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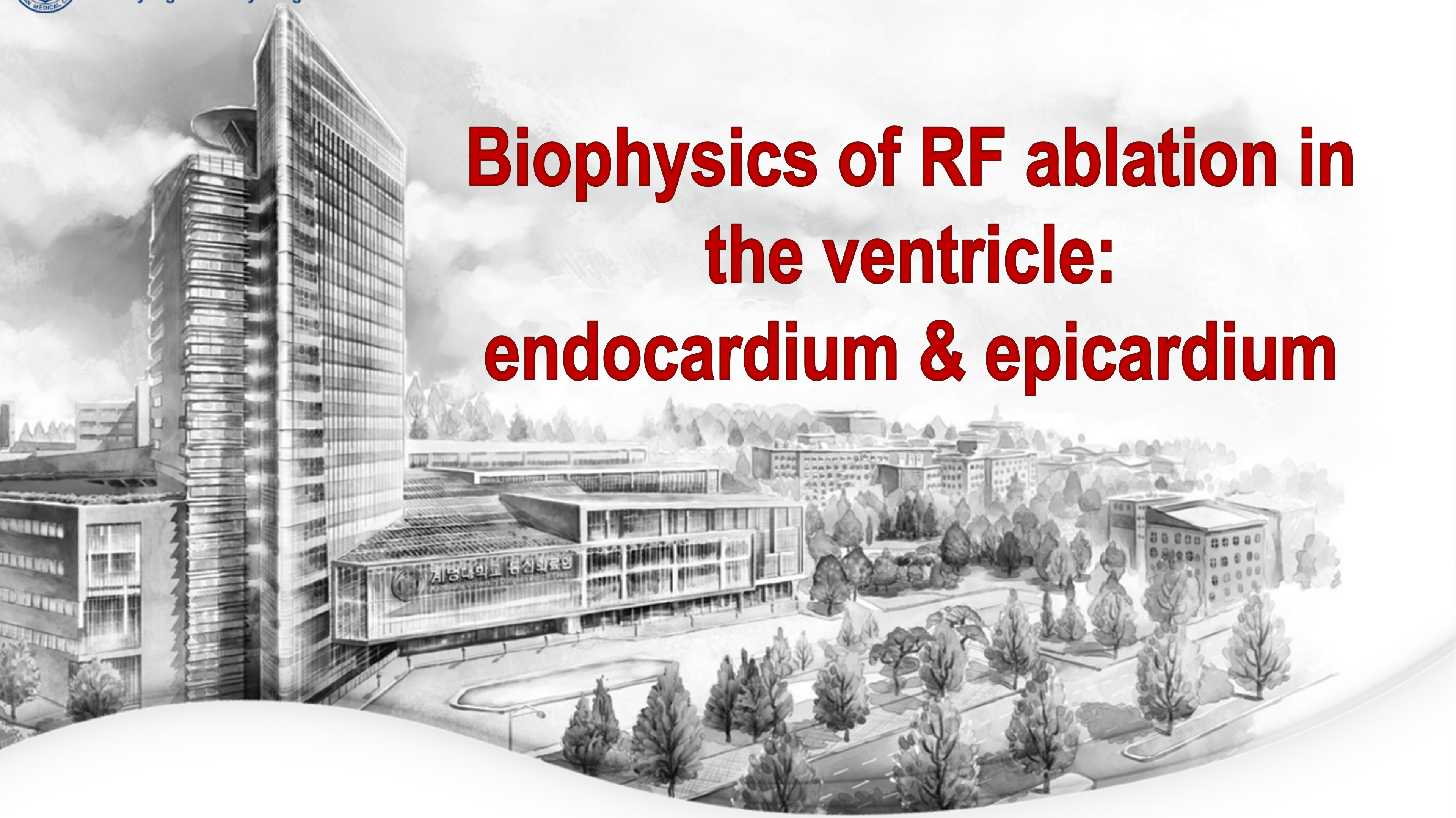
Keimyung University Dongsan Medical Center

11-03-2018



Biophysics of RF ablation in the ventricle: endocardium & epicardium

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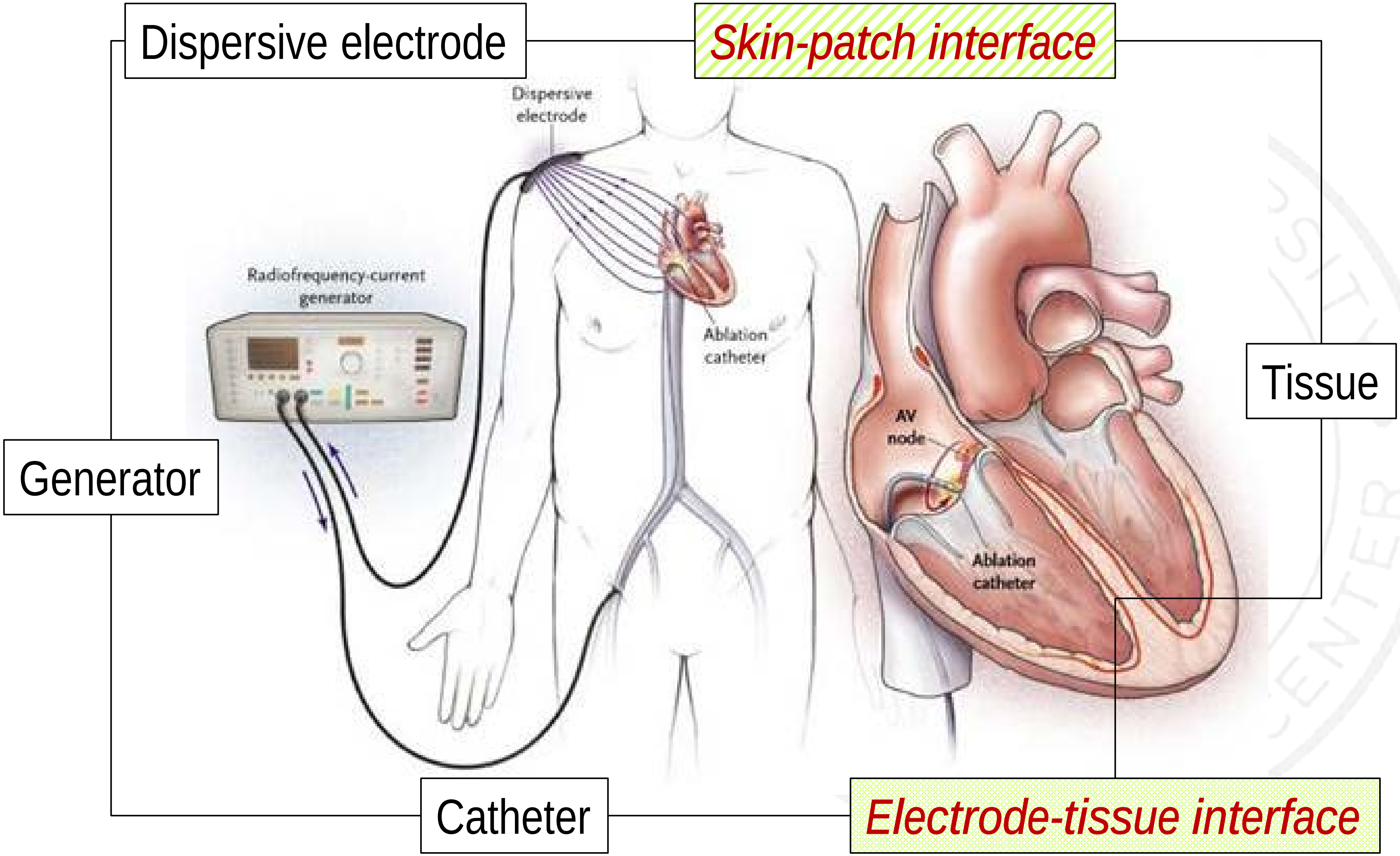
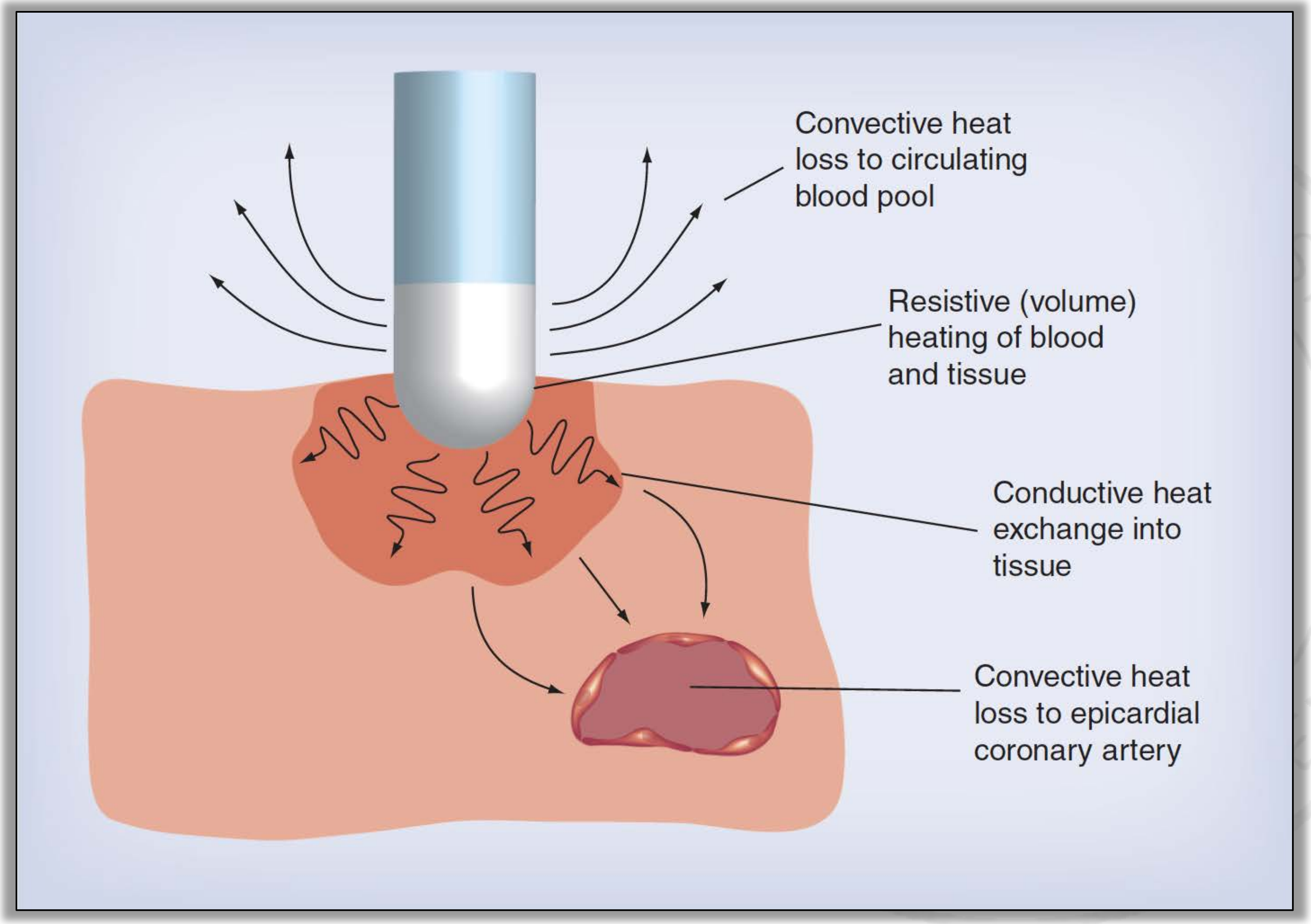
Agenda

- Principles of lesion formation by radiofrequency
- Optimal lesion formation: parameters
- RF ablation with irrigated & contact force
- Effect of different irrigants
- Epicardial ablation

Unipolar RF System



Electrode-tissue interface



Houmsse M & Daoud EG, Expert Rev Med Devices 2012;9:59

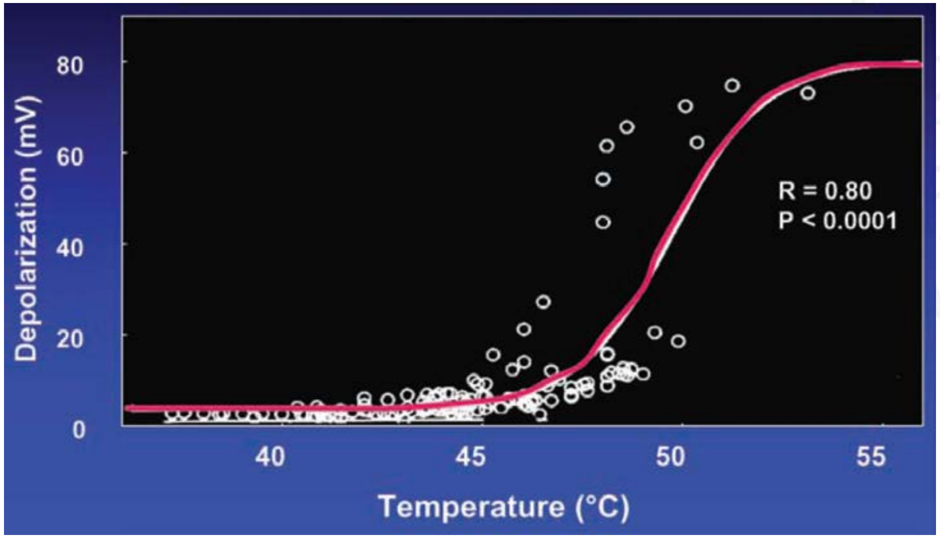
Tissue heating

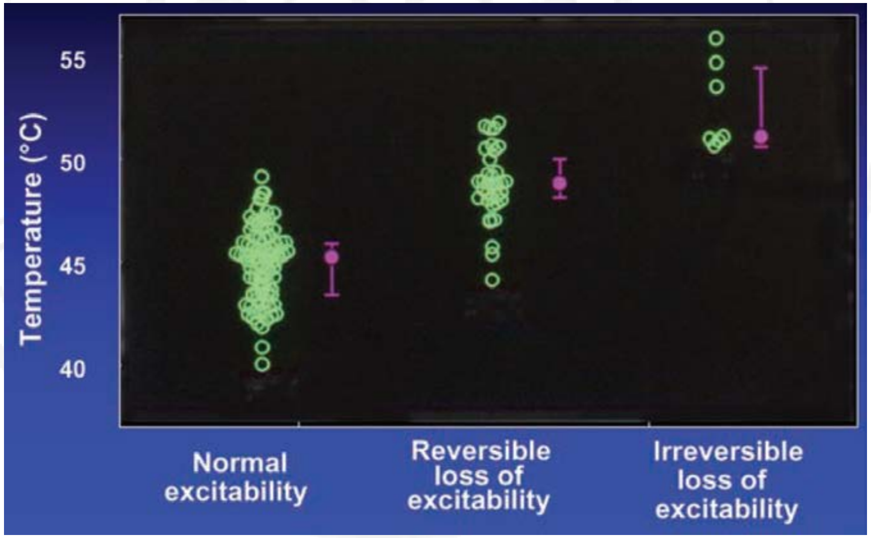
- *Resistive heat*
  - Approximately 90% of delivered power is absorbed within the first *1 to 1.5 mm* ***from the electrode surface***
  - Starts immediately with RF energy delivery

- *Heat conduction to deep tissue*
  - Thermal equilibrium: slow & requires *1~2 min* to equilibrate
  - *Thermal latency*: deep tissue temperatures continue to rise for several seconds after interruption of RF delivery

Cellular Electrophysiological Effects of Hyperthermia on Isolated Guinea Pig Papillary Muscle

- *Tissue injury by RF ablation is thermally mediated*
- *Progressive depolarization* of Vm at temperatures *>40ºC*; prominent at temperatures 45ºC
- < 45ºC: little tissue injury, 45~50ºC: in the transition
- > 50ºC: irreversible tissue injury

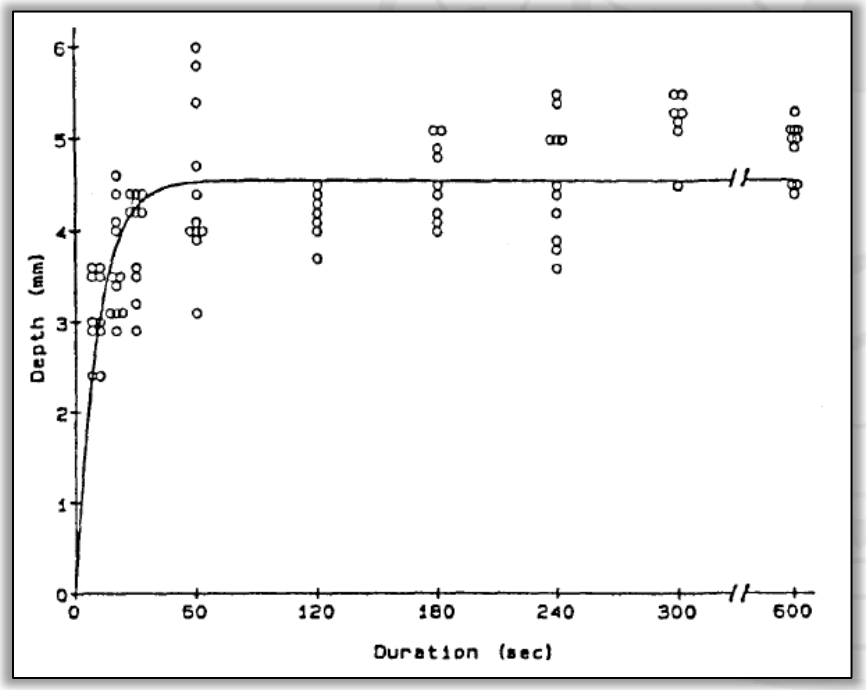




Nath S, et al. Circulation 1993;88:1826

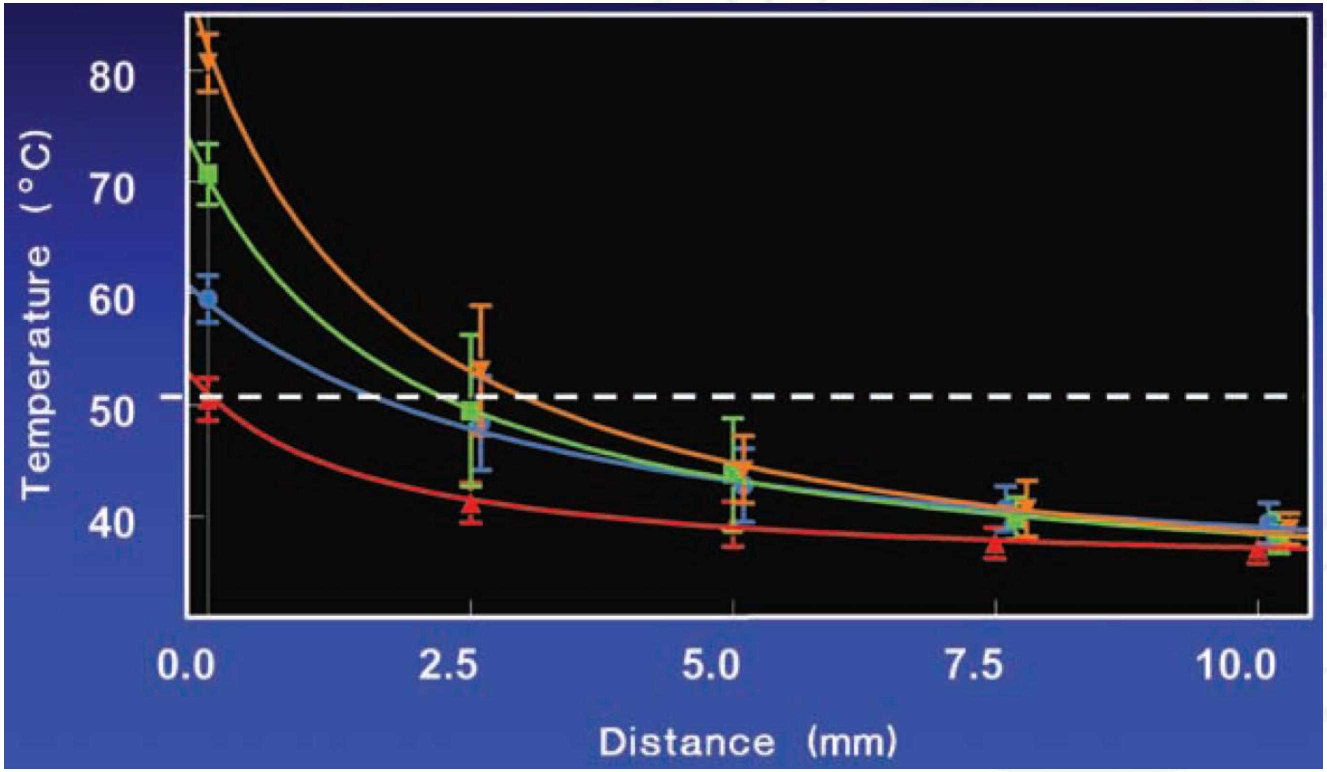
RF lesion depth vs Duration of energy delivery in vitro

- Monoexponential relationship: *Half time of lesion growth is 7.6 sec* (7~10sec)
- RF ablation requires at least 30 to 60 seconds to create full-grown lesions



Tissue heating during radiofrequency catheter ablation

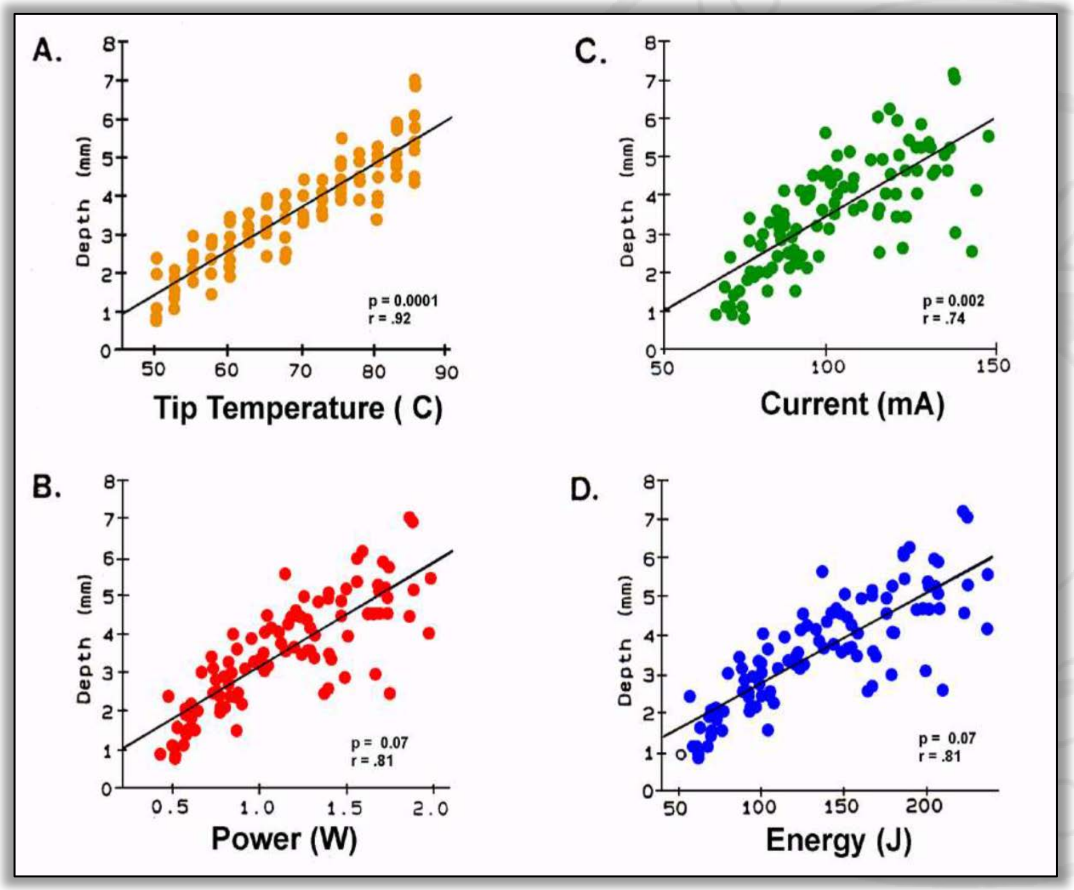
- Thermal transfer spreads out in a **radial fashion**
- Tissue temperature *decreases in an exponential fashion* with increasing distance from the source



Haines DE & Watson DD. PACE 1989;12:962

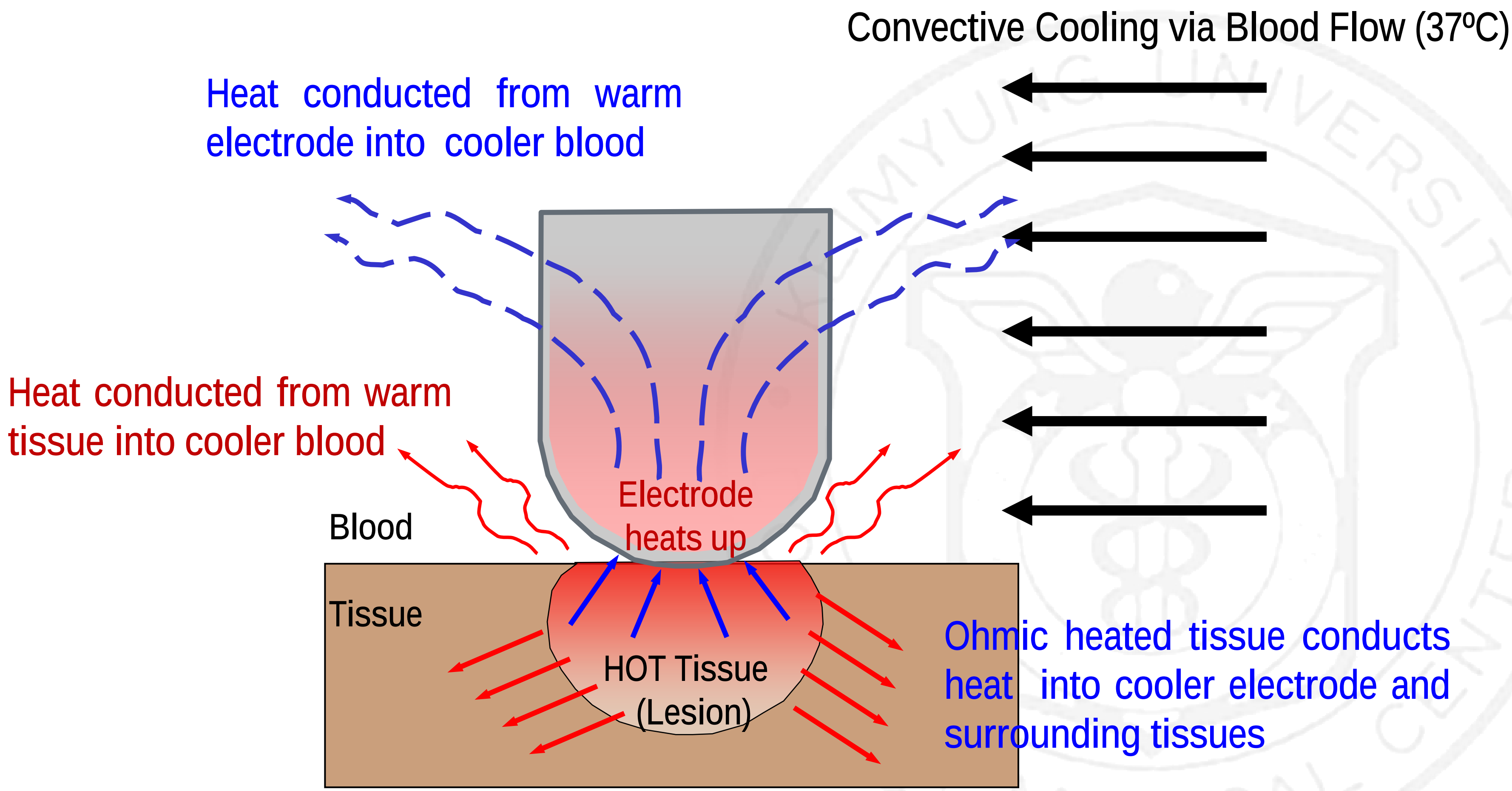
Tissue heating during radiofrequency catheter ablation

- *Electrode-tissue interface Temperature is the best predictor* of the depth of the lesion in vitro



Haines DE & Watson DD. PACE 1989;12:962

Electrode-tissue interface



Haines DE, et al. PACE 1989;12:962

Convective cooling

- Convective heat loss into the *circulating blood pool*
- **Highest tissue temperature** during RF occurs ***slightly below the endocardial surface***
- Maximum lesion width is usually ***located intramurally***, and the resultant lesion is usually ***teardrop shaped***
- Convective cooling by *coronary artery* (heat sink)
  - ✓ Can be protective for coronary artery
  - ✓ Can limit the success of ablation lesion
- *Factors increase convective cooling*

  Poor catheter contact, unstable catheter position, high blood flow

Determinants of Lesion Size

$$\text{Total amount of current delivered into tissue} = \sqrt{\frac{\text{Power (W)}}{\text{Impedance }(\Omega)}}$$

$$\text{Average current density of electrode} = \frac{\sqrt{\frac{\text{Power (W)}}{\text{Impedance }(\Omega)}}}{\text{Surface area of electrode}}$$

Unipolar RF System

Temperature-control mode

- Power delivery of RF energy is controlled by the feedback of catheter tip temperature
- *Catheter tip temperature* depends on ***tissue temperature, convective cooling, tissue contact*** of the ablation electrode, ***electrode material and its heat capacity***, and ***type and location of the temperature sensor***
- *Tip temperature is not the tissue temperature*

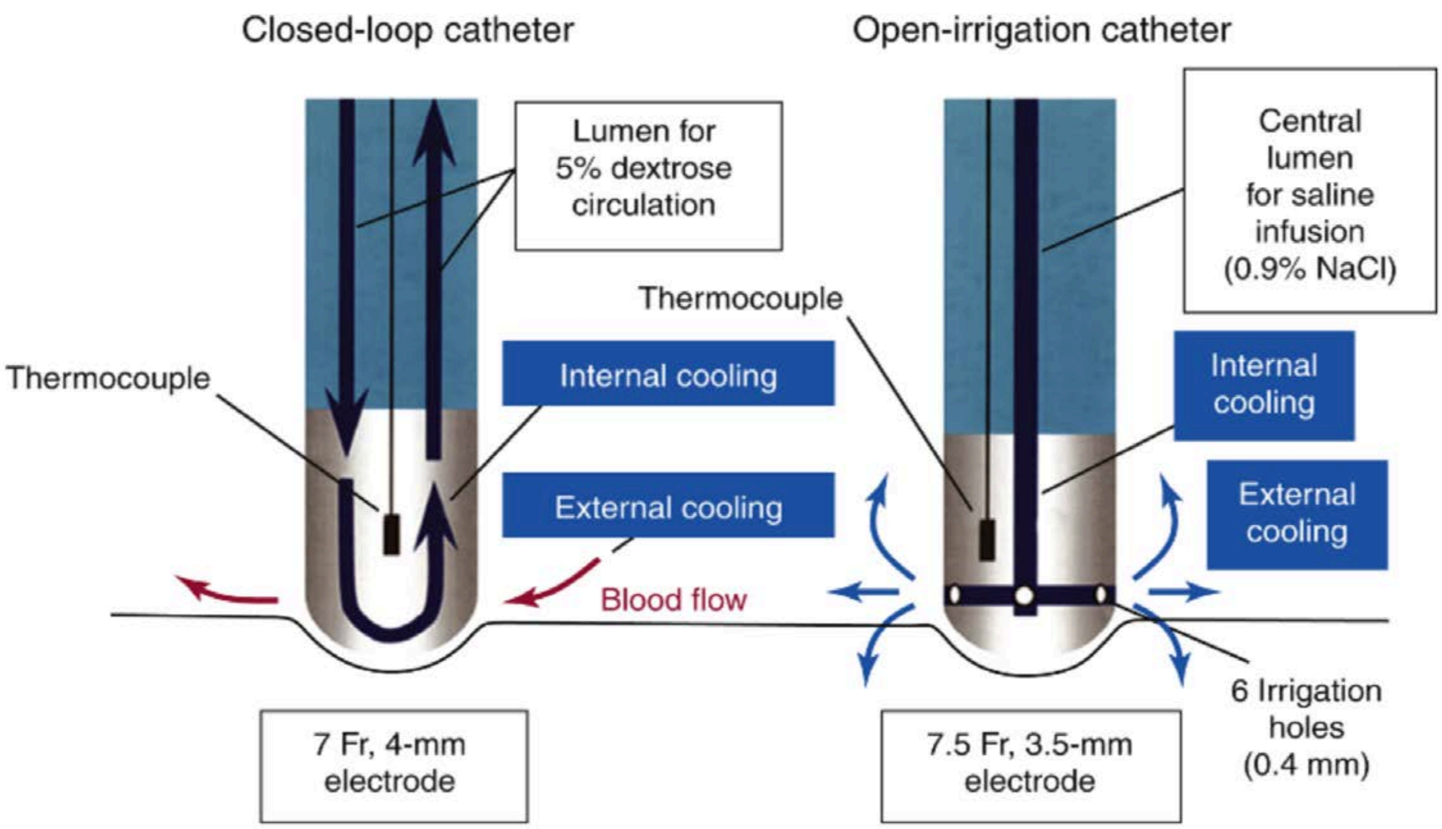
Unipolar RF System

Power-control mode

Power can be delivered at certain level *regardless of tip temperature*

Cooled Radiofrequency Ablation

- *Excessive surface heating causes coagulum formation, carbonization, and steam popping*

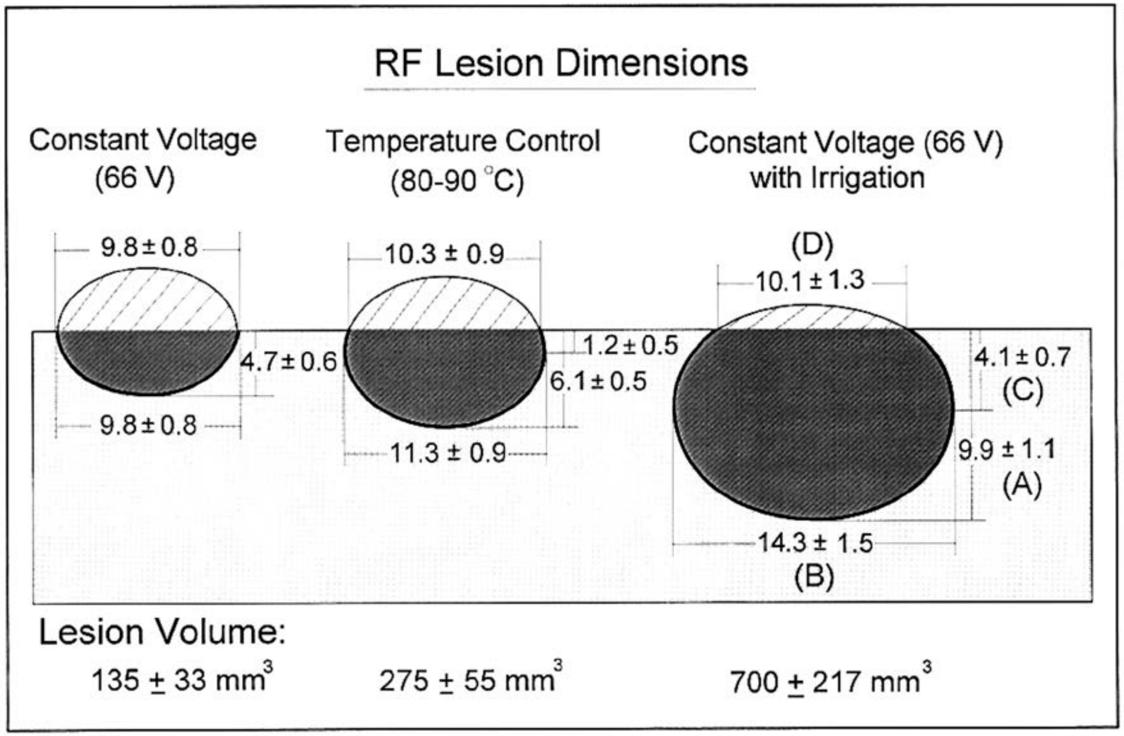


Cooled Radiofrequency Ablation

- Cooling at the tip *reduces the electrode tissue interface temperature*
- The maximum temperature displaced 1– 3.5 mm into the tissue (site of resistive heat)
- Cooling of the tip *delays or eliminates an impedance rise, avoids tip coagulum formation & allows continued delivery of RF current into the tissue*

Comparison of In Vivo Tissue Temperature Profile and Lesion Geometry for Radiofrequency Ablation With a Saline-Irrigated Electrode Versus Temperature Control in a Canine Thigh Muscle Preparation

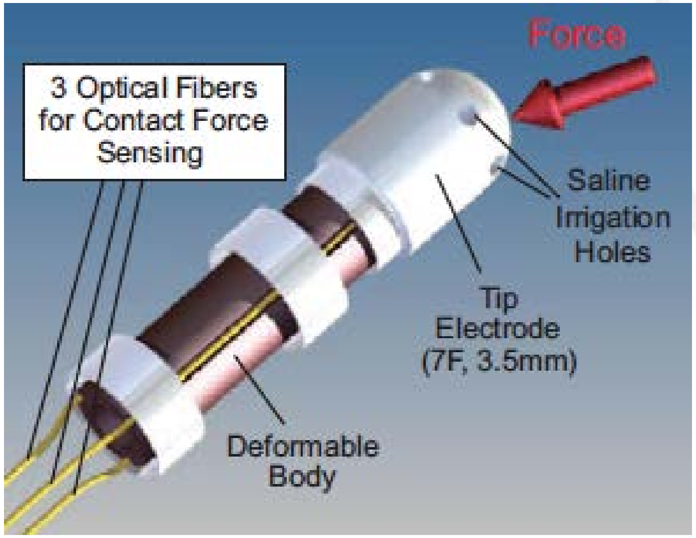
Saline irrigation maintains a *low electrode-tissue interface temperature* during radiofrequency application at high power, which *prevents an impedance rise and produces deeper and larger lesions*

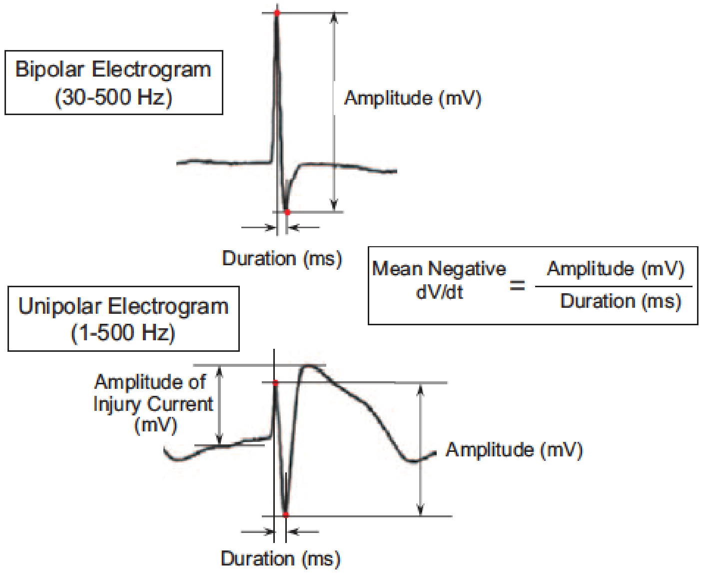


Nakagawa H, et al. Circulation 1995;91:2264

Relationship Between Catheter Contact Force and Radiofrequency Lesion Size and Incidence of Steam Pop in the Beating Canine Heart

- Assess *the lesion size of CF irrigated RF ablation in vivo*
- 8 dogs; TactiCath (7F, 3.5mm); mild (8g), moderate (21g), high (60g)
  - ✓ RV: 3 sites, 30 W, 60 sec, 17 ml/min
  - ✓ LV: 3 sites, 40 W, 60 sec, 30 ml/min
- Assess the relationship between contact force and other parameters

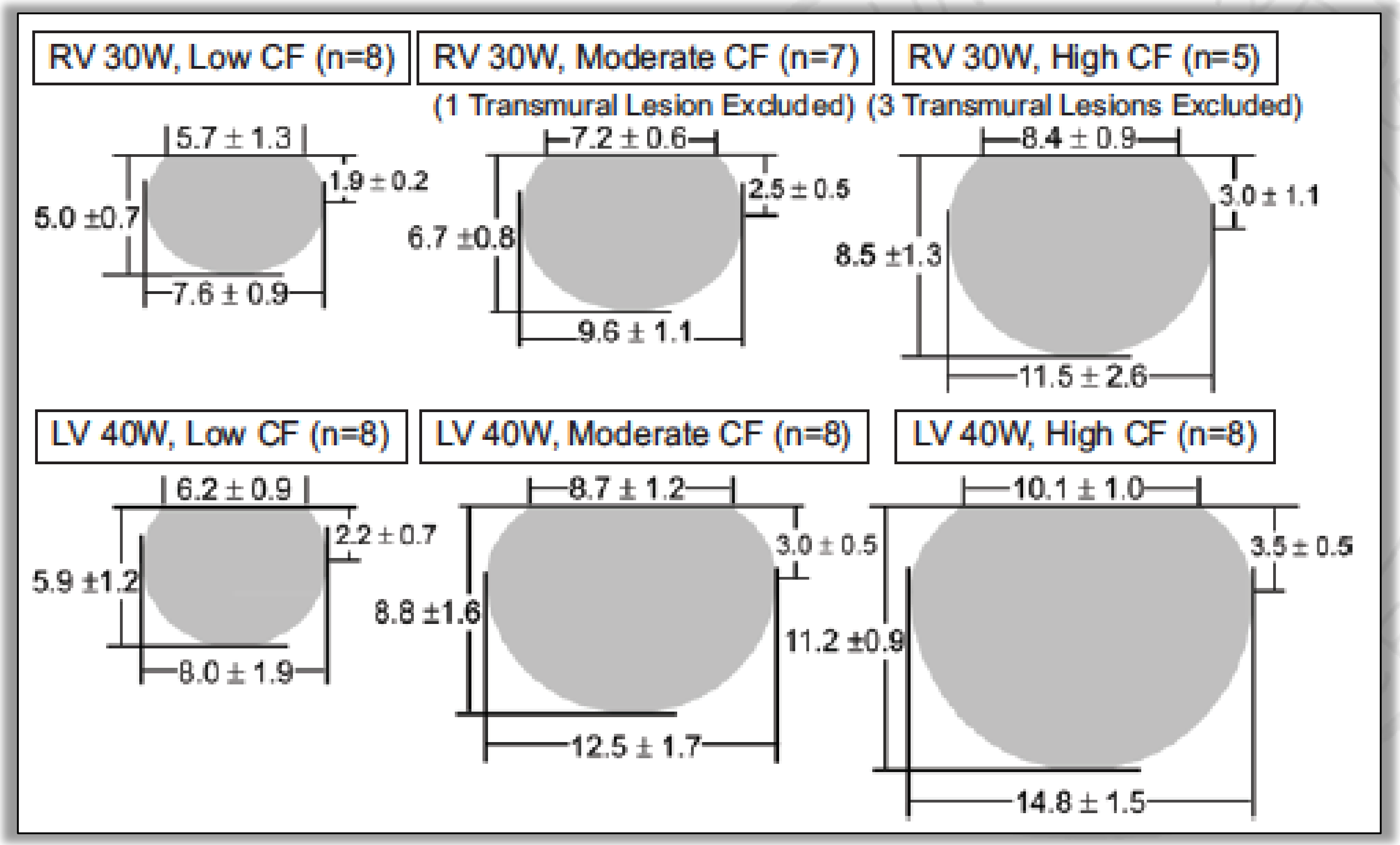




Ikeda A, et al. Circ AE 2014;7:1174

Relationship Between Catheter Contact Force and Radiofrequency Lesion Size and Incidence of Steam Pop in the Beating Canine Heart

lesion size increased significantly with *increasing CF* (*P*<0.01)

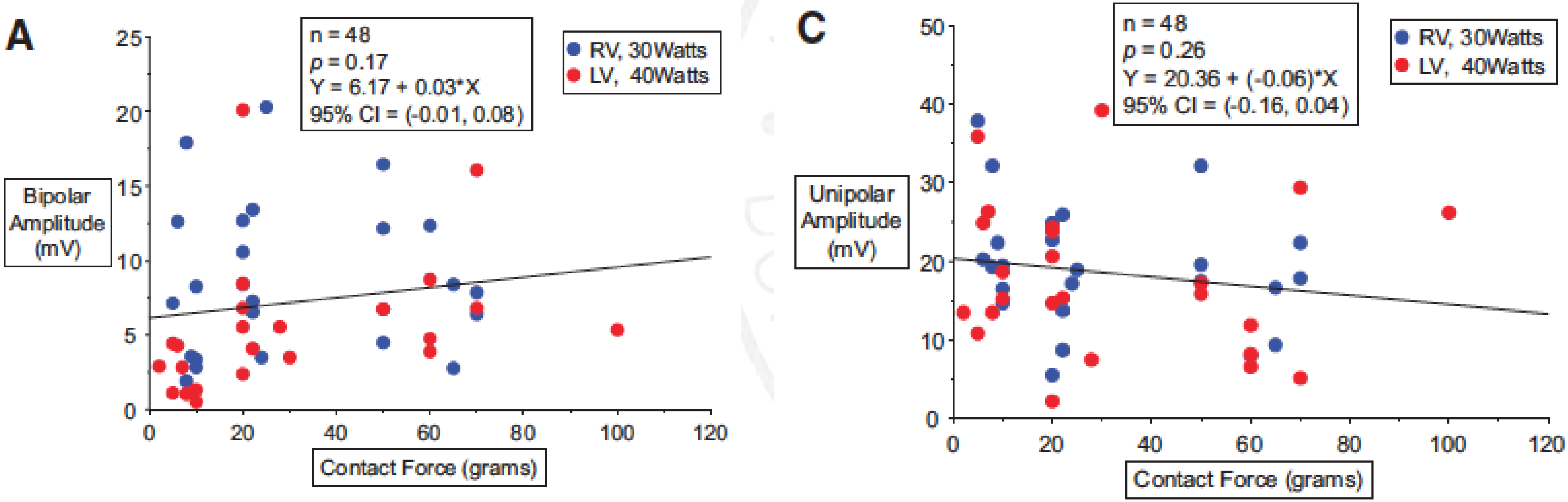


Ikeda A, et al. Circ AE 2014;7:1174

Relationship Between Catheter Contact Force and Radiofrequency Lesion Size and Incidence of Steam Pop in the Beating Canine Heart

KUDMC

Poor relationship between *CF* and the *amplitude of the bipolar or unipolar ventricular electrogram*



Ikeda A, et al. Circ AE 2014;7:1174

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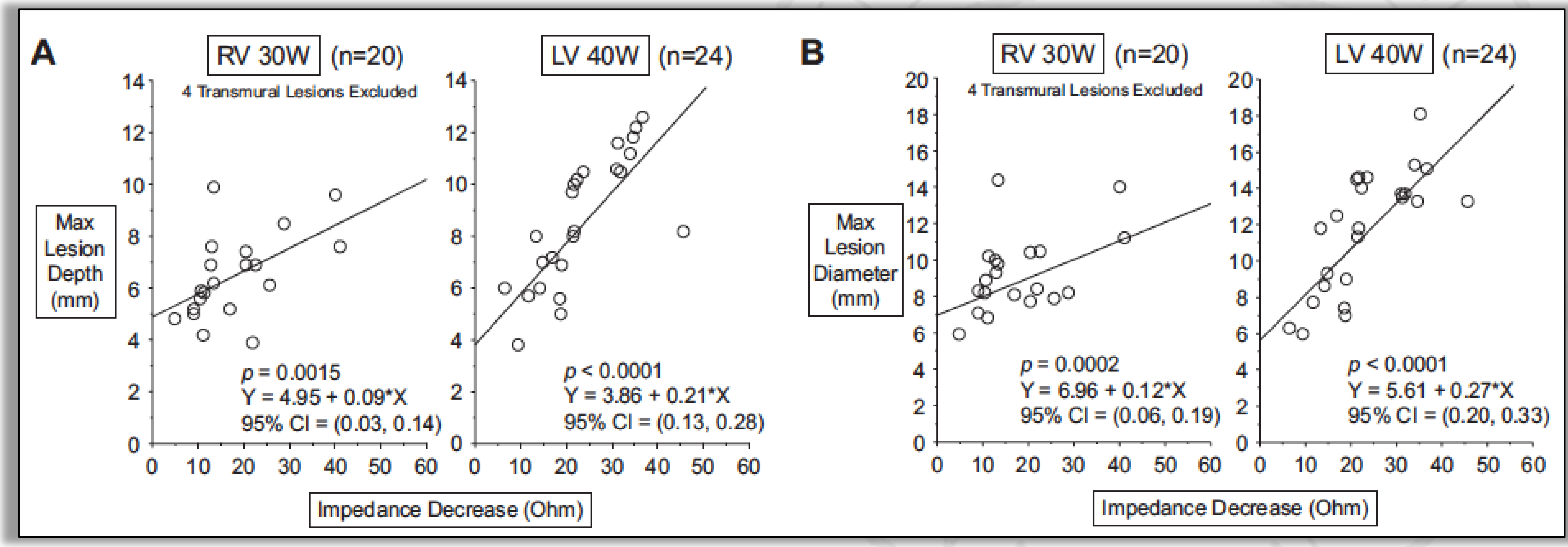
Relationship Between Catheter Contact Force and Radiofrequency Lesion Size and Incidence of Steam Pop in the Beating Canine Heart

lesion size increased significantly with *impedance decrease*



Ikeda A, et al. Circ AE 2014;7:1174

- The incidence of a *steam pop increased with both increasing CF and higher power*
- *Steam pop correlated with the degree of impedance decrease*

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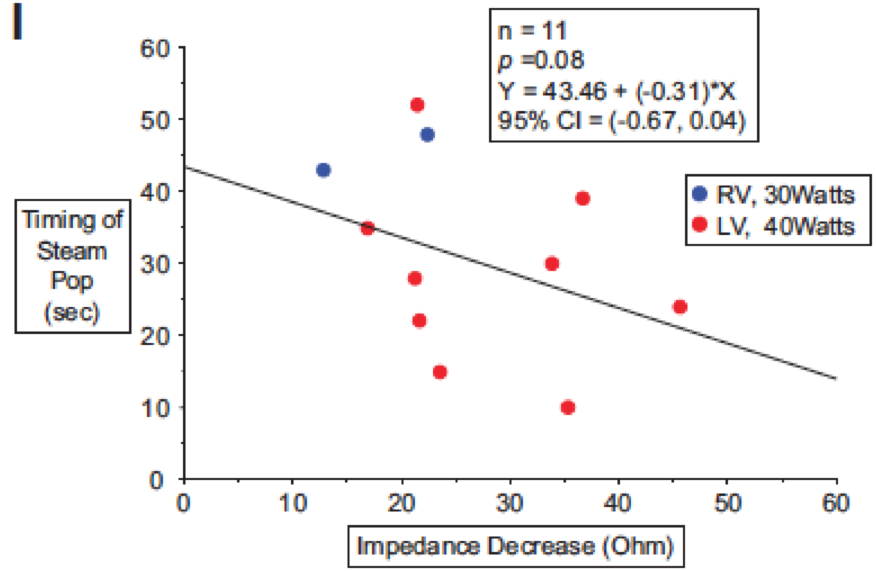

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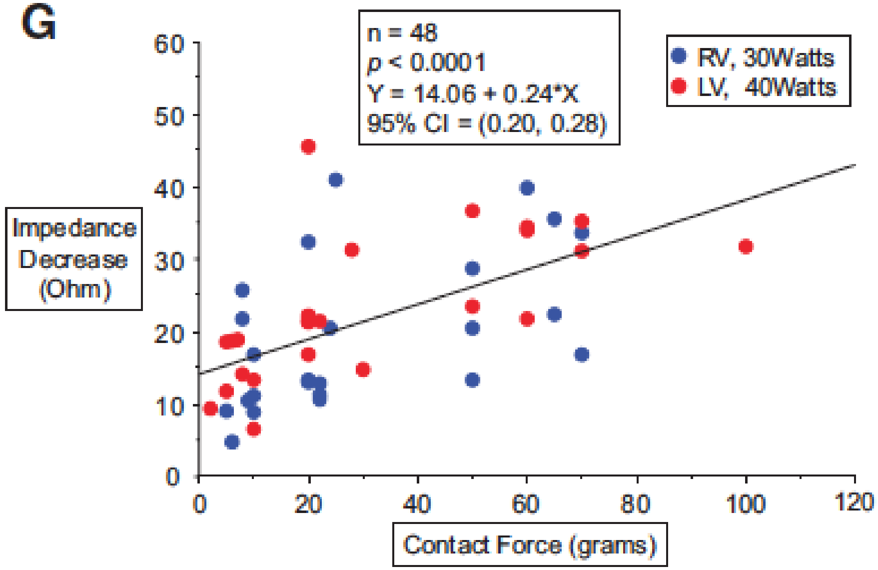

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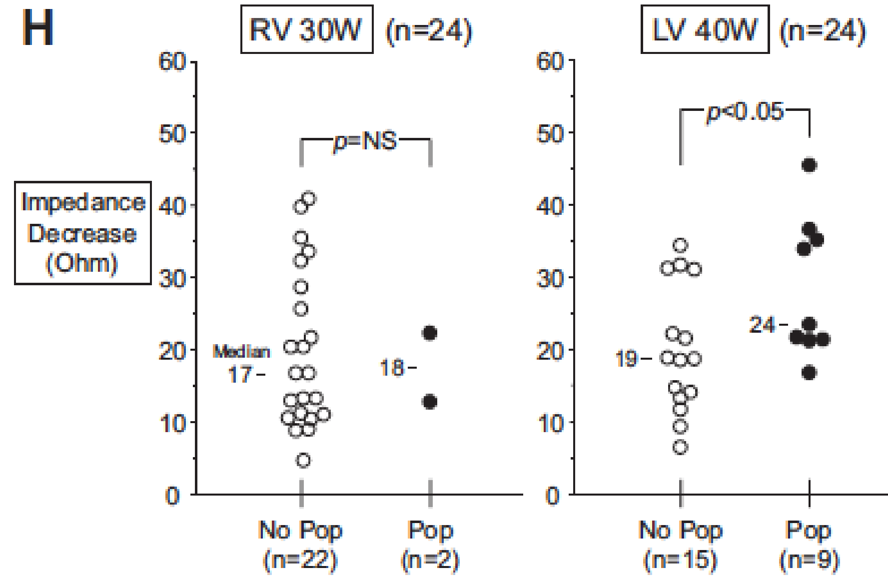
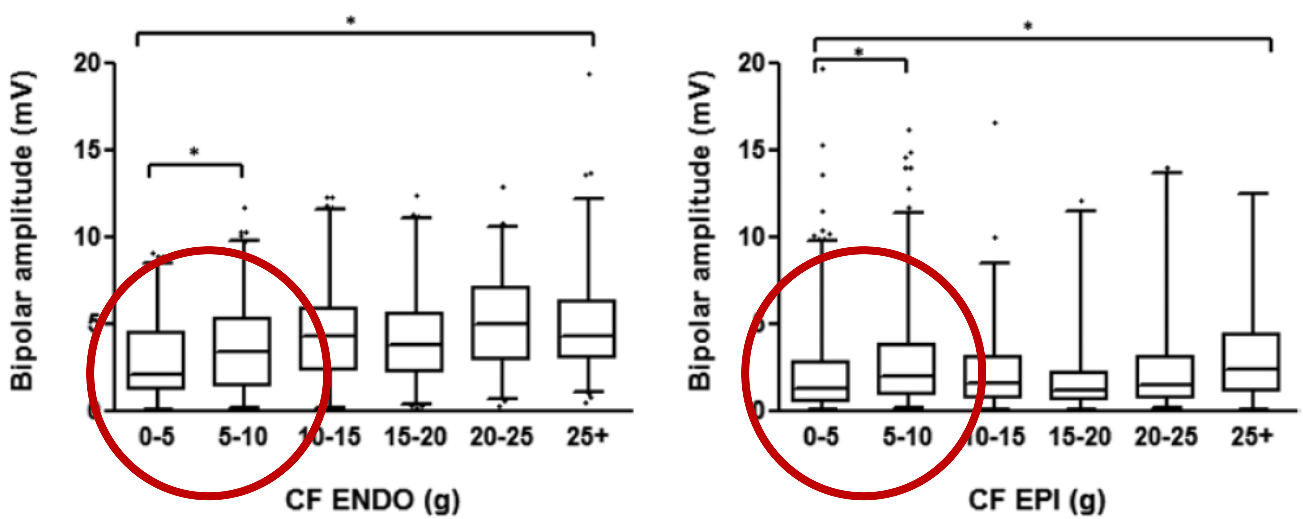


Ikeda A, et al. Circ AE 2014;7:1174

Characterization of Contact Force During Endocardial and Epicardial Ventricular Mapping

- To evaluate the *optimal CF for ventricular mapping*
- Smartouh catheter for epi & endocardial substrate mapping
- 8979 mapping points in 21 patients by 2 experienced operator
- *Bipolar signal amplitude* in healthy endocardial and epicardial tissue was found to *increase with CF ≤10 g, but not beyond*



Jesel L, et al. Circ AE 2014;7:1168

Characterization of Contact Force During Endocardial and Epicardial Ventricular Mapping

- Based on a general linear mixed model analysis
- the *best cutoff value for CF to obtain a signal amplitude >1.5 mV*
  - ✓ *LV endocardium: 7 g* (sensitivity 80%: specificity 75%)
  - ✓ *RV endocardium 9 g* (sensitivity 65%: specificity 83%)
  - ✓ *Epicardium was 4 g* (sensitivity 83%: specificity 64%)

Jesel L, et al. Circ AE 2014;7:1168

Effect of Irrigant Characteristics on Lesion Formation After Radiofrequency Energy Delivery Using Ablation Catheters with Actively Cooled Tips

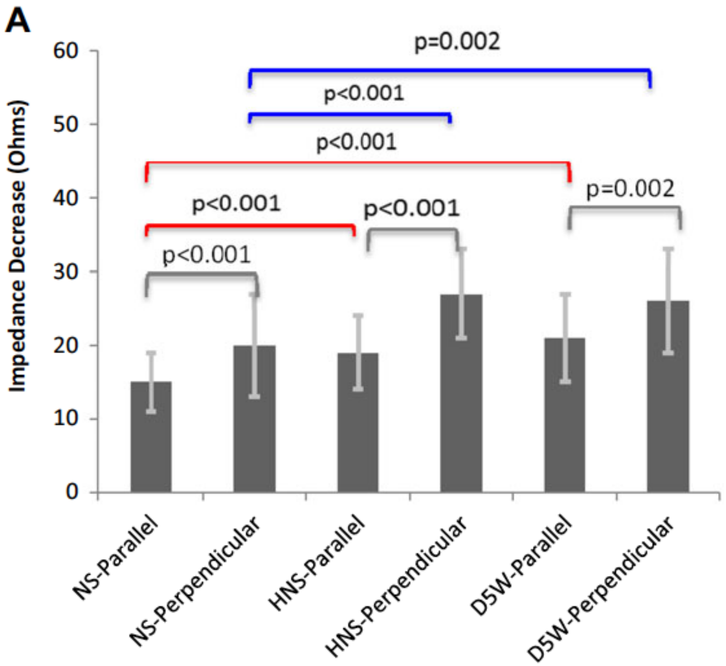
- *Ex vivo* and *in vivo* model of bovine myocardium
- Irrigated catheter with 10g force in both perpendicular & parallel position
- Assess the lesion size with different irrigants: normal saline (NS), half normal saline (HNS), dextrose water (D5W)

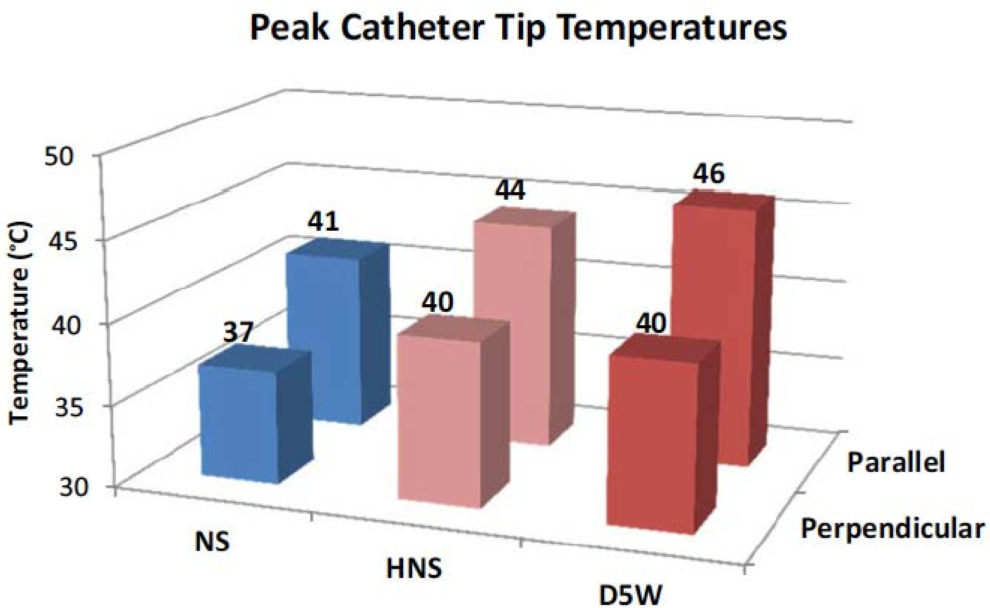
- *NaCl* has *conductive properties* and may ***disperse RF energy away from the tip–tissue interface***, thereby *reducing current density and lesion size* compared to ablation with **nonionic solutions**

Nguyen DT, et al. J Cardiovasc Electrophysiol, 2015;26792

Effect of Irrigant Characteristics on Lesion Formation After Radiofrequency Energy Delivery Using Ablation Catheters with Actively Cooled Tips

- Lesion size: *D5W* >> HNS > NS ablation
- *Steam pops* was statistically *higher only for open irrigated D5W, but not for HNS*, when compared to NS





Nguyen DT, et al. J Cardiovasc Electrophysiol, 2015;26792

Catheter Ablation of Ventricular Epicardial Tissue
A Comparison of Standard and Cooled-Tip Radiofrequency Energy

- Subxyphoid approach in 10 normal goats and 7 pigs with healed MI
- *Consideration for energy delivery in epicardial ablation*
  - ✓ Lack of current shunt by the bloodstream
  - ✓ Lack of convective cooling
  - ✓ Epicardial fat (low electrical & thermal conductivity)
- Compare the lesions by
  - ✓ Standard RF (4mm tip): target temperature 70ºC for 60 sec
  - ✓ Cooled RF (Chilli catheter): 0.6ml/min, target temperature 40ºC for 60sec

d'Avila A, et al. Circulation 2004;109:2363

KUDMC

Catheter Ablation of Ventricular Epicardial Tissue

A Comparison of Standard and Cooled-Tip Radiofrequency Energy

	Cooled-Tip RF Ablation (n=65)			Standard RF Ablation (n=33)	
	Normal Tissue (n=37)	Normal Tissue on Fat (2.6±1.2 mm) (n=7)	Infarcted Tissue (n=21)	Normal Tissue (n=22)	Normal Tissue on Fat (3.1±1.2 mm) (n=11)
Power, W	44.8±6.8	45±4.4	35.6±7.1*	25±16.8*	16±14
Temperature, °C	39.7±3.2	40.2±2	41.4±2.2	68±6.2*	69±4.1
Initial impedance, Ω	146±24	146±16	110±12*	148±13	145±11
Impedance drop, Ω	27.8±10.3	27.6±10.1	19.7±4.4*	23.8±4*	17.1±2
Lesion characteristics					
Long axis, mm	15.9±3.5	15.6±4.2	14.6±2.7	14.9±2.7	11±4.7
Short axis, mm	13.7±3.5*	12.3±4.3	11.8±2.9	11±2.7	9±2.4
Depth, mm†	6.7±1.7* (4–9)	4.1±2 (1–7)	5.5±1.2* (4–8)	3.7±1.3 (2–6)	None

*$P<0.05$.

d'Avila Andre, et al. Circulation 2004;109:2363

Catheter Ablation of Ventricular Epicardial Tissue
A Comparison of Standard and Cooled-Tip Radiofrequency Energy

Conclusions — *Cooled-tip RF ablation can generate epicardial lesions more effectively* than standard RF ablation and appears to be of particular benefit *in ablating areas with overlying epicardial fat*

d'Avila Andre, et al. Circulation 2004;109:2363

Summary

- Understanding the fundamentals is important to choose appropriate catheters and energy setting
- Ablation with an irrigated catheter would be beneficial for the VT ablation
- Open irrigated catheter using *half normal saline* would help to create the more effective lesion in VT ablation

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Thank You for Your Attention !

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