Different Thermal Ablation Techniques for Treatment of Abdominal Tumors: Pros and Cons

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New Society of Interventional Radiology

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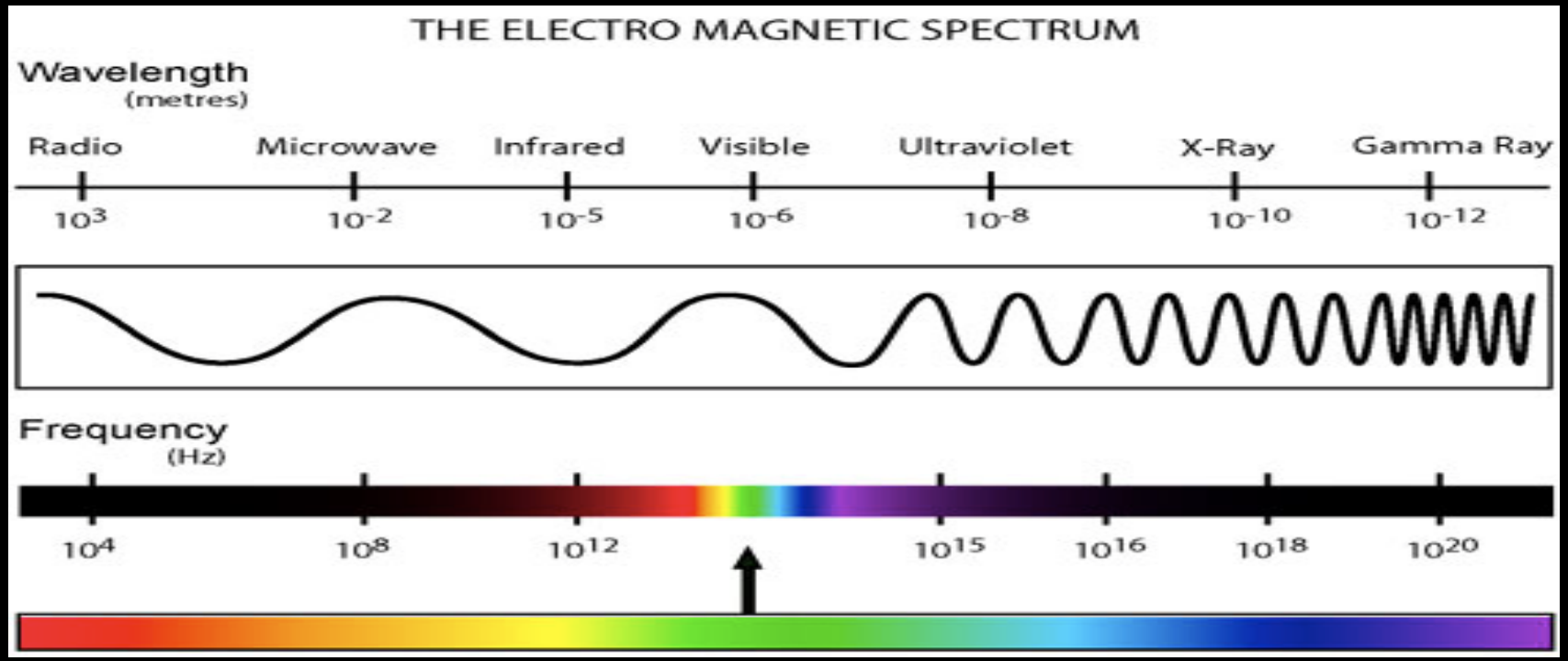
Objectives

- To review currently available thermal ablation devices
- Discuss potential advantages and disadvantages of each device
- Demonstrate examples
- Summarize

Radiofrequency Ablation

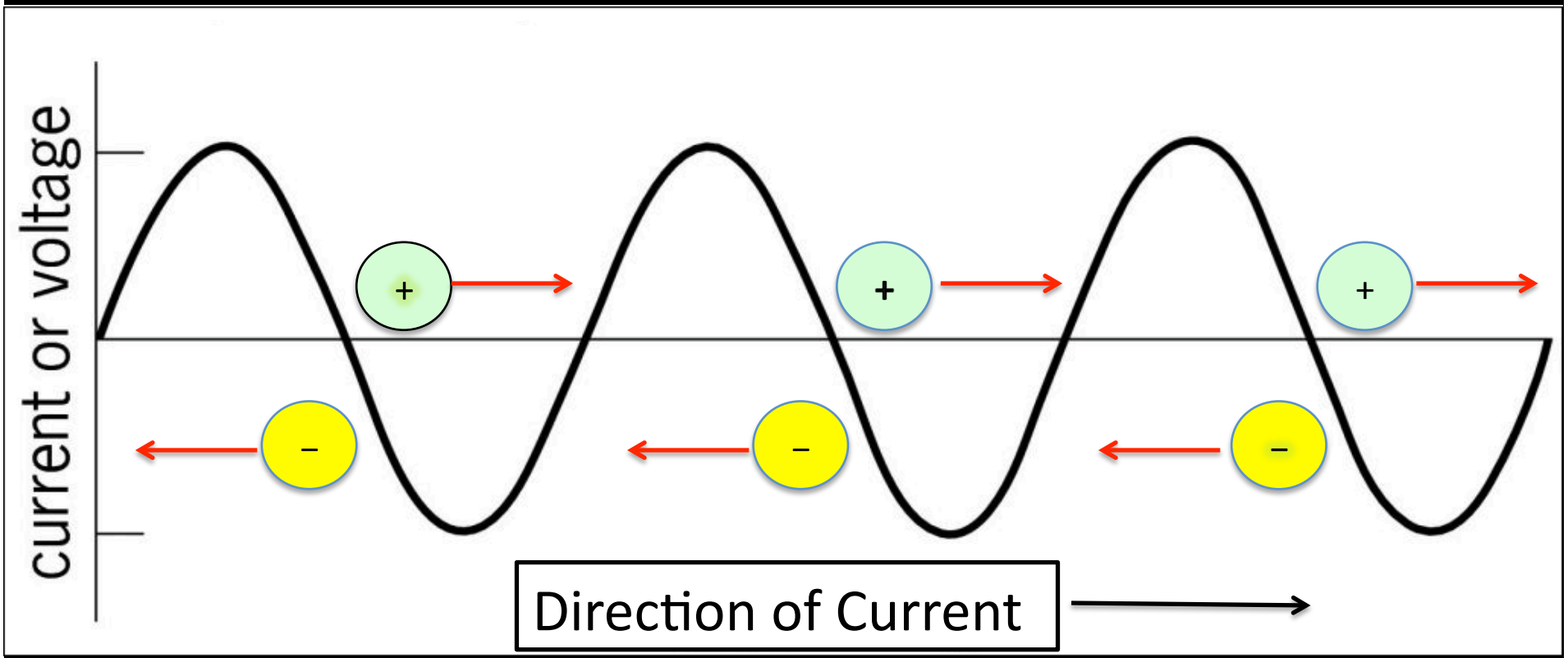
- How does it work?

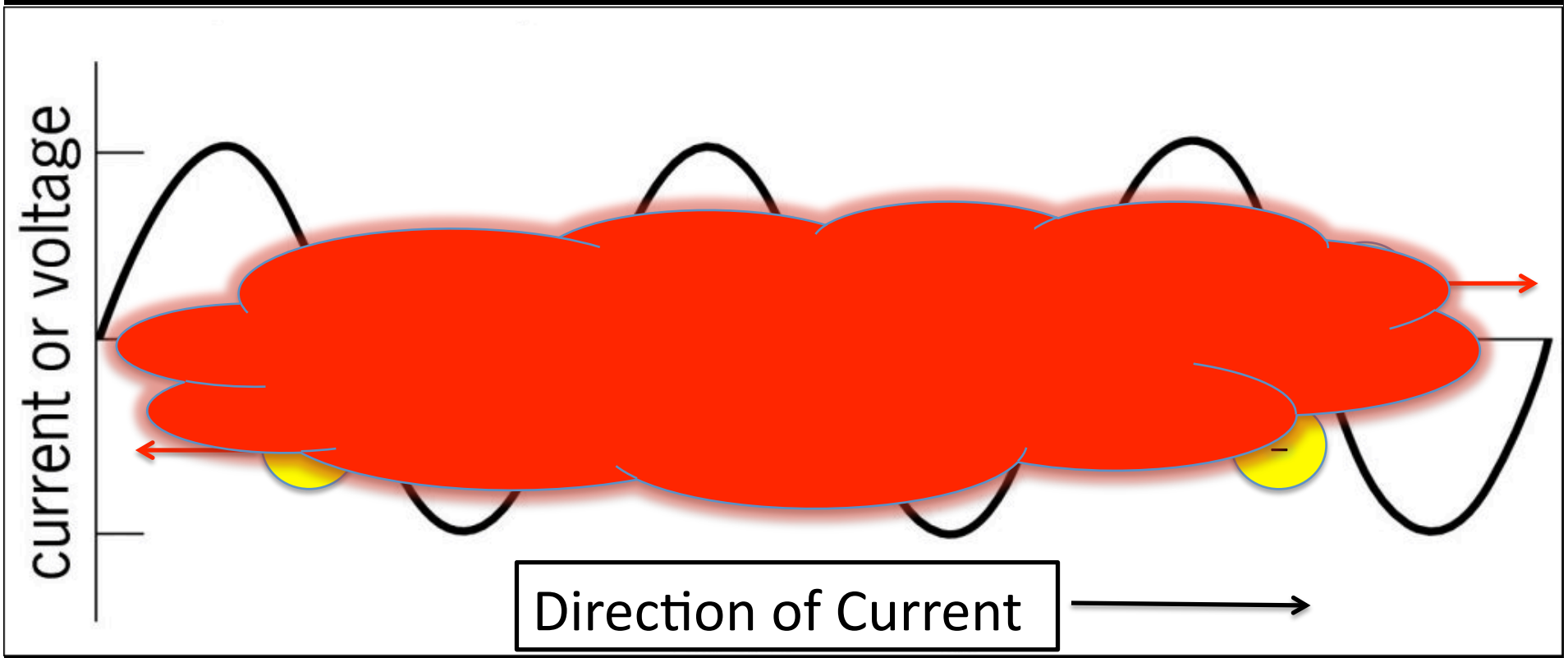
Energy, E = h x f = h x c / W



RFA-How Does it Work?

- Relies on a complete electrical circuit created through body to conduct current
- Generation of frictional heat is dependent upon presence of ions within tissue
- Direct RF heating adjacent to electrodes


current or voltage
+
+
+
–
–
–
Direction of Current

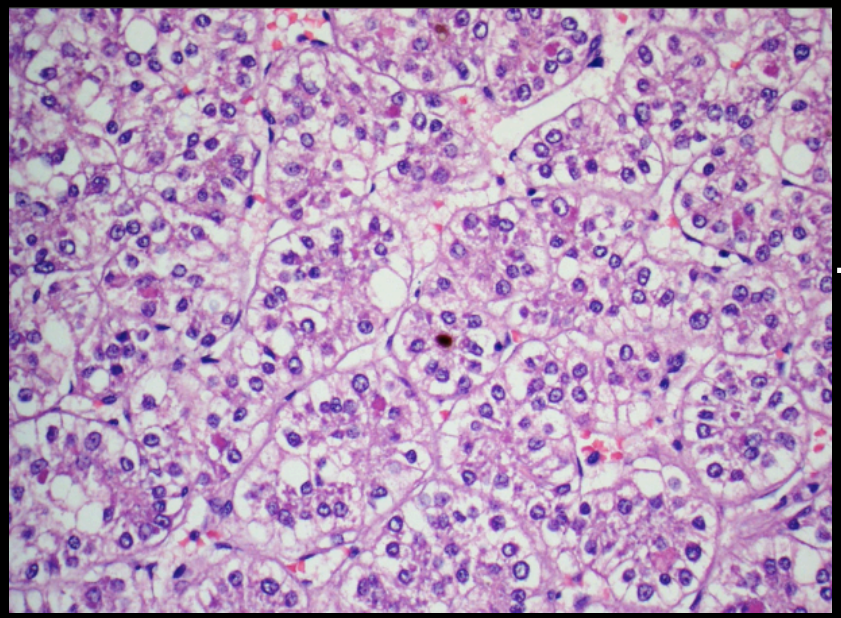

current or voltage
Direction of Current

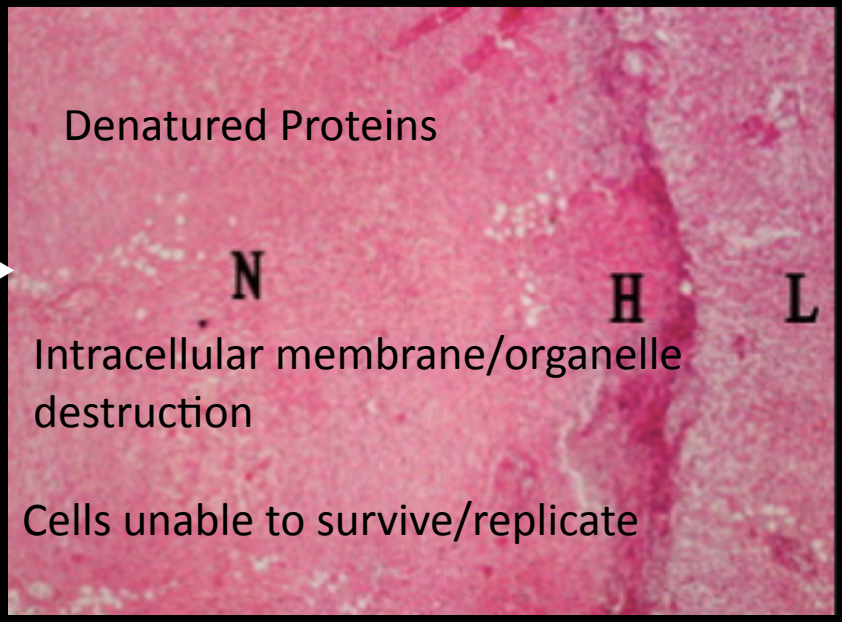
Thermal Ablation Therapy: Temperature Tissue Interactions

35 - 40° C	**Normothermia**
42 - 46° C	**Hyperthermia**
46 - 48° C	**Irreversible cellular damage @ 45**
50 - 52° C	**Coagulation necrosis, 4 - 6 min**
60 - 100° C	**Near instantaneous coagulative necrosis**
> 110° C	**Tissue vaporization**

What are the Ideal Features of Thermal Ablative Technology?

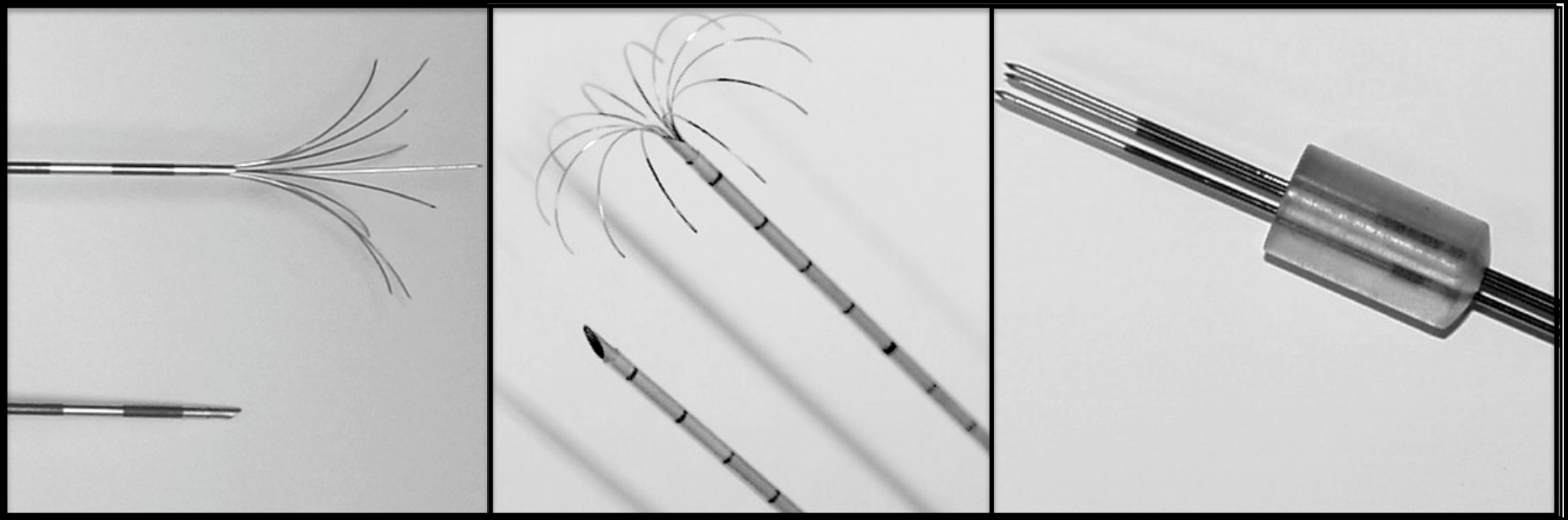
- Complete destruction of malignant cells





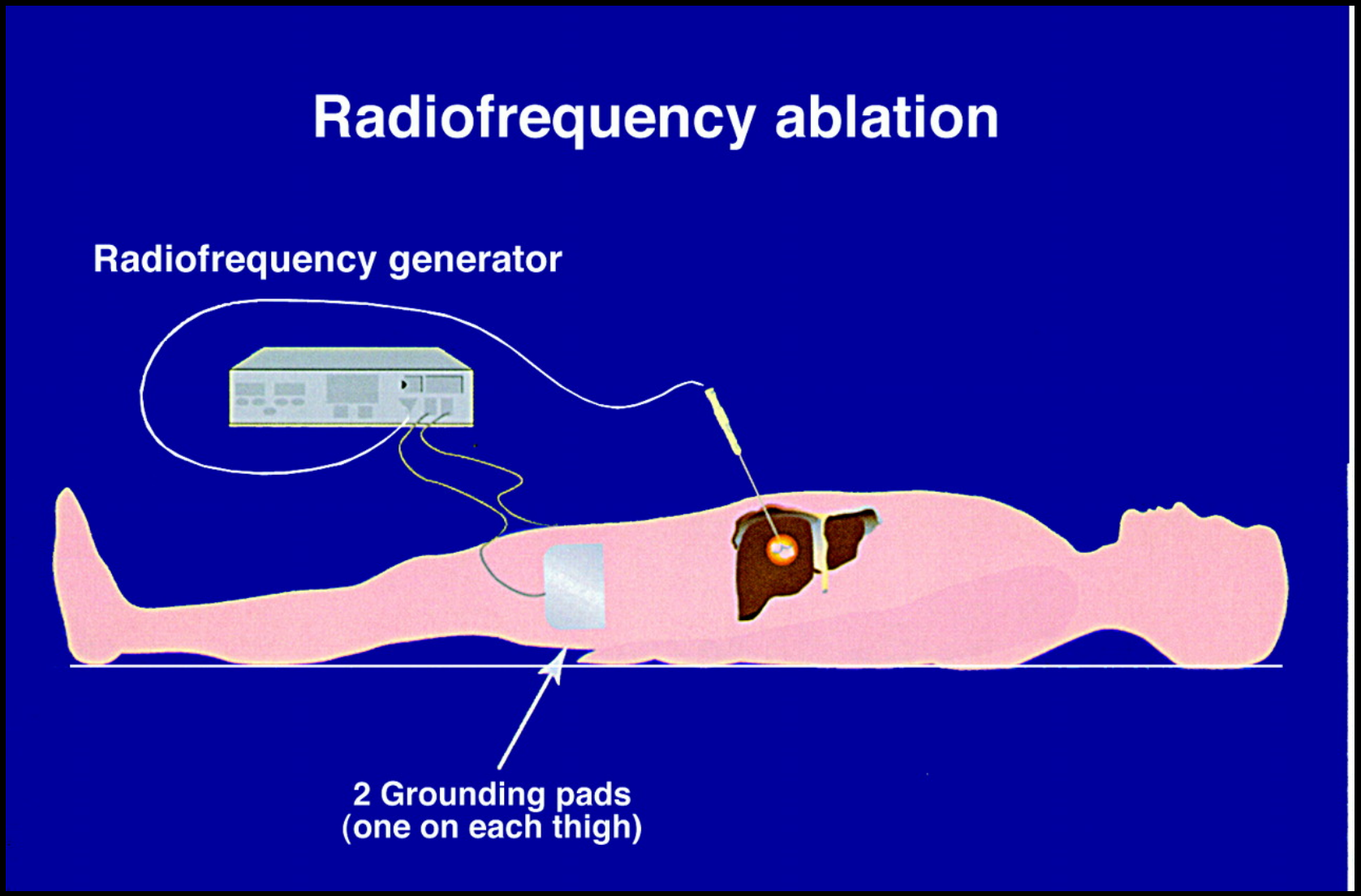
Radiofrequency Ablation Generators

Radiofrequency Ablation Electrode Applicators



August 2004 Radiology, 232, 482-490.

Radiofrequency ablation



RFA-Benefits

- Long clinical record of
  - Safety
    - Complication 0.6-9%
  - Efficacy
    - Overall survival rates for small HCC (</= 3cm) similar to surgery. RFA has benefit of less morbidity.
  - Bridging therapy for liver transplant candidates

Tumor Necrosis

Livraghi et al. (RSNA 2003)

- 1,620 patients with hepatoma - mean follow-up 24 ± 6 months
- Complete necrosis in:

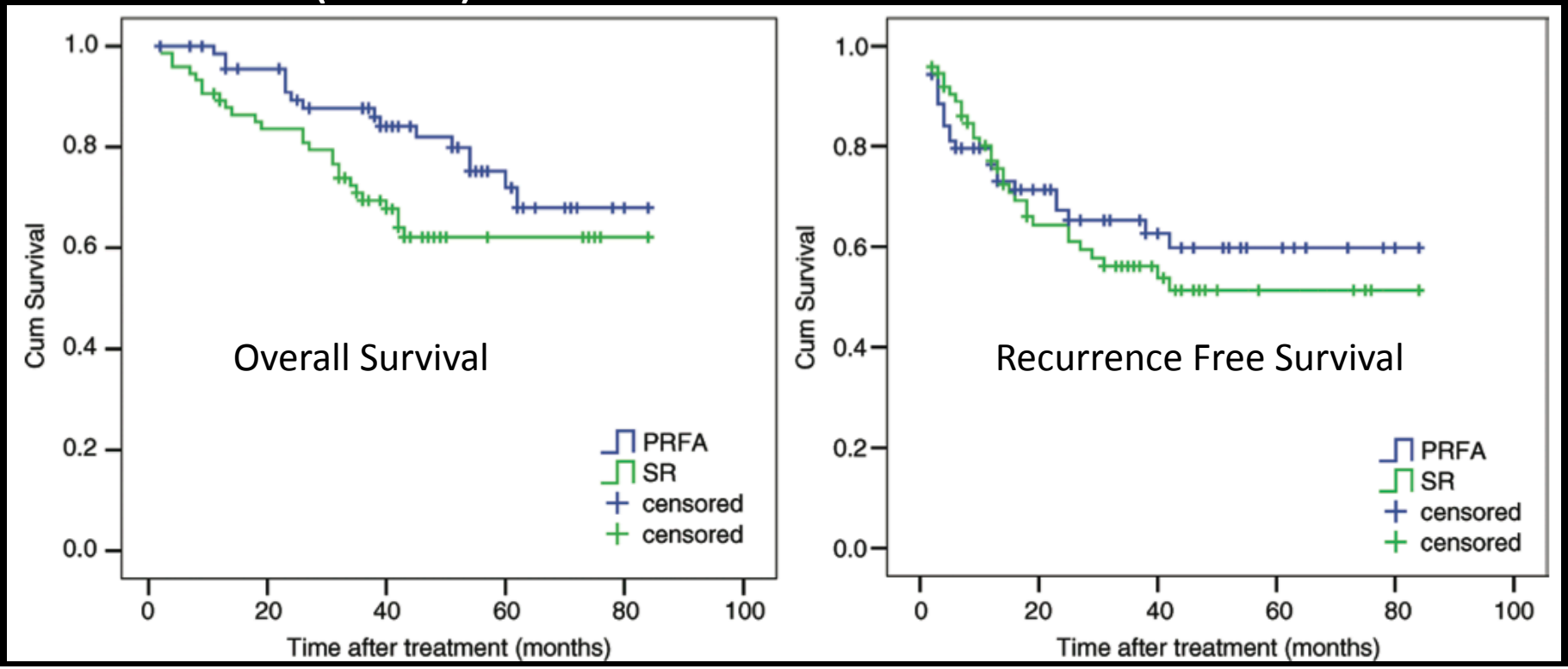
1.0 - 3.0 cm	82.3%
3.1 - 5.0 cm	64.9%
5.1 - 7.0 cm	32.4%
7.1 - 9.0 cm	12.5%
9.1 - 13.0 cm	0%

Radiofrequency Ablation versus Hepatic Resection for the Treatment of Hepatocellular Carcinomas 2 cm or Smaller: A Retrospective Comparative Study[1]

Radiology: Volume 262: Number 3—March 2012

Radiology: Volume 262(3) March 2012

- 145 Pt
  - Surgical resection (n=74)
  - RFA (n=71)



Radiology: Volume 262(3) March 2012

Overall Survival

RFA

- 1 yr = 98.5%
- 2 yr = 87.7%
- 3 yr = 71.9%

Surgical Resection

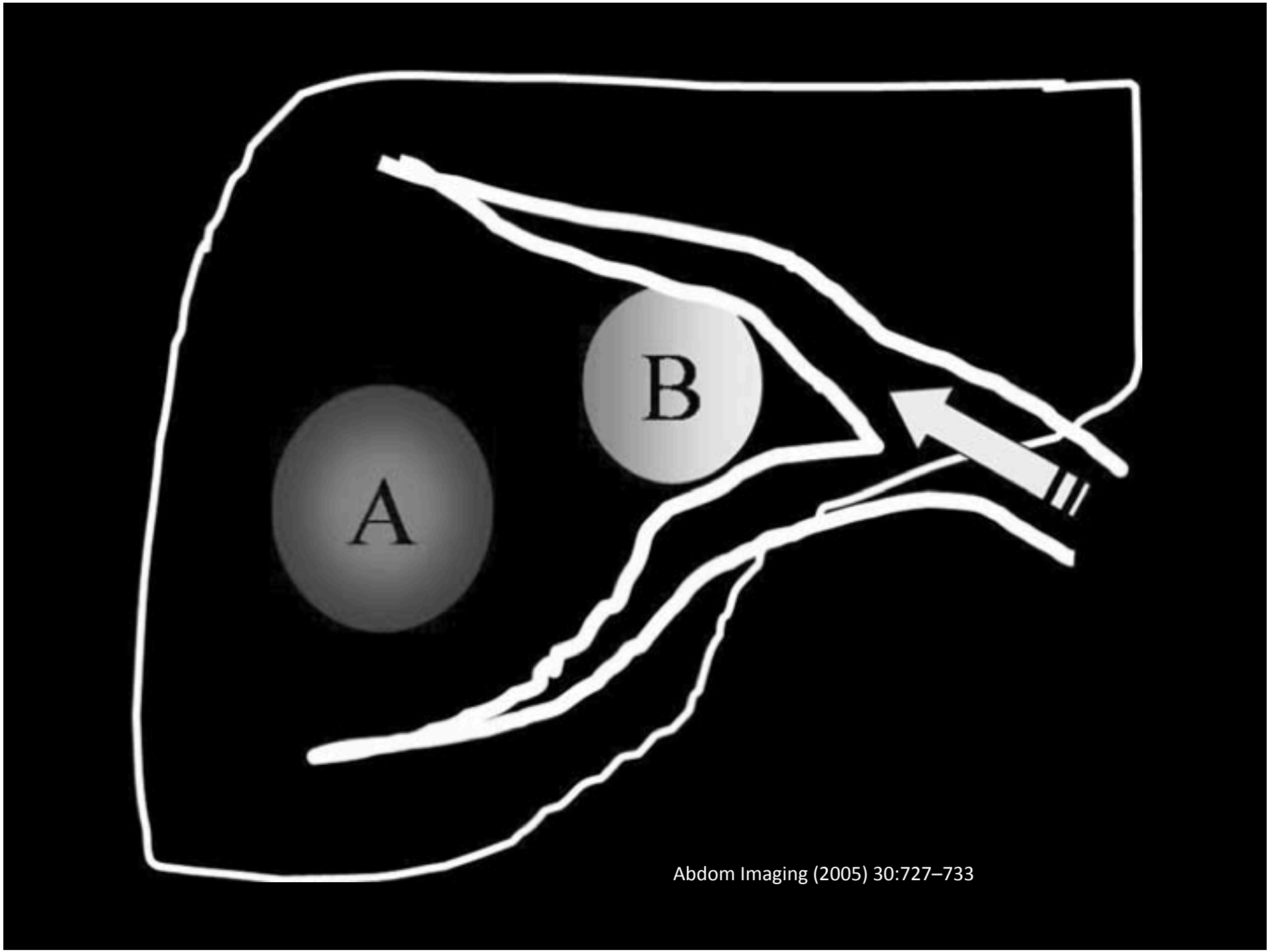
- 1 yr = 90.5%
- 2 yr = 70.9%
- 3 yr = 62.1%

RFA

- What are some of the limitations of RFA?
  - Heat sink
  - Time for multiple overlapping ablations
  - Grounding pads
  - Impedance

Heat Sink Effect - What is it?

- Perfusion mediated cooling by vascular flow
- Tumors adjacent to vessels at risk
  - 3mm vessel diameter
- Decreases extent of coagulation necrosis



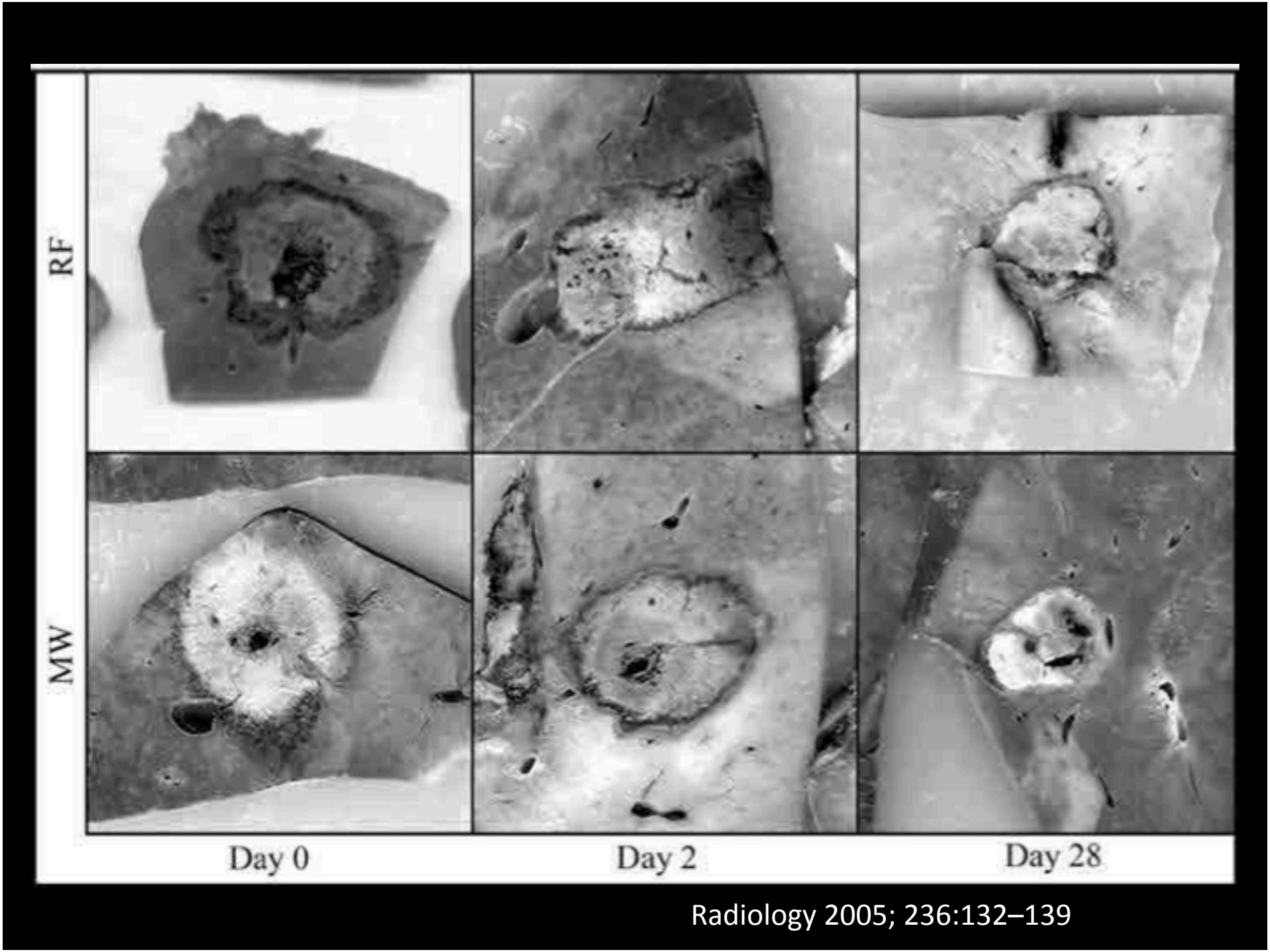
Abdom Imaging (2005) 30:727–733

RFA VS/ MWA in a Porcine Model
Radiology 2005; 236:132–139

Percentage of Deflection Measured at One Large (>3 mm) Blood Vessel for Each Ablation Zone in Group A

Ablation Type and Zone No.	Vessel Size (cm)	Distance from Vessel to Zone Center (cm)	Diameter at Vessel (cm)	Diameter Away from Vessel (cm)	Deflection (%)
MW					
1	0.3	0.5	1.1	1.2	8.3
2	0.3	0.9	2.2	2.2	0
3	0.4	0.3	1.9	1.9	0
4	0.5	0.8	1.4	1.6	12.5
5	0.6	1	1	1	0
6	0.6	0.4	1.4	1.4	0
7	0.6	0.6	1.7	1.9	10.5
8	0.6	0.6	1.6	1.6	0
9	0.6	0.4	1.8	1.8	0
Mean ± SD	0.5 ± 0.1	0.6 ± 0.2	1.6 ± 0.4	1.6 ± 0.4	3.5 ± 5.3
RF					
1	0.1	0.45	1.3	1.6	18.8
2	0.2	0.3	0.5	0.5	0
3	0.3	0.6	1.1	1.3	15.4
4	0.4	0.5	1.7	2	15
5	0.4	0.4	0.5	0.9	44.4
6	0.6	0.7	0.3	1.6	81.3
7	0.7	1	1.1	1.2	8.3
8*	NA	NA	NA	0.7	NA
9*	NA	NA	NA	1.8	NA
Mean ± SD	0.4 ± 0.2	0.6 ± 0.2	0.9 ± 0.5	1.3 ± 0.5	26.2 ± 27.9

Note.—NA = not applicable, SD = standard deviation.
* No blood vessels were visible within 2 cm of the ablation zone.



Radiology 2005; 236:132–139

Dealing with Heat Sink Effect

- Options
  - Transjugular
    - Temporary occlusion of the hepatic vein
  - Intra-op Pringle maneuver
    - Short term occlusion of the portal vein

Heat Sink Effect – *Is It Real?*

- 28 pts
- Contact with blood vessels >3 mm diameter
- Post ablation imaging 1, 3, 6, 9 12 months
- 21% showed residual at 1 month, requiring additional treatment
- 8.7% tumor progression at 1 yr

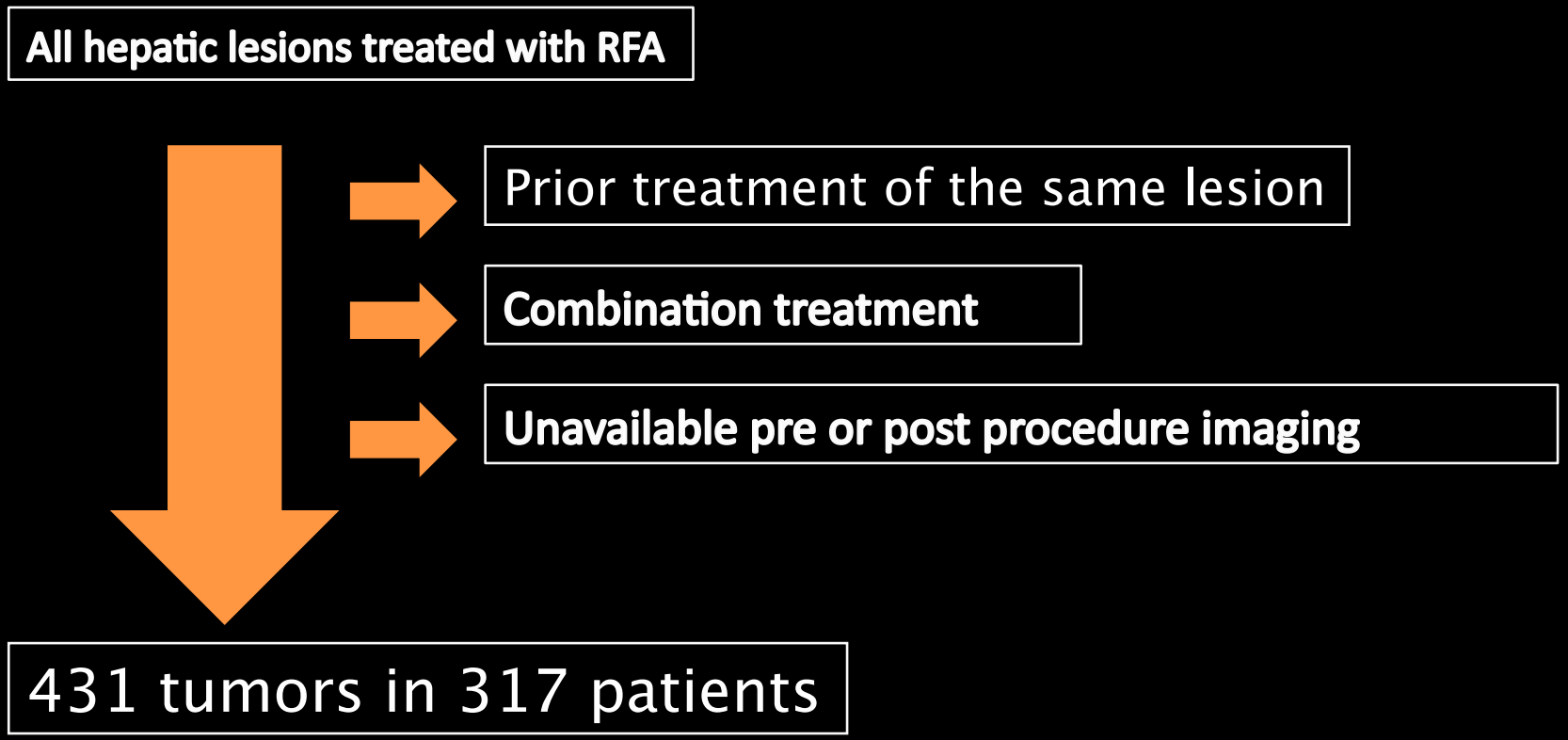
Diagn Interv Radiol. 2008 Mar;14(1):51-6.

Heat Sink Effect – *the MGH experience*

- To ascertain if there is a significant difference in treatment outcomes, residual and recurrent disease, between perivascular and nonperivascular tumors

Heat Sink Effect – *the MGH Experience*

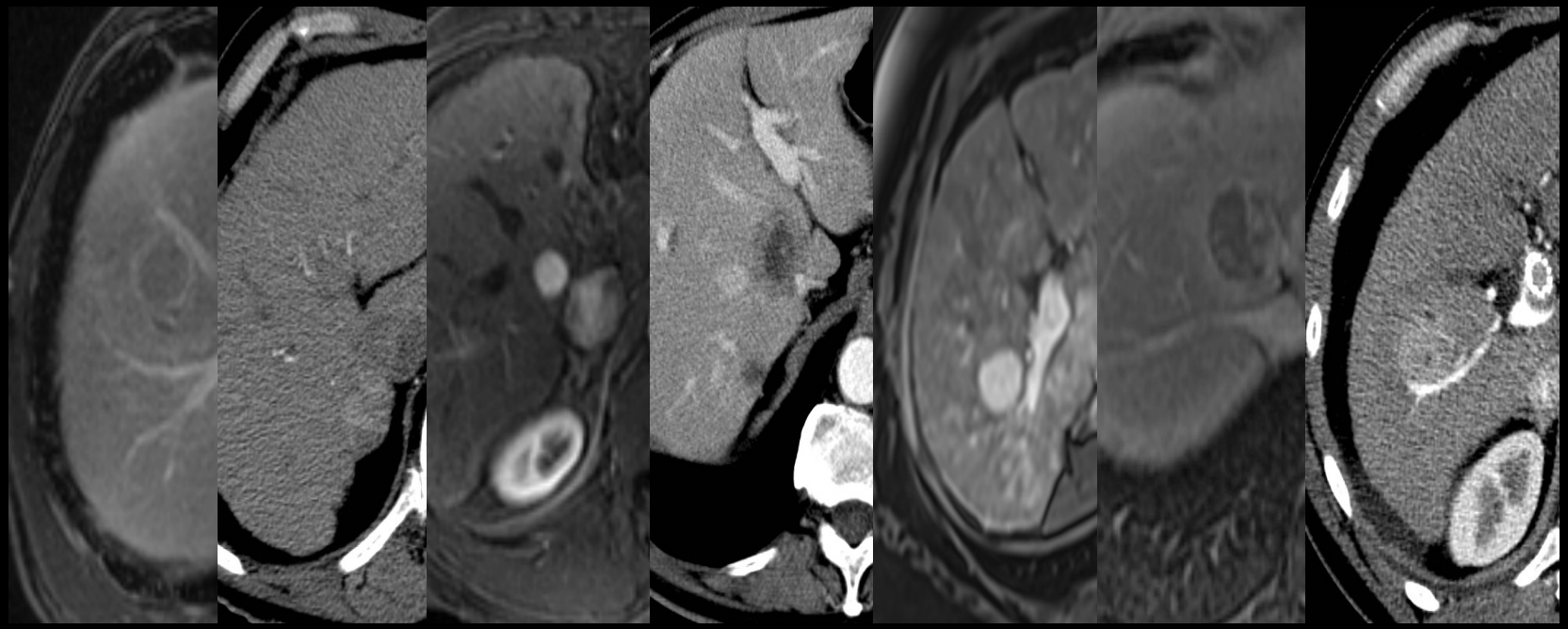
- Between January 2000 and December 2009



Classification of Hepatic Tumors

Perivascular :

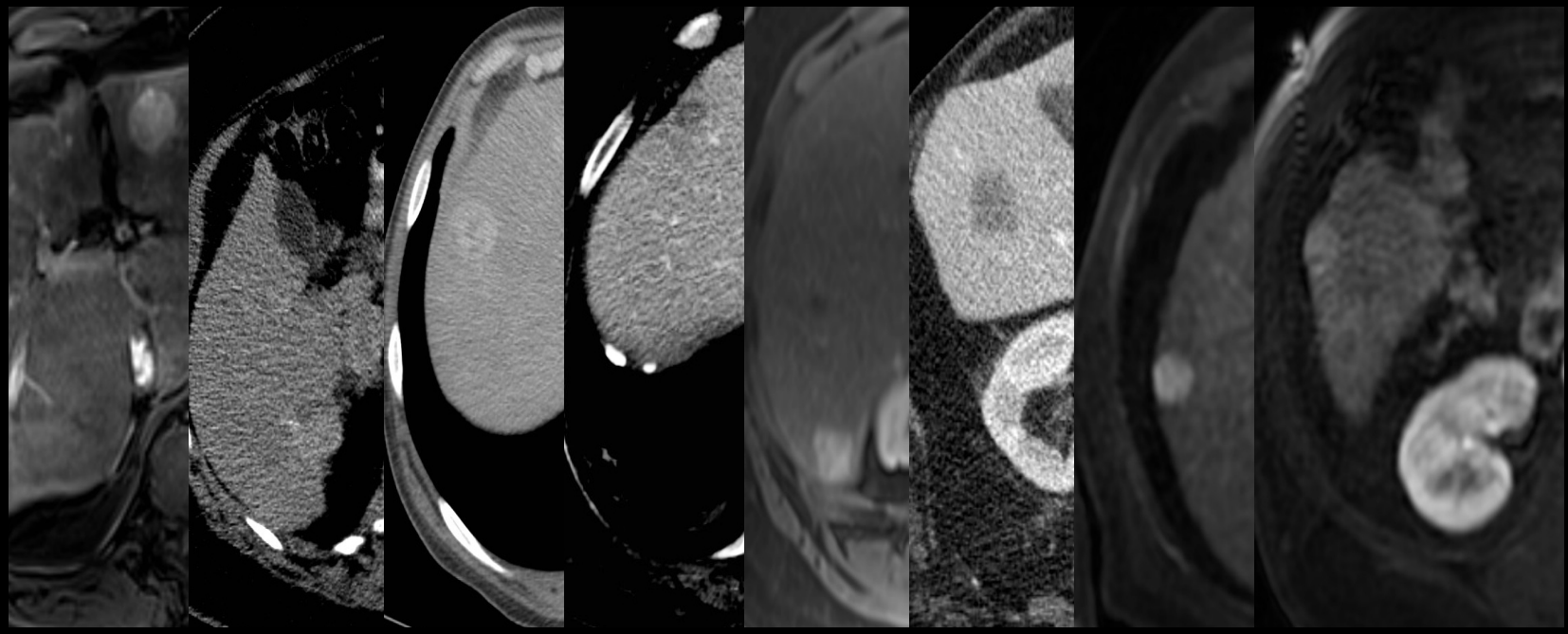
- within 3mm of any vessel greater than 3mm in diameter



Classification of Hepatic Tumors

Nonperivascular :

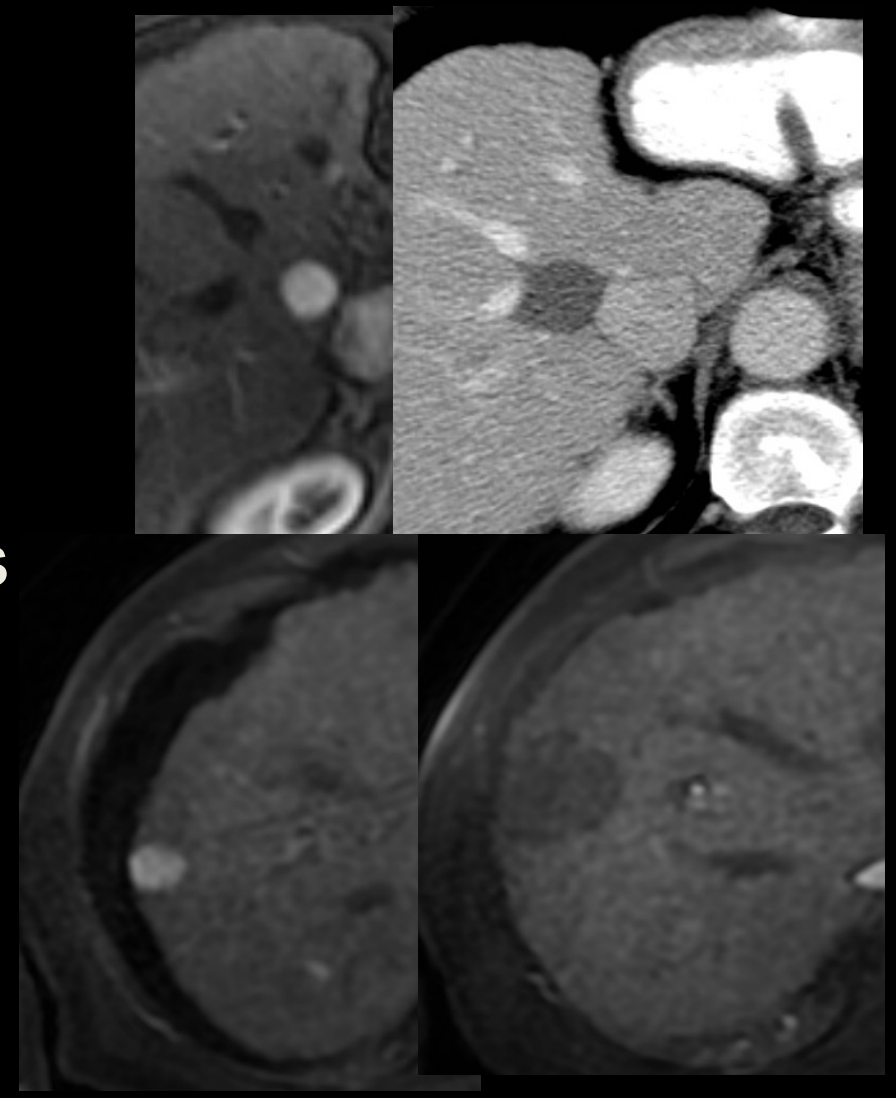
- All other lesions



Endpoints

Initial treatment success:

- Lack of imaging evidence of residual tumor at the site of ablation after either single or multiple ablation treatments within 3 months



Study population

431 tumors

- 264 HCC
- 167 metastases (colon, ovarian, breast, NET, pancreatico-biliary, leiomyosarcoma, thyroid, cholangiocarcinoma, esophageal, RCC, melanoma, lung, GIST, endometrial)

317 patients

- 213 men: 104 women
- mean age 62 (range 19 – 86 years)

	Perivascular (n = 111)	Nonperivascular (n = 320)	P value
Lesion size (cm)			
< 3	67 (60.4)	263 (82.2)	
3.1 – 5	38 (34.2)	53 (16.6)	<0.001
>5	6 (5.4)	4 (1.3)	
Mean	2.9 ± 1.5	2.2 ± 1.1	
Histology			
HCC	63 (56.8)	201 (62.8)	
Metastases	48 (43.2)	119 (37.2)	>0.25
Sex			
Male	74 (66.7)	227 (70.9)	
Female	37 (33.3)	93 (29.1)	>0.3
Age (years)	61.5 ± 11.5	61.7 ± 11.4	

Residual disease:

Overall: 101 of 431 tumors (23%)

Perivascular: 32 of 111 tumors (28%)

Nonperivascular: 69 of 320 tumors (21%)

$P > 0.1$

Local recurrence:

Overall: 75 of 364 tumors (20%)

Perivascular: 22 of 87 tumors (25%)

Nonperivascular: 53 of 277 tumors (19%)

$P > 0.2$

Conclusions

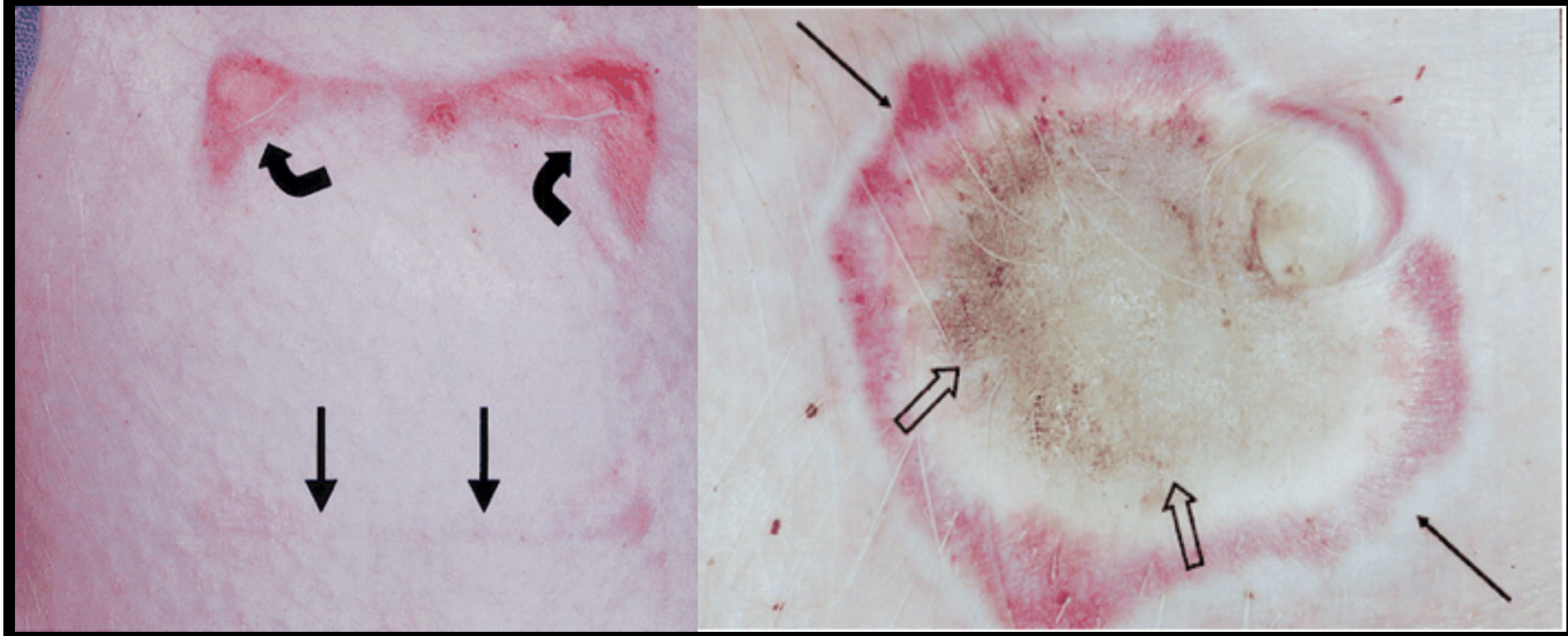
There is no significant difference in the rate of residual tumor and local recurrence between perivascular and nonperivascular tumors.

Therefore, proximity of a tumor to large hepatic vessels is not a contraindication to performing radiofrequency ablation

Heat Sink-Bottom Line

- I’ve never turned away a case due to proximity of tumor to vessels
- Need to aggressive treat these lesions
  - Electrode applicator up to vessel
  - Overlapping ablations

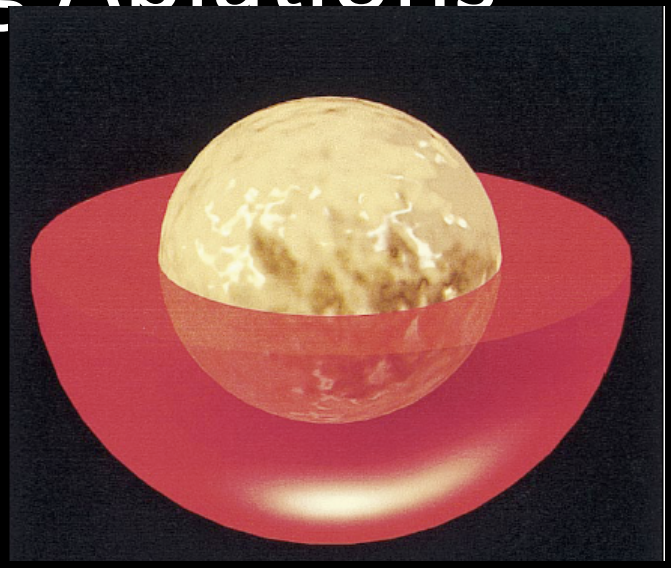
- Grounding pads-risks of thermal injury to skin



RadioGraphics 2004; 24:41–52

RFA-Overlapping Ablations

- Treatment
  - Complete tumor necrosis
  - "Surgical" margin of at least 10 mm
  - Multiple overlaps for larger tumors
  - Time consuming



- *Dodd et al. AJR 2001*

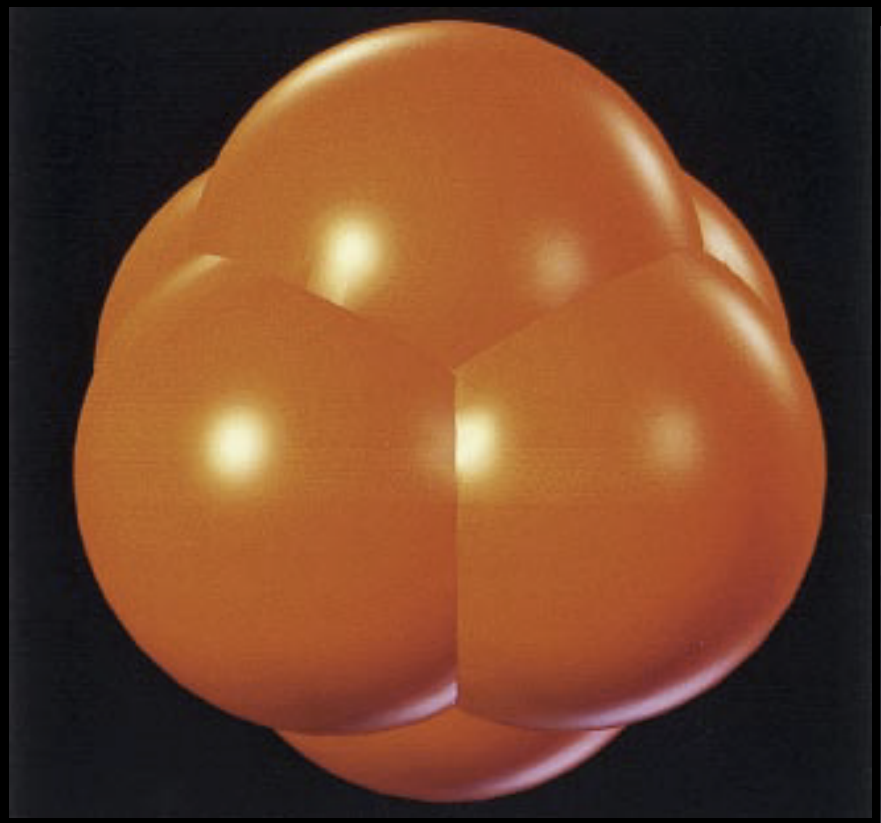
Single Ablation Model

5 cm spherical ablation
3 cm tumor

4 cm spherical ablation
2 cm tumor

3 cm spherical ablation
1 cm tumor

Six Ablation Model



5 cm spherical ablation
4.25 cm tumor

4 cm spherical ablation
3 cm tumor

3 cm spherical ablation
1.75 cm tumor

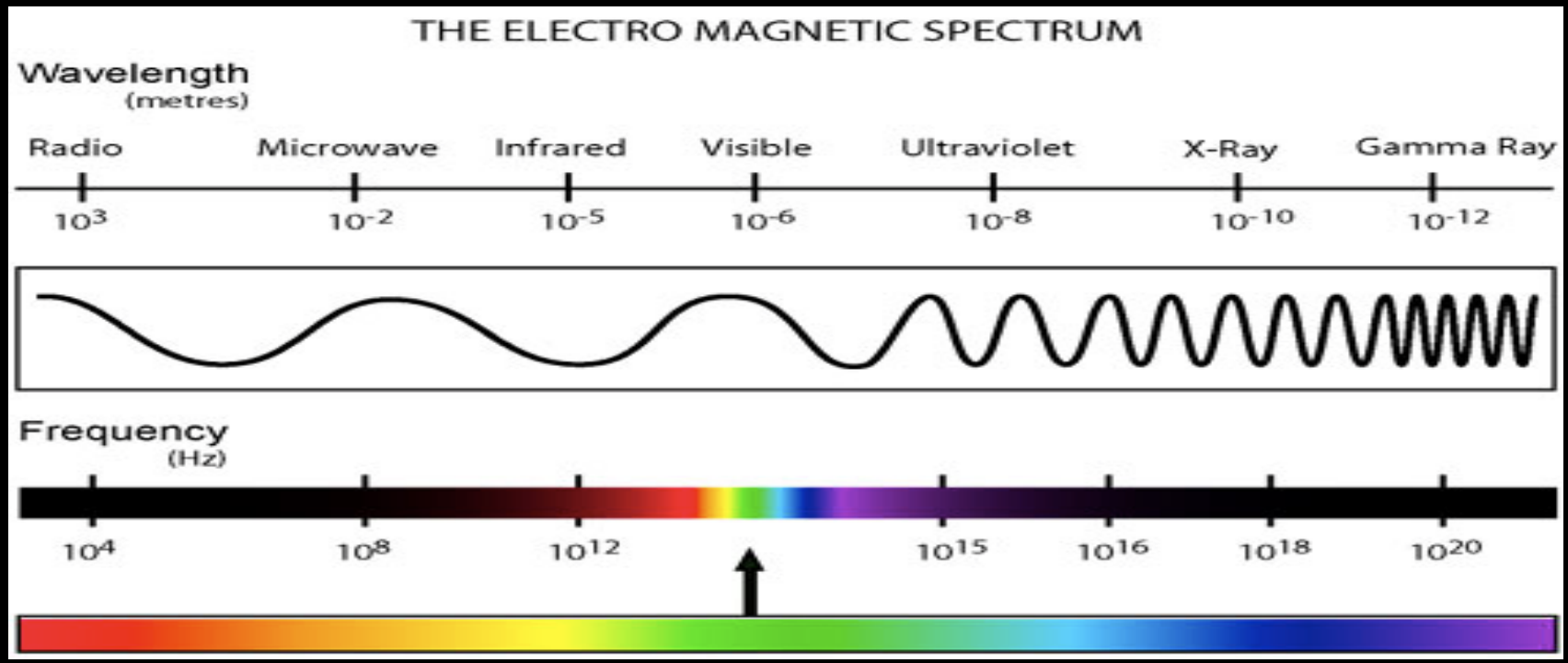
Overlapping Ablations

- Because of the need to perform overlapping ablations for most lesions, RFA can be
  - Time consuming
  - Labor Intensive

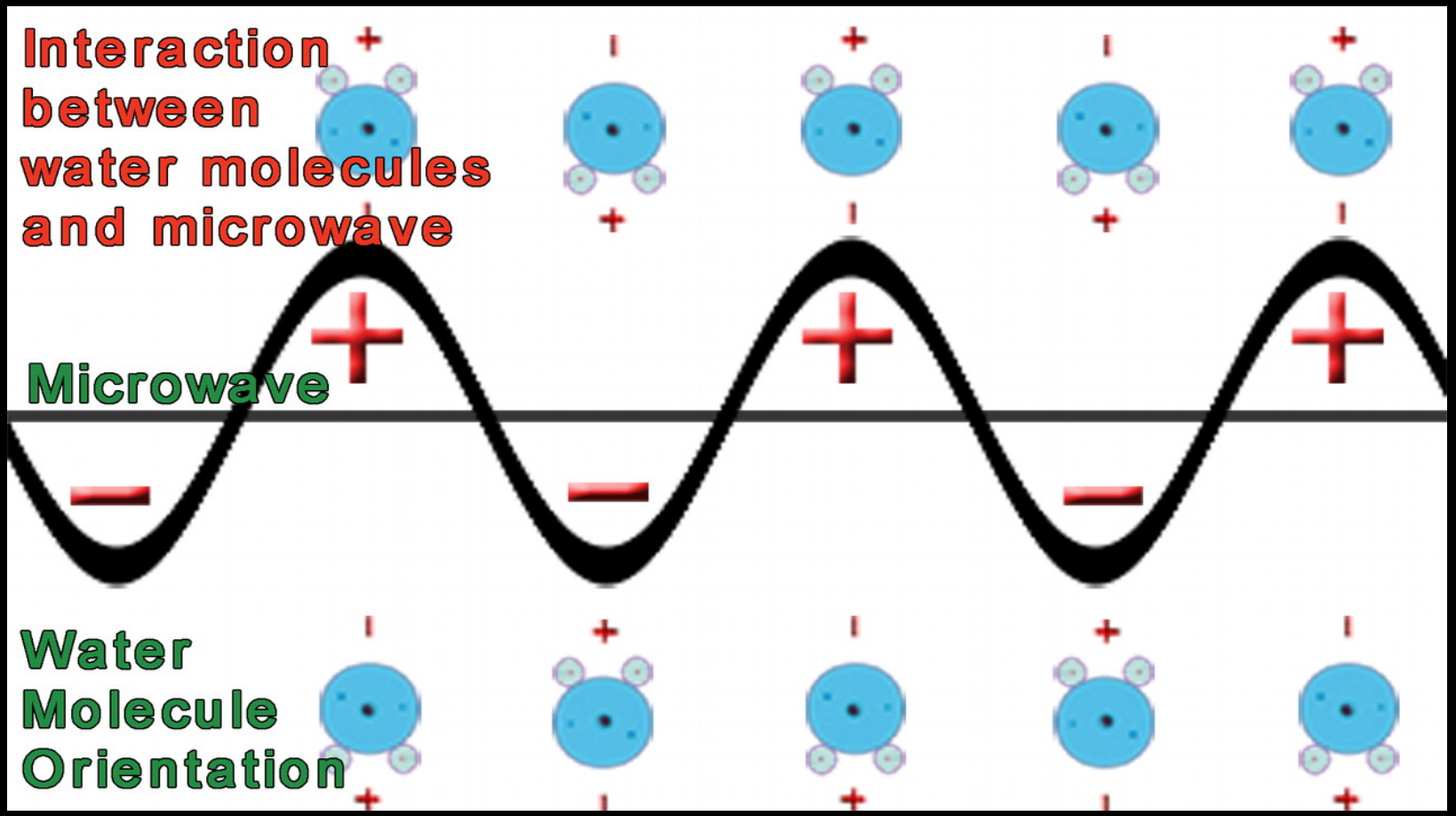
Microwave Ablation

Physics of Microwave

- Microwave refers to the region of the EMS between 900 and 2450 MHz



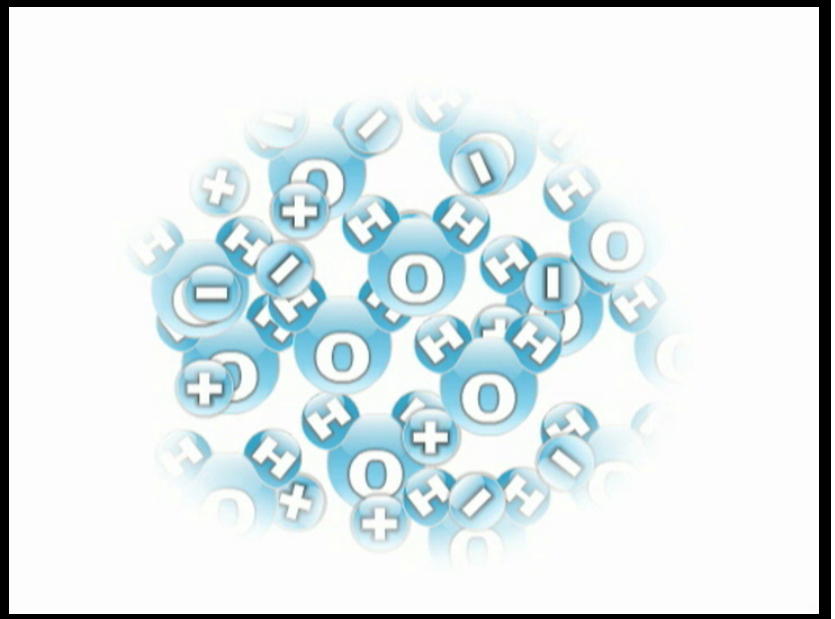
Microwave Ablation



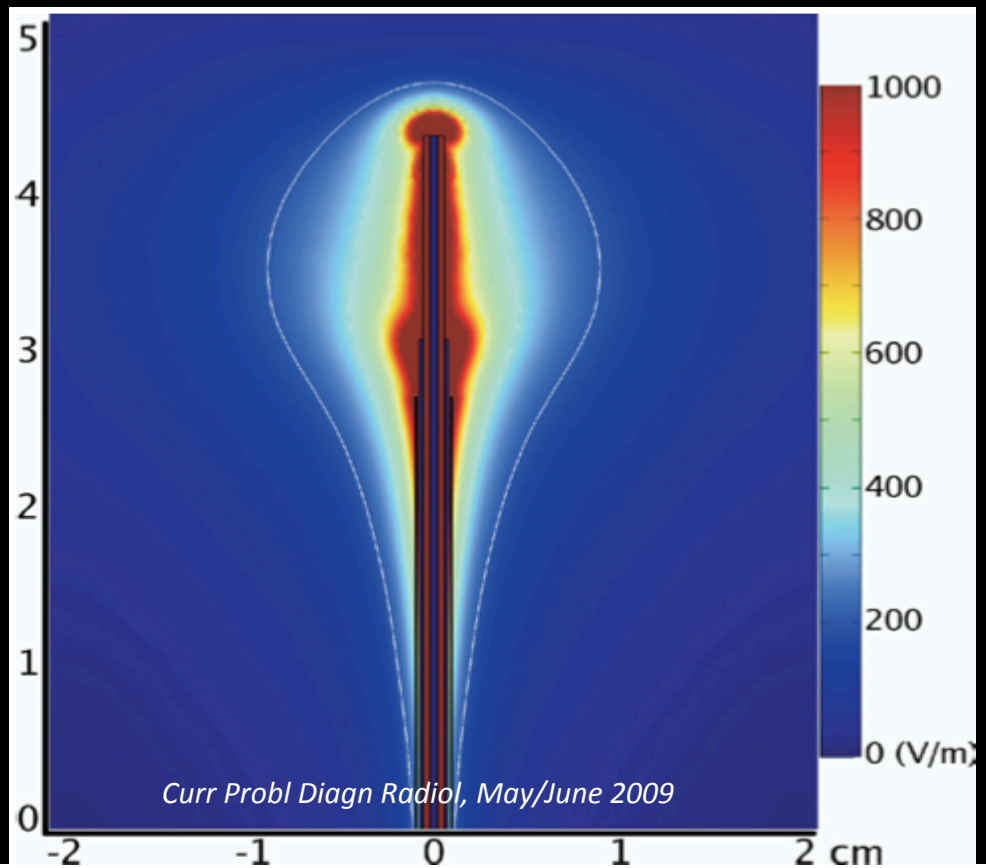
RadioGraphics October 2005 RadioGraphics, 25, S69-S83

Microwave Ablation
How it Works

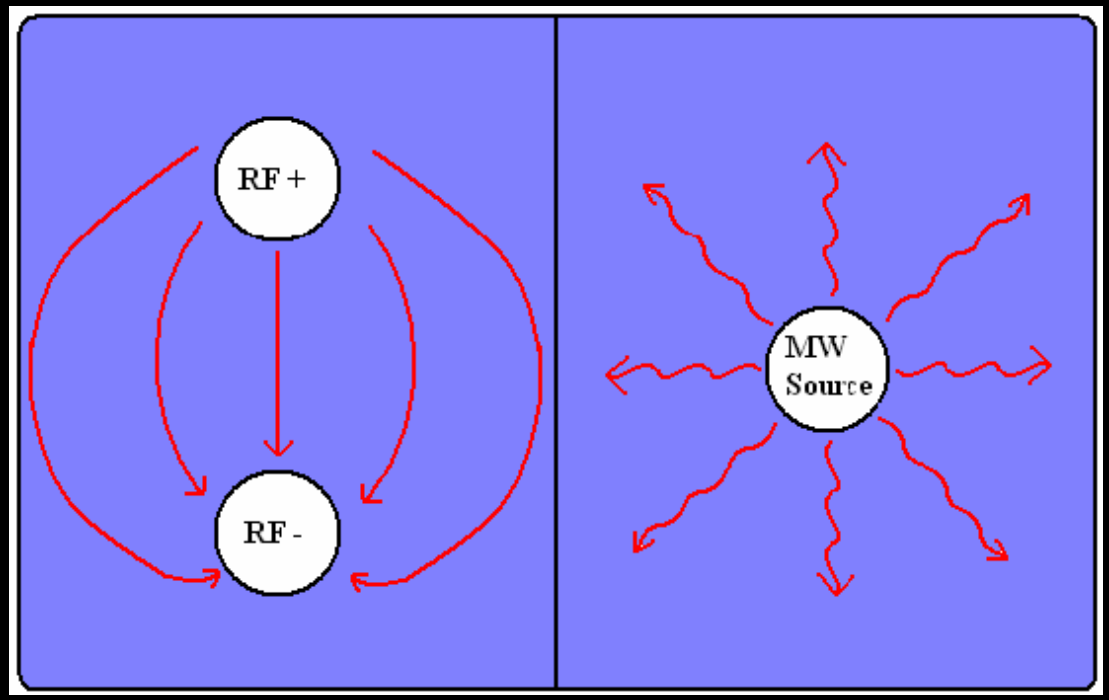
- Microwave oscillation results in oscillation of water up to a *billion* times per second!



Ion translation results in frictional heating.



Microwave Ablation
How it Works

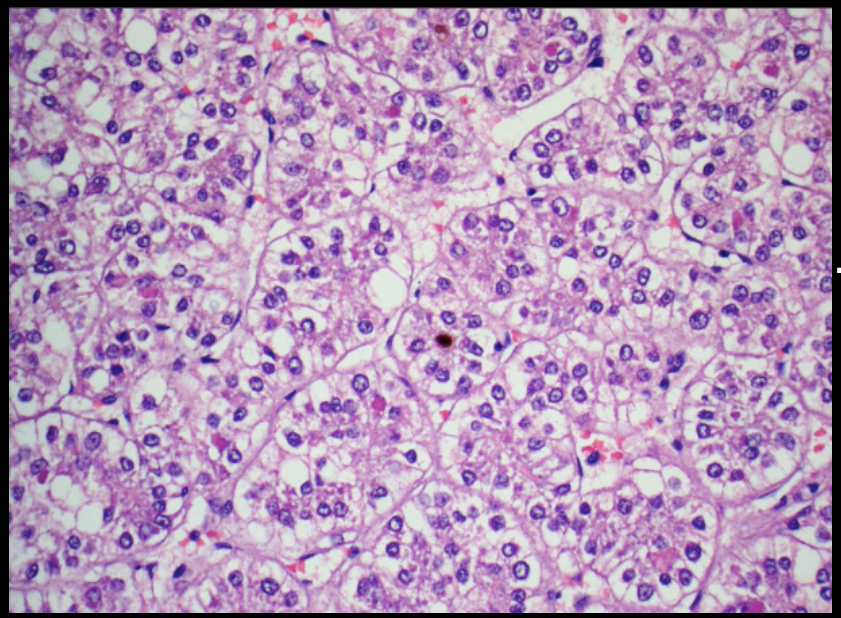


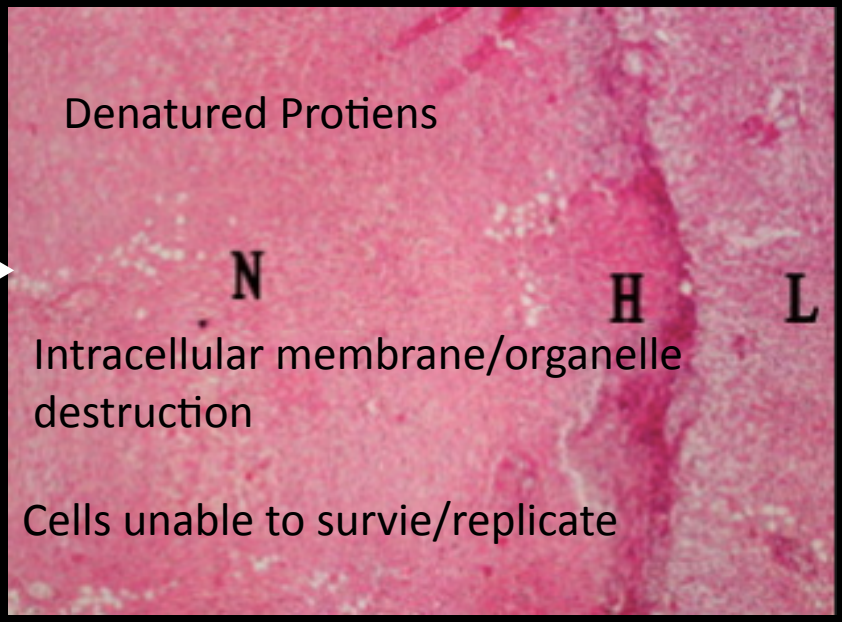
Current flow travels through the path of least impedance between two electrodes. This is governed by: **electrical conductivity (σ)**.

Electromagnetic waves travel like a ripple through a pond of water. This is governed by: **dielectric permittivity (ε).**

Physics of Microwave

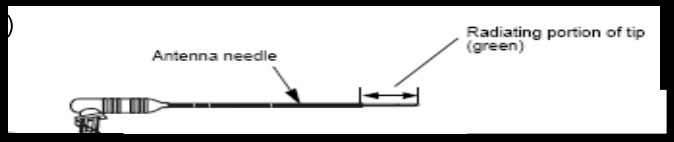
- This produces friction and heat thereby causing cell death by coagulation necrosis, no different than RFA





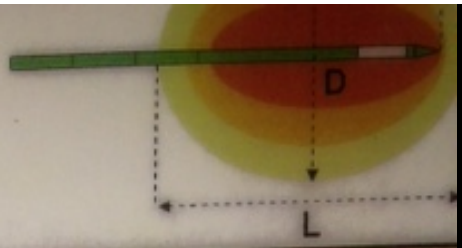

Procedure
Report
Tools
Probe 1 (connected)
Probe 2 (connected)
Probe 3 (disconnected)
Time
4:35
Target Time 5:00
Power
100
Watts
5:00
Test
Stick
Ablate
Cauterize
Ablate 1 + 2
Probe Temp
200 °C
160 °C
Coolant
Sound


AMICA


Antenna needle
Radiating portion of tip (green)

Microwave Ablation

- Potential Advantages over RFA
  - Generate larger zones of ablation in shorter times
  - Generate higher temperatures
  - Not affected by high impedance tissues
    - Lung
    - Bone



AMICA-PROBE 11G COAGULATIVE PERFORMANCE ON EX-VIVO BOVINE LIVER

Lesion Dimensions (LxD, in mm)*		Ablation Power**				
		20W	40W	60W	80W	100W****
Ablation Time***	3 min	22x18	28x24	35x28	42x30	49x34
	5min	26x23	32x27	40x35	52x39	54x39
	10min	30x26	4[illegible]	50x39	67x48	66x47
	15min	34x33	57x47	66x52	72x51	70x56

AMICA-PROBE 14G COAGULATIVE PERFORMANCE ON EX-VIVO BOVINE LIVER

Lesion Dimensions (LxD, in mm)*		Ablation Power**				
		20W	40W	60W	80W	100W****
Ablation Time***	3 min	24x16	29x20	37x25	46x32	52x36
	5min	27x20	36x28	48x34	51x37	57x38
	10min	31x27	49x36	54x40	66x46	71x48
	15min	38x33	50x42	61x48	73x55	80x57

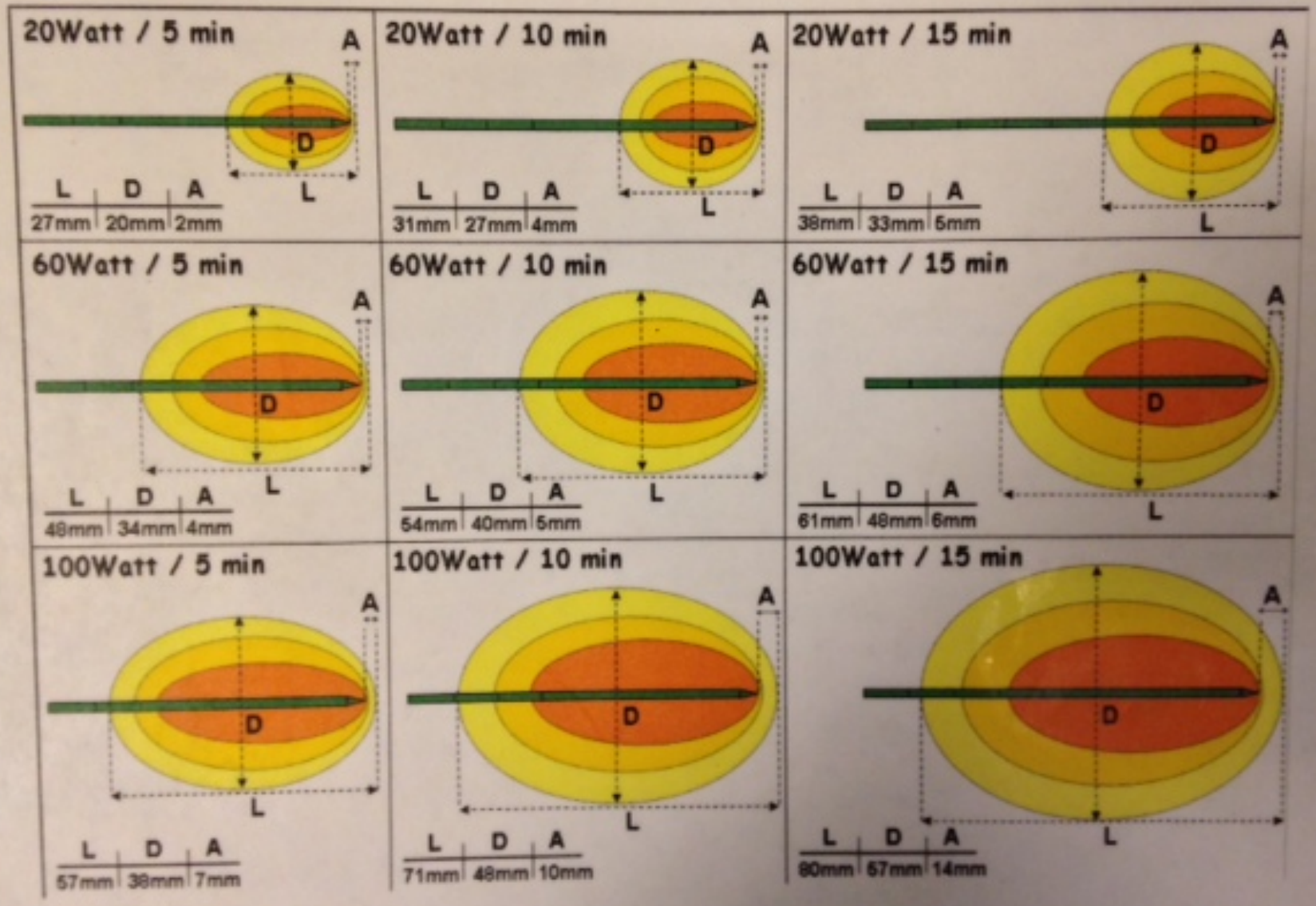
AMICA-PROBE 16G COAGULATIVE PERFORMANCE ON EX-VIVO BOVINE LIVER

Lesion Dimensions (LxD, in mm)*		Ablation Power**				
		20W	40W	60W	80W	100W****
Ablation Time***	3 min	25x15	34x22	40x25	47x28	51x27
	5min	28x19	39x26	50x31	55x34	56x36
	10min	33x25	45x33	55x39	62x40	70x44
	15min	35x30	52x38	59x41	69x48	77x55

* Lesion sizes averaged on at least 3 experimental repetitions of ex vivo ablations on adult bovine liver, initially at room temperature (~20°C); all lesions were obtained using a single probe in a single insertion. In vivo lesion sizes may differ (estimated -10% on diameter and -20% on length) mainly due to blood perfusion effects.

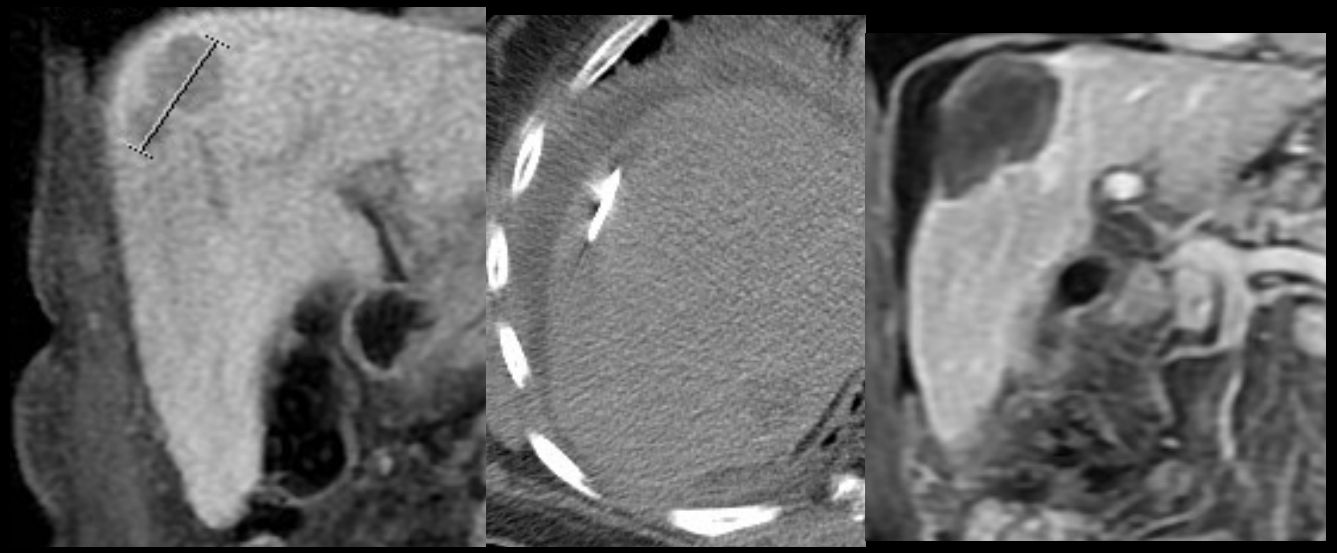
** [illegible]

Necrosis Table



Advantages of Microwave over RFA

- SPEED–
  - Larger ablation zones can therefore be achieved in much less time with higher intratumoral temperatures than RF



MWA-Potential Disadvantages

- NO grounding Pads. Eliminates potential for Grounding pad burns

- However, "backburn" can occur along antennae cables, potential for skin/abd wall burn
- Therefore all systems require some kind of cooling mechanism

  Normal Saline

  CO_2

MWA-Potential Disadvantages

- Potential “disadvantages”
  - Antennae can be “slippery”
    - Teflon coated
    - Imperative to closely monitor position throughout case

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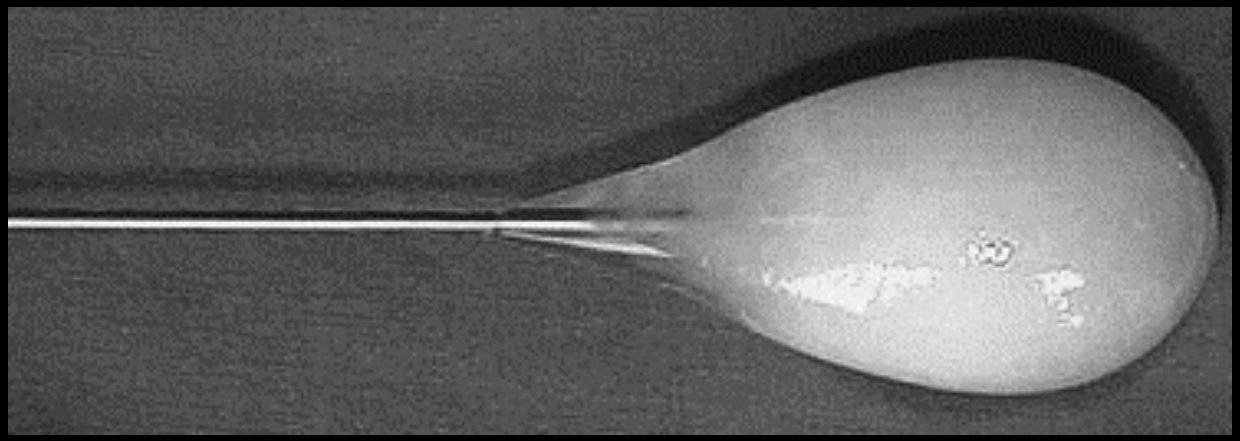
Cryoablation-How it Works

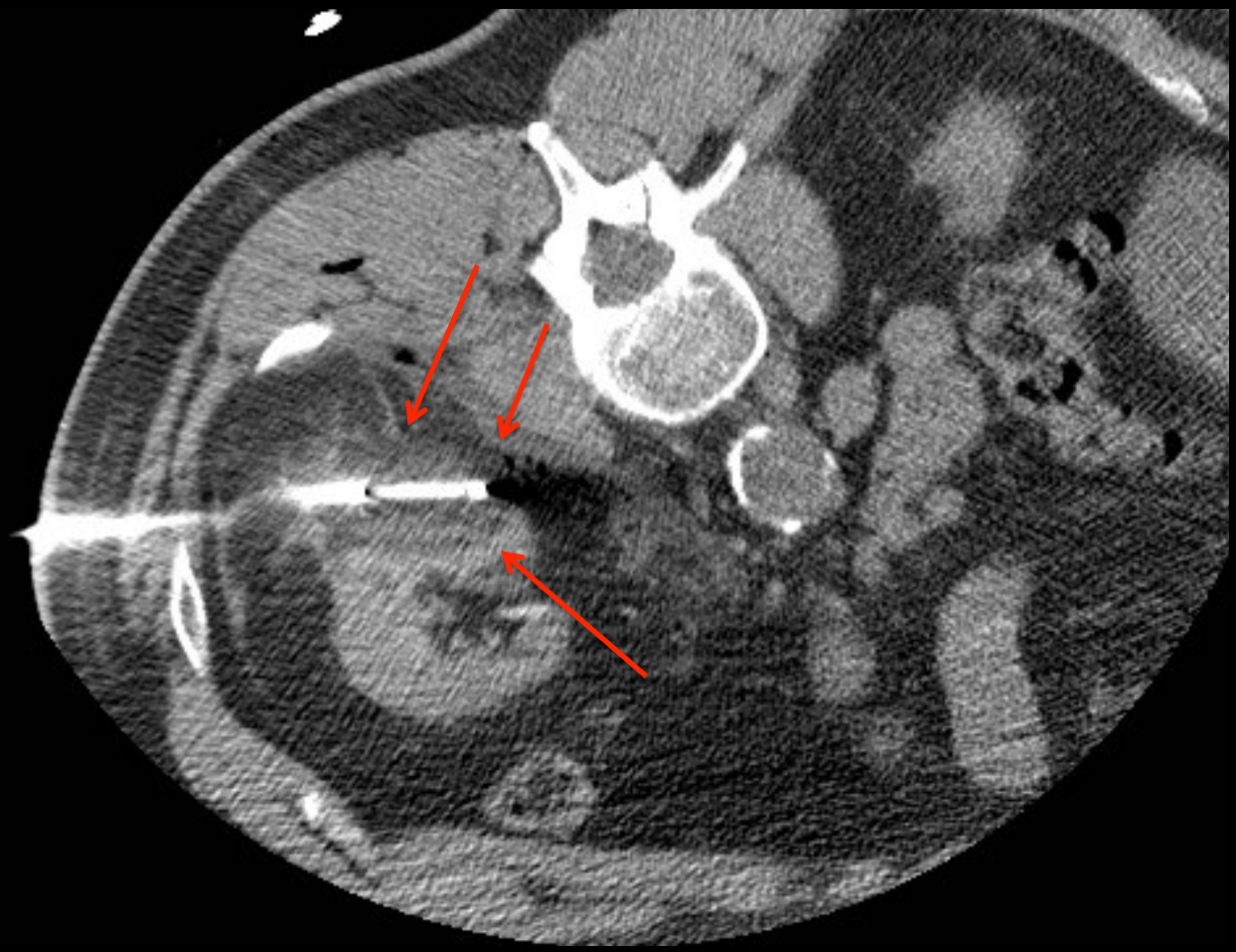
- Perfusion of compressed argon gases through needle results in ice ball formation at the needle tip
- Repetitive freeze-thaw cycles
  - Membrane rupture
  - Cellular hypoxia
  - Osmotic dehydration
  - Cellular destruction/lysis



Cryoablation

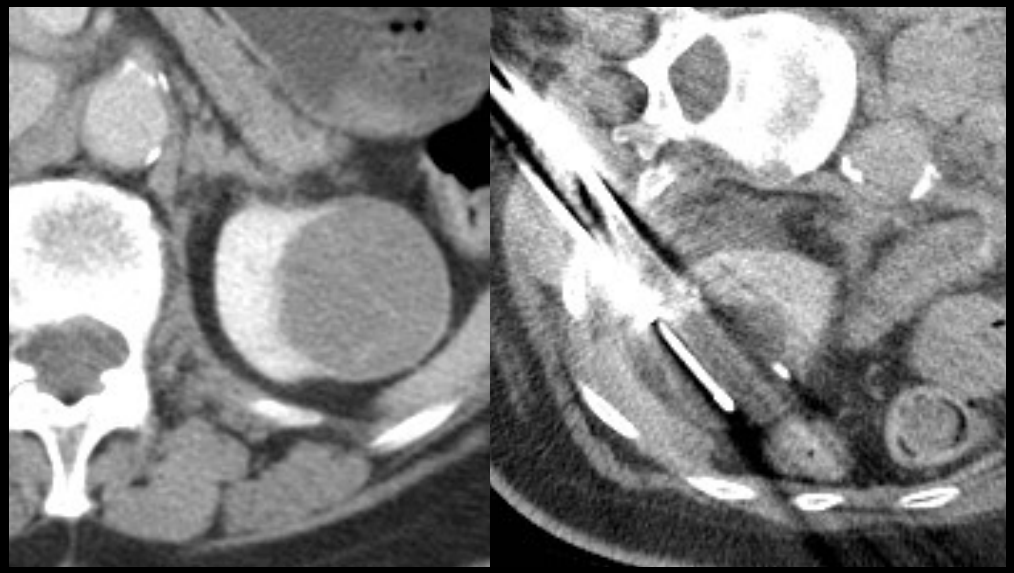
- Potential Advantages
  - May be less painful than RFA or MWA
  - Multiple probes for large zone of ablation
  - Can visualize ice ball
    - Adjust probe or treatment time if ice ball approaches critical structure
    - Place additional probes if ice size is too small

CRA-Ice Ball Formation

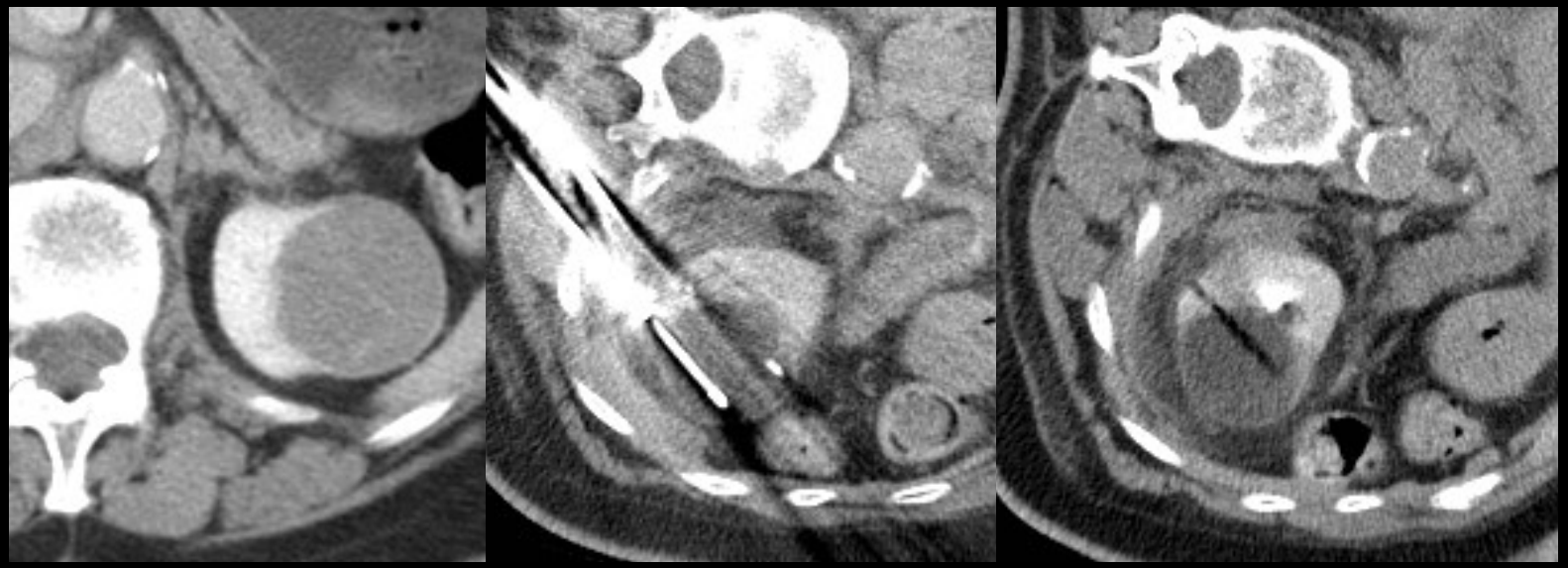


Ice Ball

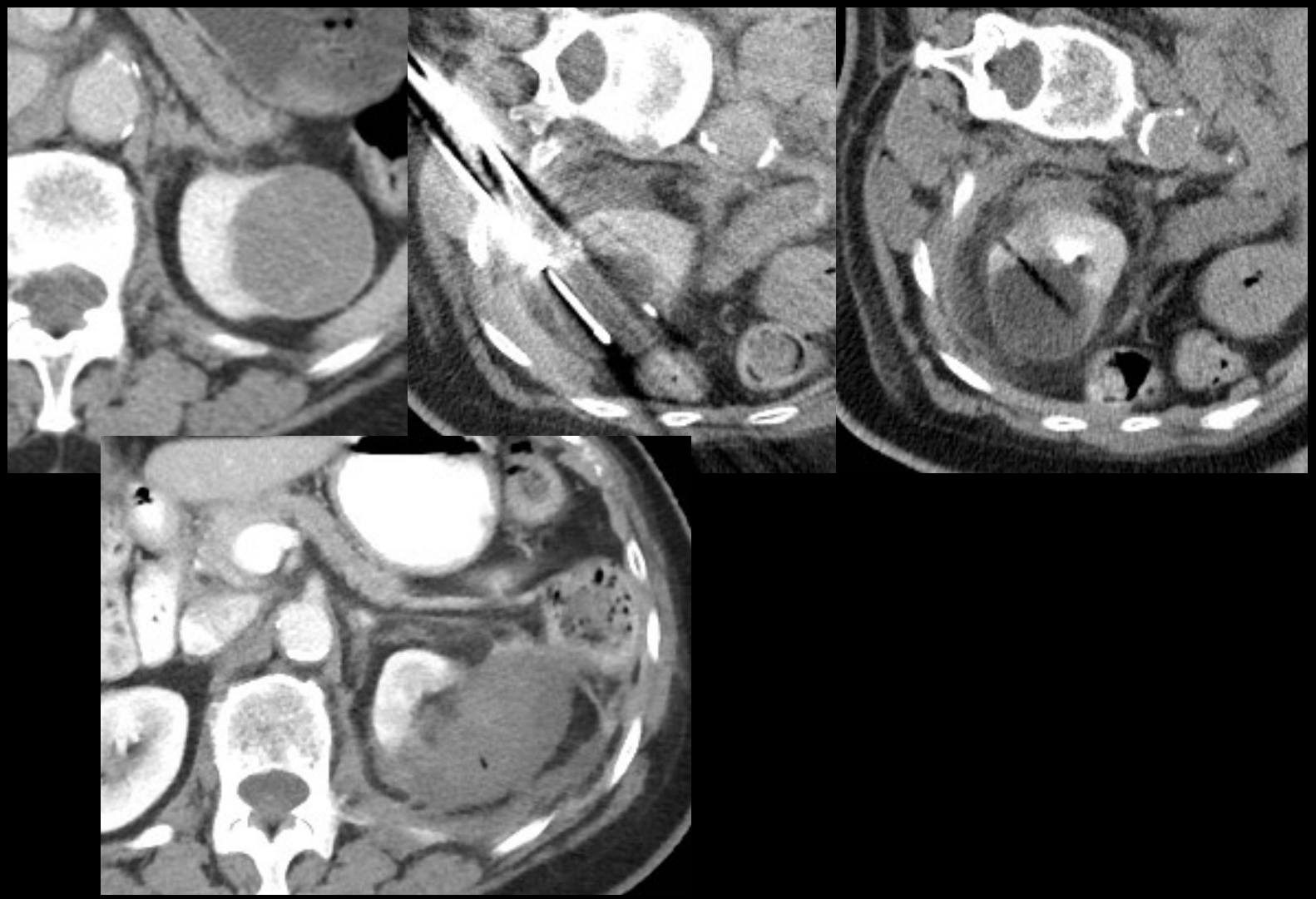
Ice Ball



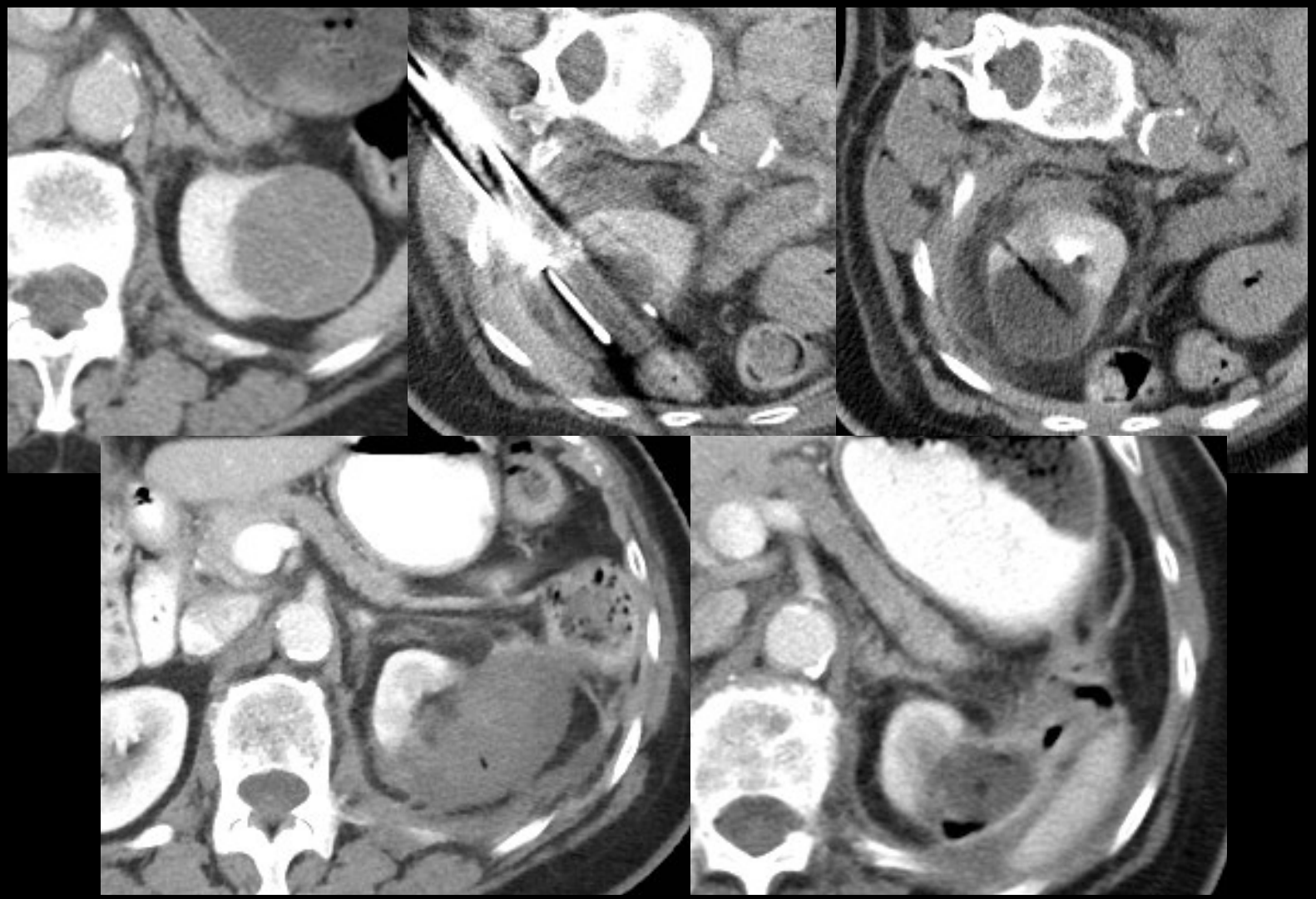
Ice Ball



Ice Ball



Ice Ball



A Comparison of Percutaneous Cryosurgery and Percutaneous Radiofrequency for Unresectable Hepatic Malignancies

Arch Surg. 2002;137(12):1332-1339

Table 1. Treatment Outcome: Tumors*

Variable	PCS	PRF	*P* Value
Initial success of treatment			
After 1 treatment	25/36 (69)	31/41 (76)	.54
HCC group	13/20 (65)	16/21 (76)	.43
METS group	12/16 (75)	15/20 (75)	.99
After ≥1 treatment	30/36 (83)	34/41 (83)	.36
HCC group	16/20 (80)	18/21 (86)	.70
METS group	14/16 (88)	16/20 (80)	.67
Local recurrence†	16/30 (53)	6/34 (18)	.003
HCC group	6/16 (38)	3/18 (17)	.25
METS group	10/14 (71)	3/16 (19)	.004

*Data are given as number/total for that group (percentage). PCS indicates percutaneous cryosurgery; PRF, percutaneous radio frequency; HCC, hepatocellular carcinoma; and METS, liver metastases.

†Determined in those with initial success of treatment following 1 or more treatments.

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Table 3. Univariate Analysis of Risk Factors: Local Recurrence

Variable*	% Local Recurrence†	*P* Value
Type of treatment		
PCS	55.2	.002‡
PRF	17.7	
Type of tumor		
HCC	27.3	.18‡
METS	43.3	
Treatment of all hepatic tumors		
Complete	34.6	.91‡
Incomplete	36.4	
Presence of extrahepatic metastases		
No	34.8	.97‡
Yes	35.3	
No. of treated tumors		
1	30.6	.40‡
>1	40.7	
No. of treatments		
1	28.9	.04§
2	42.9	
3	66.7	
4	100.0	

*PCS indicates percutaneous cryosurgery; PRF, percutaneous radio frequency; HCC, hepatocellular carcinoma; and METS, liver metastases.
†n = 63 tumors.
‡χ^2 Test.
§Mantel-Haenszel χ^2 test.

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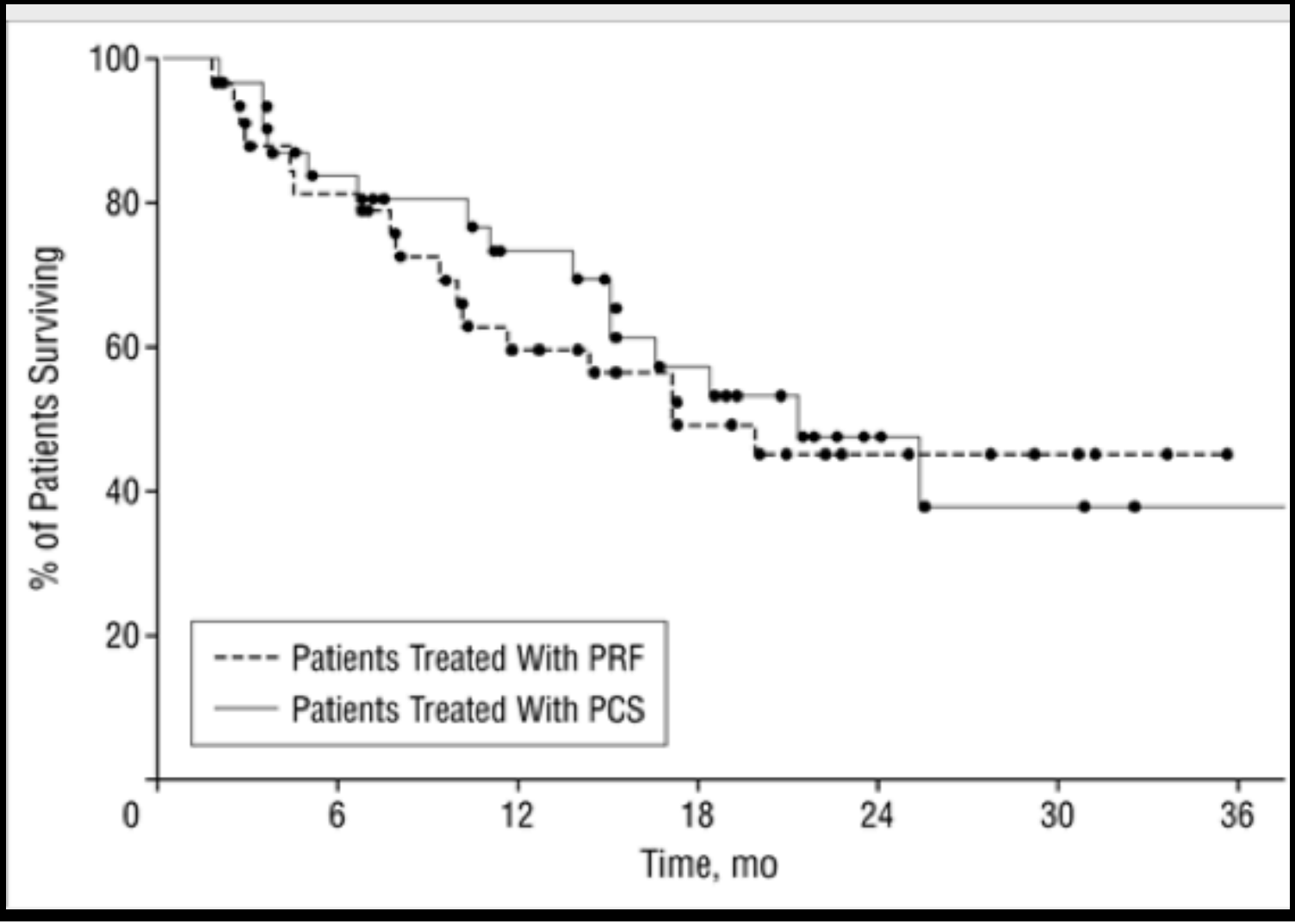

Liver Cryoablation

- Cryoshock-Rare (1%)
  - Multi-organ failure
  - Thrombocytopenia
  - Acute Respiratory Distress (ARDS)
  - Systemic Inflammatory Response Syndrome (SIRS)
  - Bleeding
  - Myoglobinuria
  - Pleural effusions

Liver cyroablation Thrombocytopenia

- 372 patients/525 cyrosessions
  - Coagulopathy in 37% from thrombocytopenia
  - No correlation with tumor size or number of cryosesstions
  - Significant drop in platelets when pre-treatment platelet counts were 350-650 x 10
  - 121.3±97.13 for 350– 650 x 109/L

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RFA vs. CA for Renal Masses Meta-Analysis

- MEDLINE, EMBASE and LILACS.
- Inclusion criteria:
  - case series design with more than one case reported
  - use of cryoablation or radiofrequency ablation
  - patients with renal cell carcinoma
  - outcome reported as clinical efficacy.
- •

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RFA vs Cryoablation Meta-Analysis

- Cryoablation clinical efficacy
  - 89% in 457 cases.
  - There was a statistically significant heterogeneity between these studies showing the inconsistency of clinical and methodological aspects.

Conclusions

- All devices discussed are effective in achieving tissue destruction via heating or freezing
- Most supportive clinical data is with RFA (liver/ renal) and CRA (renal)
- Each has its “pro and con” but there is no one device that is the “perfect” thermal ablative technology

End