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Effects of Heating on Impulse Propagation in Superfused Canine Myocardium

TIMOTHY A. SIMMERS, MD, JACQUES M. T. DE BAKKER, PHD,* FRED H. M. WITTKAMPF, PHD, RICHARD N. W. HAUER, MD

Utrecht and Amsterdam, The Netherlands

Objectives. **The goal of the study was to quantify the response of myocardial impulse propagation to hyperthermia and identify the temperatures required for transient and permanent block in conduction.**

Background. **Although it is generally accepted that the effects of radiofrequency ablation are thermally mediated, the precise response of myocardial impulse conduction to heating remains to be quantified.**

Methods. **Twenty-three preparations of ventricular myocardium from 10 beagle dogs were superfused at 36.5 to 37.5°C and paced at a cycle length of 600 ms. Heating was performed for 30 s at 5-min intervals by an independent flow of heated superfusate. A 16-electrode grid was used to record extracellular electrograms directly before each heating episode (control value) and at 10, 20 and 30 s.**

Results. **Between 38.5 and 45.4°C, conduction velocity was higher than that at the directly preceding control value ($p < 0.05$), reaching a maximum of 114% between 41.5 and 42.5°C. Above 45.4°C, a gradual decrease occurred, with transient block (absence of impulse conduction for ≤5 min) after heating to 49.5 to 51.5°C. This was followed by tachycardia in 69% of all cases immediately after cessation of heating. Permanent block occurred after a significantly higher temperature of 51.7 to 54.4°C had been reached. Pacing at sites allowing preferential conduction either parallel or perpendicular to fiber orientation caused no difference in reaction to heating. Repeated heating of some preparations to 47.0 to 50.5°C revealed no cumulative effects on conduction velocity.**

Conclusions. **Transient and permanent block in impulse conduction occurred at 49.5 to 51.5°C and 51.7 to 54.4°C, respectively, in superfused canine myocardium, the former frequently being followed directly by tachycardia. Reaction of conduction velocity to hyperthermia was independent of myocardial fiber orientation and number of preceding heating episodes. Results may contribute to a better understanding of electrophysiologic phenomena observed during radiofrequency ablation procedures.**

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It is generally accepted that the clinical effects of radiofrequency catheter ablation result from thermal injury (1,2). However, the precise relation between heating and the corresponding response of impulse conduction in the target tissue remains to be quantified.

To date, a limited number of studies have addressed the effects of heating on conductive properties in myocardium (3–7), Purkinje fiber (8,9) and nerve axon (10). Although information has been presented on the temperature required to cause complete conduction block during radiofrequency delivery in vitro (11–13) and in vivo (14), to our knowledge no previous report has quantified the response in impulse conduction to the entire spectrum of temperatures between normal and blocked conduction. Furthermore, although myocardial fiber orientation has been demonstrated to affect impulse propagation (15), the possible role of this factor in the response to heating has not previously been investigated.

In the present study, superfused preparations of canine ventricular myocardium were used as a model to examine the effects of progressive heating on impulse conduction. In addition, these effects were specified for conduction parallel and perpendicular to myocardial fiber orientation.

Methods

Preparation. Ten beagle dogs weighing 12 to 14 kg were anesthetized using intravenous sodium pentobarbital (600 mg) and etomidate (125 mg), followed by endotracheal intubation and ventilation. The heart was removed by median sternotomy and immediately submerged in Tyrode's solution at 4°C (composition, mmol/liter): Na^+ 156.5; K^+ 4.7; Ca^{2+} 1.5; $H_2PO_4^-$ 0.5; Cl^- 137; HCO_3^- 28; glucose 20. Preparations of left and right ventricular epicardial myocardium of ~40 × 40 × 2 mm were cut and affixed epicardial side up to polyvinyl chloride

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Address for correspondence: Dr. Timothy A. Simmers, Department of Cardiology, Heart-Lung Institute E03-406, University Hospital Utrecht, P.O. Box 85500, 3508 GA Utrecht, The Netherlands.

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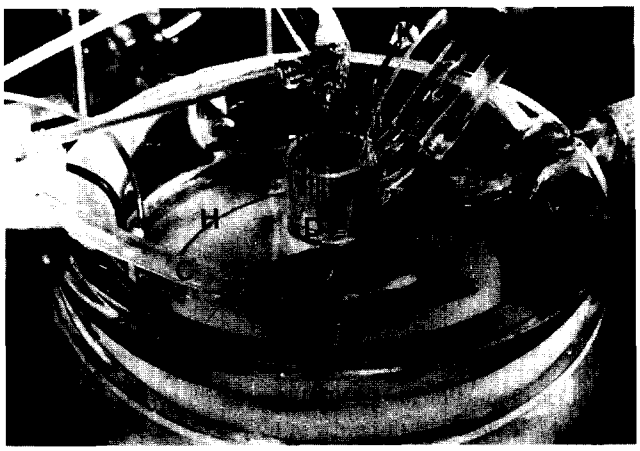

Figure 1. Illustration of the experimental setup. A = superfusion bath; B = inflow; C = outflow; D = cylinder used for local heating, with flexible silicon rubber "skirt" to reduce local pressure on the preparation and leakage of heated superfusate to the nonheated zone; E = independent inflow; F = outflow; G = 4 × 4 silver/silver chloride electrode grid; H = indifferent electrode (**ring**); I = preparation of canine ventricular epicardial myocardium affixed to polyvinylchloride slide; J = thermistor probe in heated zone; K = bipolar stimulation electrode. Not shown are the second thermistor and reference electrode outside heated zone.

slides using cyanoacrylate tissue adhesive. Preparations were kept on ice in Tyrode's solution aerated with 95% oxygen, 5% carbon dioxide pending further use.

All animals received humane care in compliance with the "Principles of Laboratory Animal Care" formulated by the National Society for Medical Research.

Figure 1 shows the experimental setup. Slides were pinned to the base of a superfusion bath, fed by a continuous flow (50 ml/min) of oxygen– and carbon dioxide–aerated Tyrode's solution. Temperature in the superfusion bath was monitored constantly (Exacon M9200 probe C-NO3, response time 0.1 s) to ensure a stable baseline temperature of 36.5 to 37.5°C. Heating was performed through a cylinder (diameter and depth 20 mm) lowered onto the central area of the preparation using a micromanipulator. The cylinder was fed by an independent 400-ml/min flow of oxygen– and carbon dioxide–aerated superfusate from a second reservoir at a preset temperature above baseline. A second thermistor was present within the cylinder in contact with the surface of the preparation to monitor temperature increase during the heating protocol. This was positioned at approximately the center of a 4 × 4 silver/silver chloride electrode grid, which was lowered into the cylinder to the surface of the preparation using a second micromanipulator directly before heating, to allow monitoring and recording of unipolar extracellular electrograms relative to a ring electrode at the periphery of the superfusion bath. Interelectrode distance was 4 mm, electrode diameter 0.5 mm and length 25 mm, allowing adequate superfusion of the area within the cylinder. Finally, a silver/silver chloride reference electrode was positioned on the preparation outside the cylinder to confirm continuing excitability in the nonheated zone. The signal from this electrode was monitored continuously and displayed on a Tektronix 2220 dual-channel storage oscilloscope.

Table 1. Temperature per Heating Episode; Incrementally Heated Group

Episode No.	Temperature (°C)	
	Mean ± 1 SD	Range
1	41.2 ± 1.15	38.5–42.8
2	42.9 ± 1.83	39.0–44.7
3	44.3 ± 1.62	41.3–46.3
4	45.4 ± 1.41	42.5–47.4
5	46.9 ± 1.39	44.1–48.6
6	47.6 ± 1.03	45.7–48.8
7	48.7 ± 1.16	47.2–50.1
8	49.2 ± 1.29	46.6–50.6
9	49.6 ± 1.20	47.4–51.0

Experimental protocol. Each preparation was allowed to stabilize in the superfusion bath for 20 min before experiments were started. Stimulation was performed outside the cylinder in the bipolar mode via a pair of silver wires at a site selected to allow preferential conduction parallel to fiber orientation: current strength twice diastolic threshhold, pulse width 2 ms and basic cycle length 600 ms. Fiber orientation was deduced from an isochrone activation map obtained during stimulation of the preparation at the center of the grid as previously described (15), where isochrones are more closely spaced in a direction perpendicular to fiber orientation because of slower conduction than parallel to fiber orientation. Preparations in which local activity could be recorded from at least 12/16 electrodes of the grid at baseline were used for further analysis; preparations failing to retain or regain excitability after a temperature exposure with signal dV/dt of at least 0.1 V/s and conduction velocity of at least 75% of baseline were discarded. Heating was performed by introducing flow into the lowered cylinder for 30-s episodes at 5-min intervals; half-time of temperature increase at the surface of the preparation was ~0.75 s. Both the cylinder and the electrode grid were kept raised between episodes to enable adequate superfusion of the preparation at the baseline temperature. Temperature during the first heating episode was (mean ± SD) 41 ± 1.4°C (range 38.5 to 42.8) and was raised by increments of 1.2 ± 0.6°C at each successive episode until the occurrence of transient conduction block. Actual temperatures for the first nine incremental heating episodes are shown in Table 1. In four preparations, more than nine heating episodes were required to obtain transient block; however, the low number of cases does not justify inclusion in the table. Transient conduction block was defined as absence of local activity for no more than 5 min at all electrodes showing activity at baseline, with continuing activity at the reference electrode outside the heated area. Unipolar signals were recorded simultaneously from the 16 electrodes of the grid at the preparation's surface directly before heating and at 10, 20 and 30 s.

Signal acquisition and analysis. Signals were amplified 500× with filter bandpass set at 0.1 to 1,000 Hz. Electrograms were stored in digital format on a microcomputer with a sampling frequency of 2 kHz.

Three variables were analyzed at 10, 20 and 30 s of heating, each expressed as a percent of the control value directly preceding each heating episode: 1) *number of electrodes displaying local activity*, defined as a clearly discernable signal with a dV/dt of at least 0.1 V/s (16–18); 2) *conduction velocity*, calculated from activation times relative to the stimulus of adjacent pairs of points in the grid (parallel to the direction of impulse propagation) still demonstrating local activity at 30 s of heating. Activation time was defined as the interval between the stimulus and point of the steepest negative dV/dt component of the unipolar intrinsic deflection. Velocity during heating was calculated only if activity was recorded from at least three electrodes that was sufficient to suggest an activation sequence comparable to the pattern before heating, and always using the same points as during control measurements. 3) *dV/dt of the downslope of the remaining signals* was analyzed, using only those points present both at the control situation and at 30 s of heating to allow valid comparison. Average dV/dt of remaining signals at 10, 20 and 30 s of heating was thus expressed as a percent of average dV/dt of signals from the same electrodes at the directly previous control situation. The dV/dt of each individual signal was determined using custom software on an interactive computer system, where the steepest negative component of the electrogram was automatically identified and calculated from three consecutive samples (sampling at 2 kHz) and displayed on screen. Subsequent confirmation and, if necessary, manual correction were performed if the steepest component recognized by the computer was an artifact.

A second group of preparations was used to investigate the influence of myocardial fiber orientation on the parameters analyzed during heating. Two stimulation sites were chosen, allowing preferential conduction either parallel or perpendicular to fiber orientation as described. During the heating protocol, the preparation was exposed to each temperature setting once at each stimulation site. The first exposure was alternately during parallel or perpendicular conduction, followed by a 5-min interval before a second exposure at the same temperature elevation during stimulation at the other site.

To identify any possible cumulative effect of repeated heating on the variables analyzed, a third group of preparations was repeatedly exposed to a temperature of 47.0 to 50.5°C for 30 s at 5-min intervals. Control values of the three variables between heating episodes were compared with those at baseline. In addition to this, linear regression analysis of control values in the incrementally heated group was performed on the number of heat exposures to identify any correlation suggesting a cumulative effect of heating.

Finally, in a fourth group of preparations, the heating protocol was started directly at a temperature 1.5 to 3°C higher than the average temperature identified as leading to transient conduction block to identify the temperature required for permanent block in myocardial conduction. This was defined as absence of activity for 20 min at all electrodes showing activity at baseline.

Statistical methods. Continuous data are expressed as group mean value ± 1 SD. Comparative statistics were performed using a two-tailed paired Student *t* test for results of heating during conduction parallel and perpendicular to fiber orientation and in comparing data with the associated control or preceding value. An unpaired *t* test was used in comparing results of repeated and immediate high-temperature exposure with the progressively heated group. Correlations among temperature, number of preceding heating episodes and the three variables analyzed were tested by linear regression analysis where applicable. A p value <0.05 was considered significant.

Results

Effects of progressive heating: temperature leading to transient conduction block. A total of nine preparations from six dogs were used for analysis. Directly before each heating episode, temperature at the tissue surface within the lowered cylinder was always between 36.5 and 37.5°C. For the purpose of analysis, temperatures were categorized into groups of 1°C, starting at 38.5°C. The number of electrodes recording local activity at baseline was 14.9 ± 1.3. The absence of recording from some electrodes was attributable to the presence of poor electrode–tissue contact caused by an unevenness in the preparation or an anatomic obstacle such as epicardial fat or a coronary vessel. The grid was positioned in such a fashion as to avoid the presence of such structures within the heated zone as much as possible. During heating up to 44.5°C, no significant difference was seen in the number of electrodes with local activity relative to the preceding control value, above which a gradual decrease was observed until block ($p < 0.05$) (Fig. 2 and 3).

Conduction velocity at baseline conditions in all preparations was calculated to be 0.35 ± 0.13 m/s. For all temperature categories between 38.5 and 45.4°C, conduction velocity was significantly greater than the preceding control value ($p < 0.05$), reaching a maximum of 114 ± 10.1% between 41.5 and 42.5°C. Above 45.4°C, conduction velocity decreased ($p < 0.001$), with transient conduction block occurring in a narrow temperature zone at 50.3 ± 1.1°C (range 49.5 to 51.5, median 50.3) (Fig. 4). Time to return of conduction was related to the temperature leading to transient block, lower temperatures being associated with more rapid recovery (range 10 to 240 s; $r = 0.61$, $p = 0.05$).

At baseline, dV/dt of signals was 1.4 ± 0.6 V/s. At any given temperature, the range in values for dV/dt was appreciably larger than those for other variables. This warrants caution in the interpretation of apparent decreases in dV/dt based on analysis with results grouped in 1°C intervals. The correlation between temperature and dV/dt of remaining signals was poor up to 45.5°C ($r = -0.05$) but significantly stronger >45.5°C ($r = -0.5$). Values for dV/dt at heating up to 45.5°C did not differ significantly from the preceding control values ($p =$

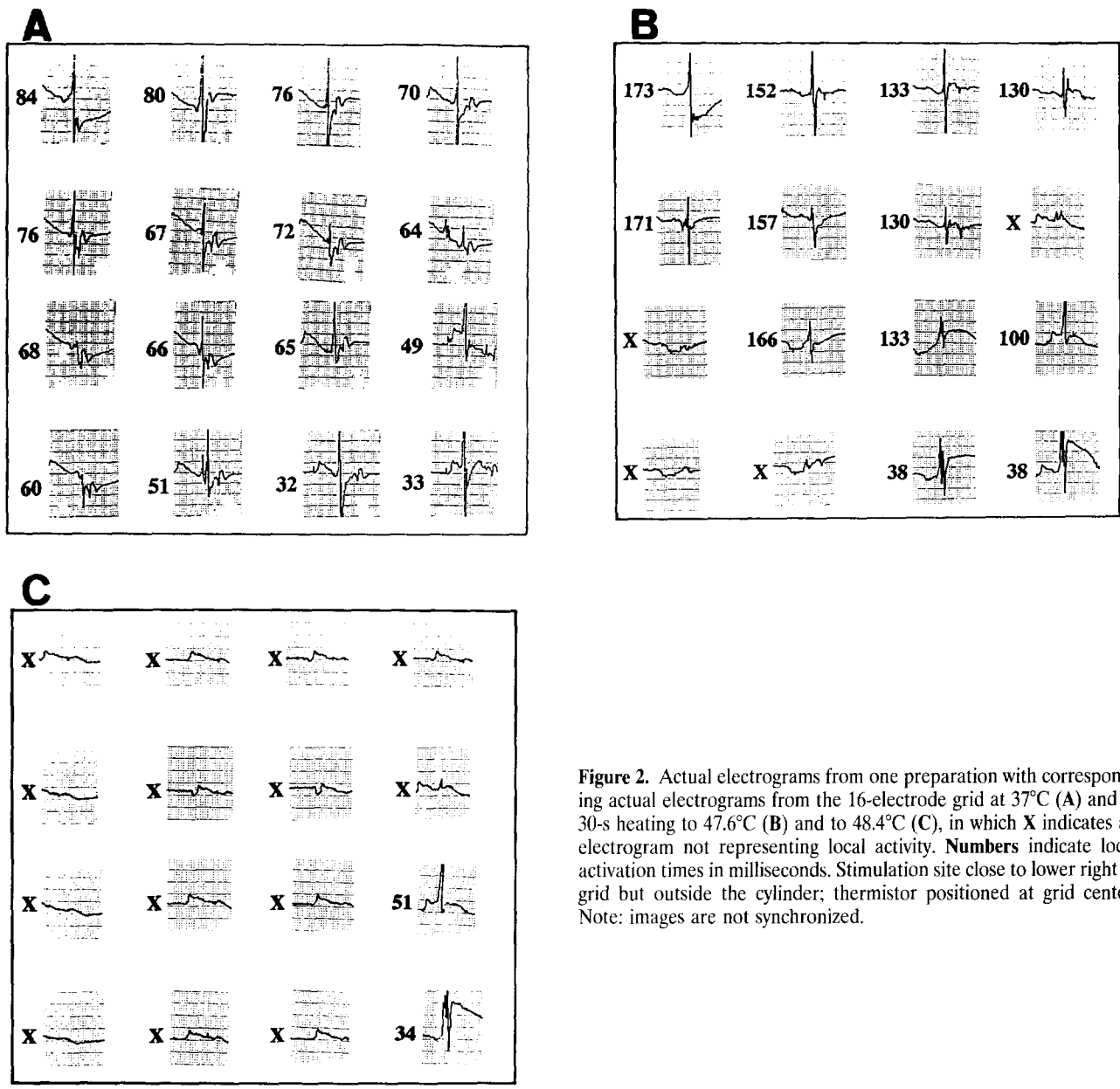

Figure 2. Actual electrograms from one preparation with corresponding actual electrograms from the 16-electrode grid at 37°C (**A**) and at 30-s heating to 47.6°C (**B**) and to 48.4°C (**C**), in which **X** indicates an electrogram not representing local activity. **Numbers** indicate local activation times in milliseconds. Stimulation site close to lower right of grid but outside the cylinder; thermistor positioned at grid center. Note: images are not synchronized.

0.64), but a significant decrease was observed on heating to ≥45.5°C ($p < 0.0001$) (Fig. 5).

During experiments, no significant change was observed in control values between heating episodes for either the number of electrodes recording activity or conduction velocity. However, a significant decrease was observed in control value of dV/dt after four heating episodes ($p < 0.001$), from 67.2 ± 27.8% to a minimum of 47 ± 26% of the baseline value after nine exposures.

Effect of myocardial fiber orientation. This was examined using four preparations from three dogs. Conduction velocity at baseline was calculated to be 0.34 ± 0.12 m/s during preferential conduction parallel and 0.24 ± 0.10 m/s perpendicular to fiber orientation. Analysis of results from a total of 32 paired temperature exposures during preferential conduction either parallel or perpendicular to previously determined fiber orientation showed no significant differences in the analyzed parameters to result from this factor. This is illustrated for conduction velocity in Figure 6.

Effect of heating duration. During the 17 episodes of hyperthermia leading to transient block in impulse conduction, variables were evaluated at 0, 10, 20 and 30 s of heating duration. Results are shown in Figure 7. A progressive decrease was seen in all variables leading up to transient block, with 5 of 17 occurrences of block at 0 to 10 s, 6 of 17 between 10 and 20 s, and 6 of 17 at 20–30 s of heating.

Effect of repeated heat exposure. Five preparations from four dogs were repeatedly (three to seven times) exposed to a

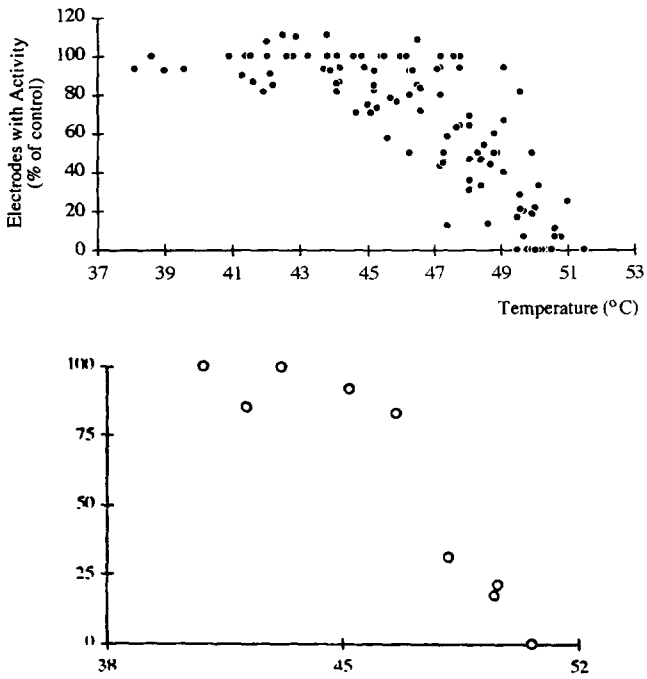

Figure 3. Top, Number of electrodes recording activity at 30 s of heating as a percent of the directly preceding control value, plotted against temperature. Number at baseline: 14.9 ± 1.3. **Bottom,** Representative example from one preparation.

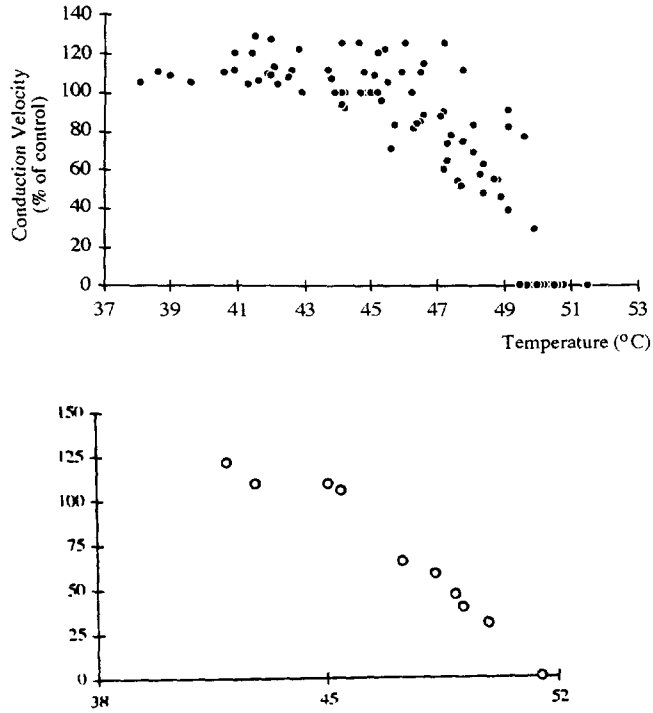

Figure 4. Top, Conduction velocity at 30 s of heating as a percent of the directly preceding control value, plotted against temperature. Baseline conduction velocity in all preparations 0.35 ± 0.13 m/s. **Bottom,** Representative example from one preparation.

temperature of 47.0 to 50.5°C. All variables had previously been demonstrated to be negatively affected in this temperature range. Reductions in number of electrodes recording activity, conduction velocity and dV/dt of remaining signals did not differ significantly from values at the same temperatures in the incrementally heated group. Transient block occurred in three preparations as a result of the first heat exposure at temperatures that did not differ significantly from those in the incrementally heated group (49.0, 49.6 and 50.2°C in repeatedly heated versus 50.3 ± 0.6°C in incrementally heated preparations). Finally, no significant change was seen in control values after five heating episodes for the first two variables; however, dV/dt decreased significantly after two heating episodes >47°C ($p < 0.05$).

Tachycardia. This phenomenon was defined as the occurrence of electrical activity more rapid than and independent of stimulation at cycle length 600 ms. Tachycardia was observed directly after nine incidences of transient conduction block (69% of all cases). Temperature causing transient block followed by tachycardia was 50.3 ± 0.6°C versus 49.7 ± 0.8°C for transient block not followed by tachycardia ($p = 0.18$). Tachycardia cycle length fluctuated markedly but was on average ~200 ms. Attempts at termination by pacing maneuvers were unsuccessful and failed to evoke overdrive phenomena; tachycardia was invariably self-limiting, terminating after 1.7 ± 1.2 min.

Temperature leading to permanent conduction block. Five preparations from three dogs were immediately exposed to a temperature of at least the average temperature plus twice the corresponding standard deviation previously demonstrated to cause transient conduction block in the group of incrementally heated preparations. Permanent block occurred at a temperature of 53.6 ± 0.6°C (range 51.7 to 54.4, median 53.8) and required only a single heating episode in 4 of 5 preparations. In the fifth preparation, permanent block occurred at 53.5°C after an initial episode of heating to 52.1°C had induced only transient block.

The experimental protocol was originally designed in this manner to prevent any possible cumulative effects of heating to relatively high temperatures on the value for permanent block. Repeated heating failed to demonstrate a cumulative effect on conduction velocity; however, three preparations were heated incrementally beyond the point of transient block up to the point of permanent block in impulse conduction. In these preparations, permanent block occurred at 52.9 ± 0.8°C (53.8, 52.2 and 52.7°C). In each case, the preceding episode led to transient block at a temperature <1°C below the temperature finally required for permanent block. The temperature thus identified did not differ significantly from that of 53.6 ± 0.6°C found in the first five preparations ($p = 0.4$) and was within the same range but was significantly higher than the temperature required for transient block in the incrementally heated group ($p < 0.0001$).

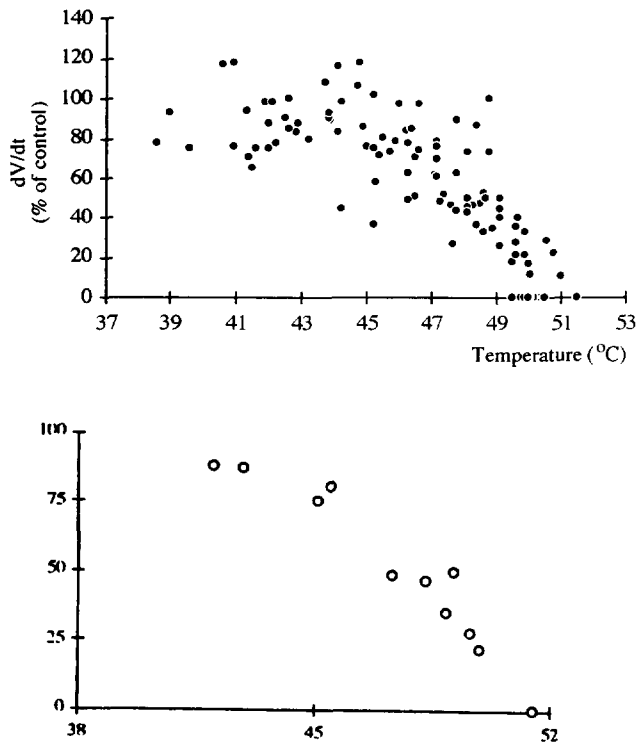

Figure 5. Top, Values for dV/dt of remaining signals at 30 s of heating as a percent of the directly preceding control values for the corresponding electrodes, plotted against temperature. Value at baseline 1.4 ± 0.6 V/s. **Bottom,** Representative example from one preparation.

Discussion

The present study represents an analysis of the effects of heating on impulse propagation using isolated superfused epicardial canine ventricular myocardium as a model.

Transient and permanent conduction block. Similar to previous in vivo (19) and in vitro (6) studies, conduction velocity parallel to fiber orientation at baseline conditions in the present study was 0.35 ± 0.13 m/s. During heating to temperatures of up to 45.4°C, conduction velocity was observed to increase relative to the velocity immediately before the heating episode. At higher temperatures, a gradual decrease in conduction velocity ensued until the occurrence of transient conduction block. The number of electrodes recording activity in the heated zone did not differ significantly from baseline until 44.5°C, above which a temperature-related decrease occurred. A progressive decrease in dV/dt of remaining signals was observed at >45.5°C.

Although the response of impulse conduction to this entire spectrum of heating has not previously been described in myocardium, Chapman (10) investigated the effects of both cooling and heating until conduction block in squid axon. He demonstrated an initial increase in conduction velocity during heating, followed by a decrease preceding transient block. In vivo studies by Brooks et al. (4) and Burgess et al. (5) described a shortening of refractory periods and decrease of conduction times in dogs during epicardial heating to ~45°C.

In the present study, transient conduction block was reproducibly observed in a relatively narrow temperature zone at 50.3 ± 1.1°C (n = 17). Although this value was obtained after multiple heating episodes at lower temperatures, it is very similar to the value reported by Haines and Watson (11) at the border between viable and nonviable myocardium during radiofrequency ablation in vitro. Furthermore, transient block was seen to occur after the first heating episode in three of the preparations repeatedly exposed to a temperature of 47.0 to 50.5°C, at values that did not differ significantly from the incrementally heated group. Finally, a cumulative effect of heat exposures on conduction velocity seems unlikely in view of the uniformity of control values in the incrementally heated group and of control values and velocity at 30 s of heating in the group repeatedly exposed to 47.0 to 50.5°C.

Permanent conduction block was observed at a higher temperature than transient block, at 53.6 ± 0.6°C (range 51.7 to 54.4) in the group in which the heating protocol was started immediately at 1.5 to 3.0°C above the point of transient block. However, given this protocol a minor overestimation of the temperature required to cause permanent block could not be excluded. Nevertheless, an identical temperature of 53.6°C required to cause irreversible tissue injury by radiofrequency ablation was reported for isolated perfused and superfused porcine ventricular myocardium by Whayne et al (13). Moreover, with a cumulative effect of heating on conduction velocity excluded, three preparations were heated incrementally beyond the point of transient block until the occurrence of permanent block in impulse conduction. The three temperatures of 52.2, 52.7 and 53.8°C thus identified as leading to

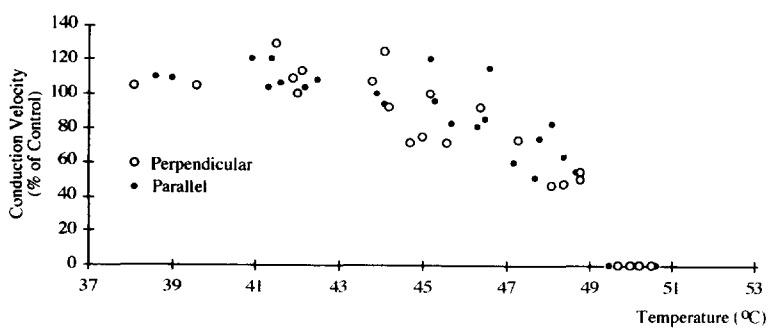

Figure 6. Conduction velocity both perpendicular (**open dots**) and parallel (**closed dots**) to fiber orientation at 30 s of heating, expressed as a percent of the associated control values, plotted against temperature. Baseline conduction velocity perpendicular, 0.24 ± 0.12 m/s; parallel, 0.34 ± 0.12 m/s.

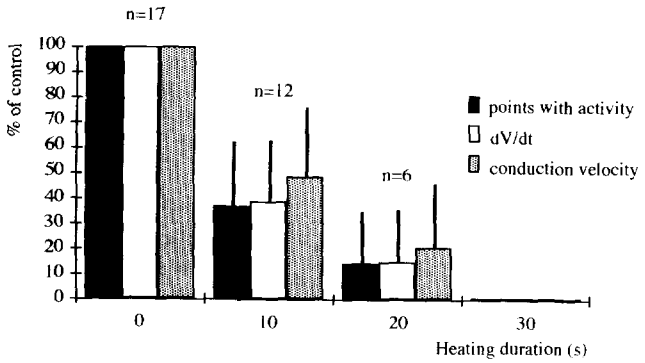

Figure 7. Number of electrodes recording local activity, dV/dt of remaining signals and conduction velocity as a function of heating duration during heating episodes leading to transient block. **Numbers** indicate the number of preparations showing impulse conduction at the corresponding heating duration. Shown are mean values; **vertical bars** = 1 SD.

permanent block were all well within the range identified using the original protocol.

Langberg et al. (14) reported temperatures of 50 ± 8 and 60 ± 16°C for the occurrence of transient and permanent accessory pathway block, respectively, in patients undergoing radiofrequency ablation for Wolff-Parkinson-White syndrome. However, temperatures in that study were measured using a thermistor embedded in the ablation electrode. Temperature at the electrode–tissue interface is higher than in surrounding myocardium, and a hyperbolic temperature decay is seen relative to distance from the site of radiofrequency current delivery (11,12,20,21). It is, therefore, plausible to assume that the actual temperature in the accessory pathway at the moment of conduction block is somewhat lower than the 60 ± 16°C reported by Langberg et al. (14) and thus closer to that observed in this and other in vitro studies (11,13).

Influence of myocardial fiber orientation. Myocardial fiber orientation has been demonstrated to affect myocardial impulse propagation in vivo (15), conduction being more rapid parallel than perpendicular to fiber orientation. The possible effects of this factor on conduction during hyperthermia have not previously been investigated. Results of the present study, where heating was performed during preferential conduction both parallel and perpendicular to fiber orientation, demonstrate no effect of this factor on the electrophysiologic response to heating.

Tachycardia. Tachycardia was observed after 69% of occurrences of transient block in the present study. This phenomenon is reminiscent of the ventricular ectopic activity and tachycardias described by Wittkampf et al. (22) and the atrioventricular (AV) junctional ectopic activity described by Huang et al. (23) during and after radiofrequency ablation in dogs. The AV junctional ectopic activity has also been described as a frequent finding during radiofrequency delivery near the AV node in humans (24,25). Previous studies (7,8) have described a decreased rest transmembrane potential and increased slope of phase 4 depolarization in response to heating. This suggests that the observation of ectopic activity during and after radiofrequency ablation and heating of myocardium is caused by abnormal automaticity in the hyperthermic zone. Observations during heating of guinea pig papillary muscle recently reported by Nath et al. (26) strongly support this hypothesis. In the present study, circumstantial evidence is in support of enhanced automaticity as the mechanism of the tachycardias observed after heating. Cycle length was markedly variable, with a tendency to decelerate before terminating. Pacing maneuvers not only failed to terminate tachycardia, but also failed to evoke overdrive phenomena.

Study limitations. 1) The current study presents results obtained using an in vitro canine model, dictating care in their extrapolation to the in vivo human situation. 2) Results only apply to myocardial impulse propagation in the immediate subepicardial layer. Measurements were carried out at the epicardial surface to avoid the subendocardial heterogeneity in conduction velocity as a result of the presence of both myocardial cells and the Purkinje network and the unevenness of the endocardial surface. Nevertheless, response to heating may be different for various conductive cardiac tissues, including the subendocardial layer exposed to radiofrequency delivery in the clinical setting. Studies by Selvester et al. (19) and Liu et al. (27) describe electrophysiologic inhomogeneity of the ventricular wall in dogs. 3) The application of results to phenomena observed during radiofrequency ablation rests on the supposition that the clinical effects of radiofrequency catheter ablation are exclusively thermally mediated. In fact, this remains to be proved. 4) The possibility of a bias in results caused by cumulative detrimental effects on preparations other than by heating alone cannot be entirely ruled out. Spach et al. (28) demonstrated a 0% to 4% decrease in conduction velocity in superfused canine myocardium over 2 h, reflecting a natural "decay" as a function of time. Preparations used in the present study were superfused for a maximum of 110 min. It therefore seems unlikely that this factor may have caused any significant bias in results.

In the incrementally heated preparations, a significant decrease was seen in control values for dV/dt after four heat exposures (corresponding with temperatures above ~43 to 44°C). Although this suggests a possible cumulative effect of heating on the preparations, this was not evident for either conduction velocity or the number of electrodes recording local activity. Published reports lack parallel observations, and results of the present study offer no plausible explanation for this phenomenon. Nonetheless, it is conceivable that the decrease in dV/dt observed is a reflection of a general deterioration of the preparations during the course of the experiments, not yet expressed as a decrease in conduction velocity. In light of these observations, it is likely that results of the present study contain some overestimation of the effects of hyperthermia on dV/dt, in particular in the temperature zone >43°C. However, this does not apply to conduction velocity, which the present study was primarily designed to examine.

Clinical implications. The present study demonstrates that permanent myocardial conduction block occurs at a signifi-

cantly higher temperature than transient block, both in a narrow range of <3°C. Given a hyperbolic decrease of myocardial temperature during radiofrequency ablation relative to distance (11,12,20,25), this implies that the zone of permanent conduction block is surrounded by an area with transient effect. On the basis of descriptions of this hyperbolic function provided by Haines and Watson (11) and Wittkampf et al. (20), a temperature of 53.6°C should be reached at ~4.5 mm from the site of 25-W radiofrequency current delivery and 50.3°C at ~5.5 mm. This 1-mm larger radius represents an increase of >80% in the volume of affected myocardium. The occurrence of transient conduction block thus indicates a given temperature in the target tissue and hence a specific distance from the position of the radiofrequency ablation electrode. This knowledge could facilitate target localization. Analogous to the practice of ice mapping in arrhythmia surgery, heating to the temperature required to cause transient block could, moreover, provide information on target proximity in radiofrequency ablation, allowing the use of electrophysiologic response to pinpoint target localization.

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