaveric evaluations have demonstrated that the temperature at the end of the probe is close to that of the irrigation fluid at the level of the skin [19, 28]. Secondly, we refer to room temperature and imply that this is equivalent to fluid temperature but this was not verified. Irrigation fluid bag was left in the room in advance, so it was reasonable to assume that they were equal to the room temperature. Interval time was not measured between different utilization.

Our study is one of only few in vivo analytic evaluations, with the single-operator protocol limiting the biases associated with the use of different probes in other studies. Data collection was simple and per-protocol. This is the first study to compare the effect of the acromial and glenohumeral spaces on intraarticular temperature, while we were not able to demonstrate a significant difference in terms of risk of temperature increases.

Conclusions and clinical implications

From our database, we were able to identify danger zones which the surgeon may encounter during radiofrequency ablation in shoulder surgery. These conditions occur when the operating room temperature is elevated (notably ≥ 19.5 °C) and therefore the temperature of the inflow fluid, when the surgeon uses few portals (≤ 2) and when the arthropump pressure is high. Clearly, these results are only relevant for a bipolar radiofrequency device and specifically in the shoulder. These results open a way of studying the association of different parameters and establish precise recommendations that must be validated by an in vitro study with rigorous temperature measurement methodology.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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