MW ablation: From Theory to Practice

Prof. S.N. Goldberg, MD FSIR

Image-guided Therapy and Interventional Oncology Unit

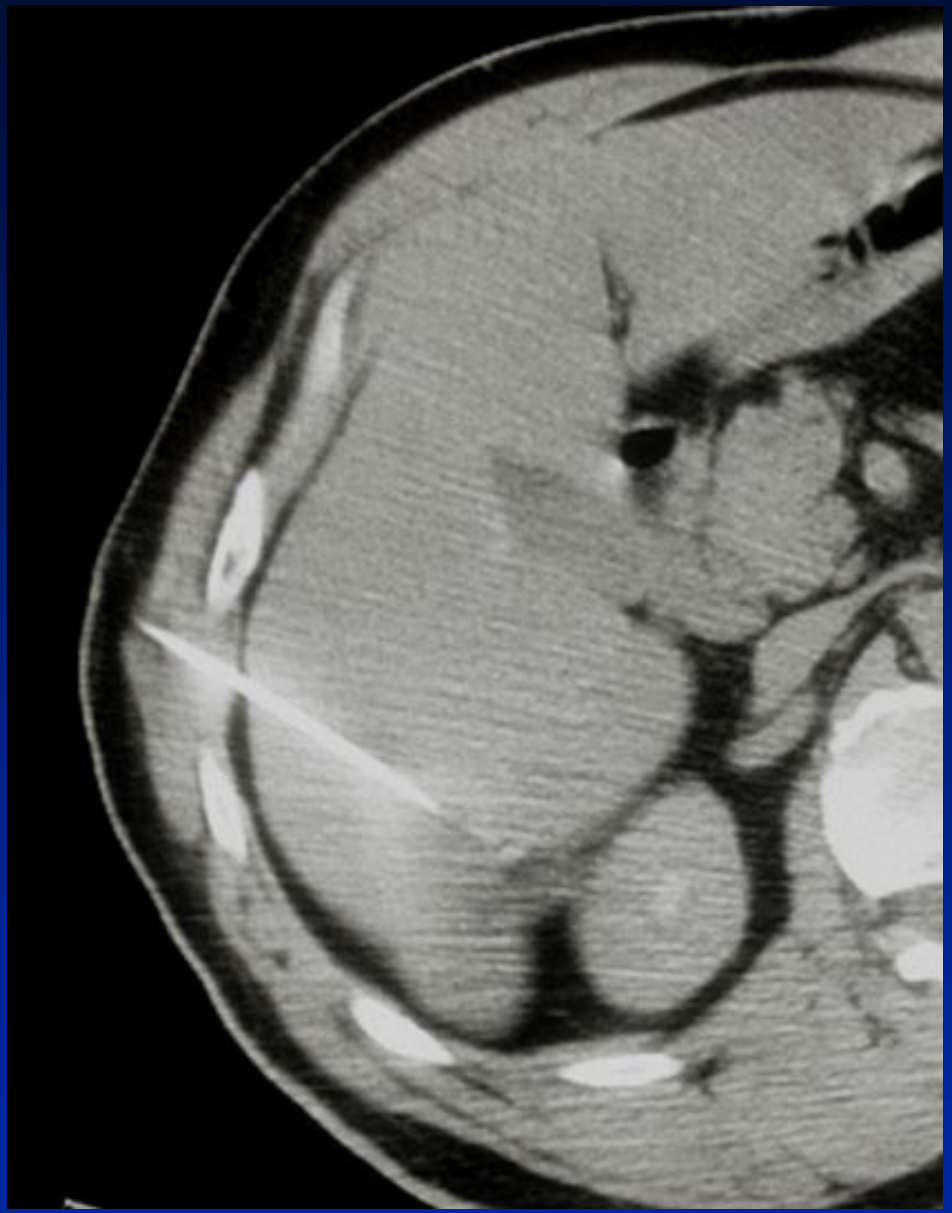
Dept. of Radiology

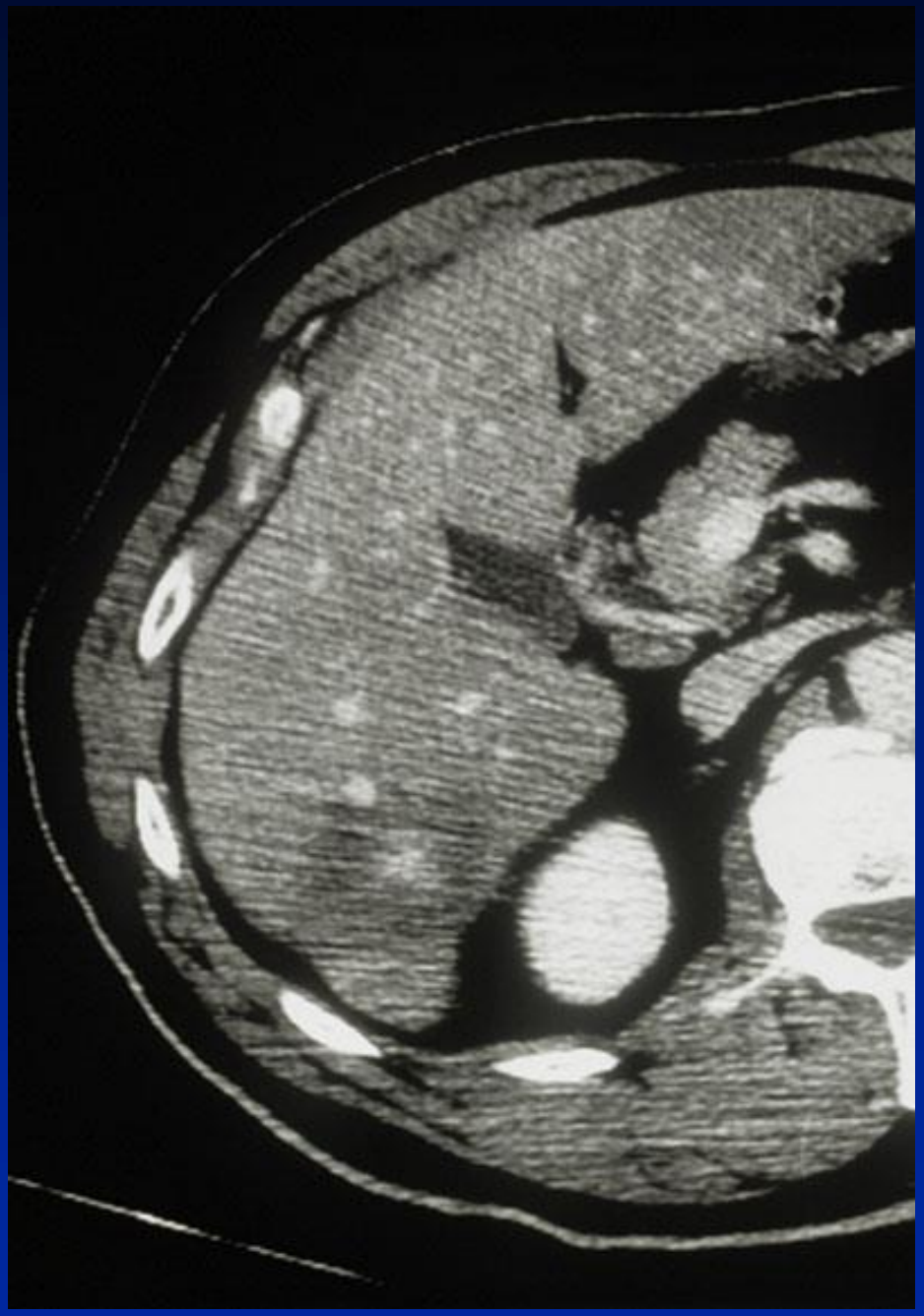
Hadassah Hebrew University Medical Center, Ein Karem

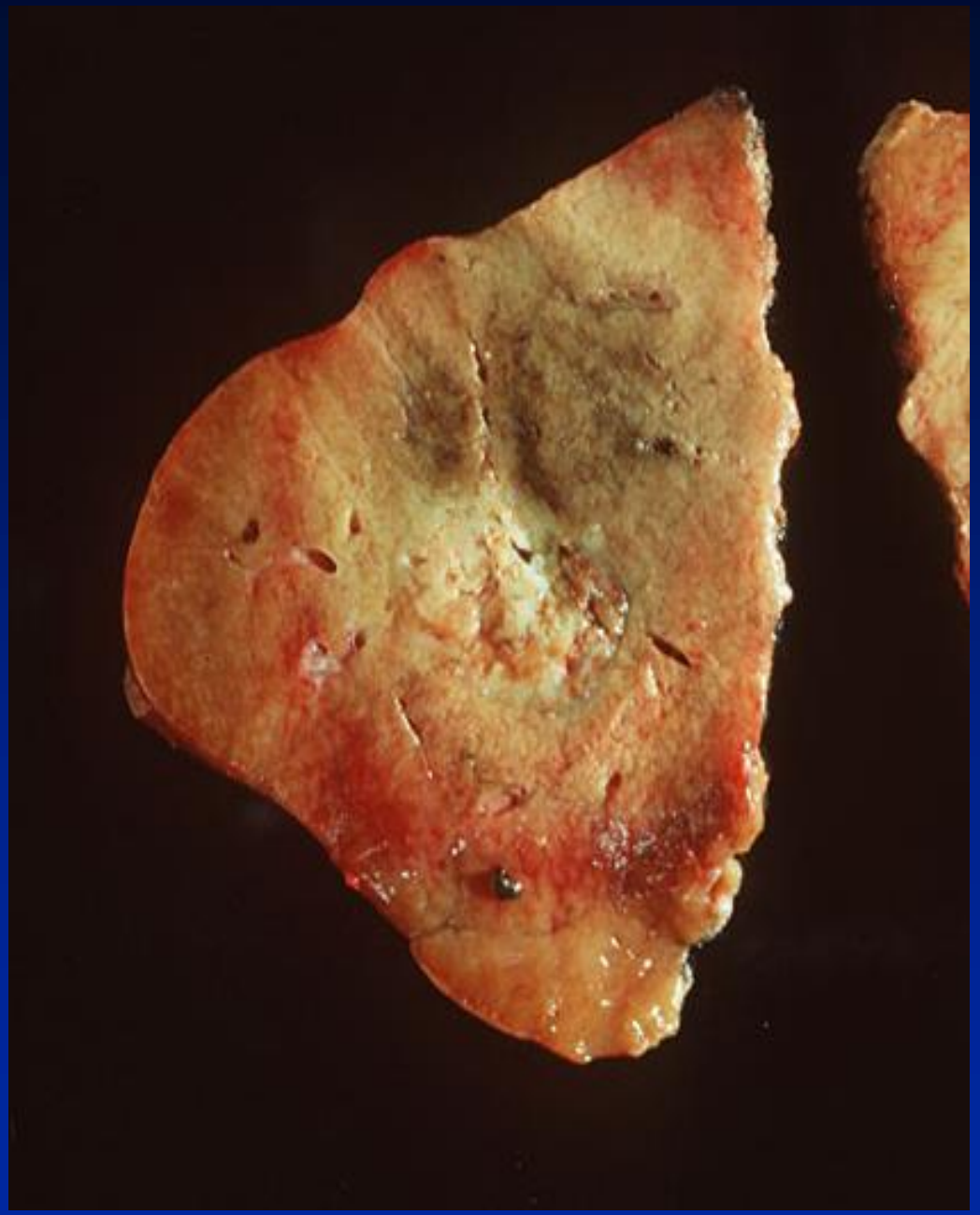
MW ablation: From Theory to Practice

Clinical rationale, technology development, performance characterization & optimization


:18 +C
OV 36.0cm
ND
120







Percutaneous Image-Guided Therapy: Potential Benefits for the Oncology Pt.

- Direct tumoricidal effect
- Minimal systemic effects
- Less invasive than surgery
- Less expensive than surgery
- Applicable to non-surgical candidates

Image-guided Tumor Ablation: Expanding Clinical Applications

Acceptance

- Liver
- Kidney
- Lung
- Bone

Early Experience

- Head / Neck
- Breast
- Pancreas
- Prostate
- Adrenal

Image-Guided Tumor Ablation: Ideal system characteristics

- Complete (large volume) ablation
- Reproducible, predictable coagulation volume
- Minimally invasive
- Minimal morbidity
- Quick and easy
- Less expensive than alternatives

Image-Guided Tumor Ablation: State of the Art

- **Currently, no widely-available method that satisfies all the requirements of an ideal ablation system**
- **Among thermal methods, there are limited data to suggest that one agent is more effective than another**
- **Often based upon operator preferences or technique**
- **Trade-offs must be made**
  - » Completeness vs. time, aggressiveness, complexity, etc.

MW Ablation: Potential Advantages

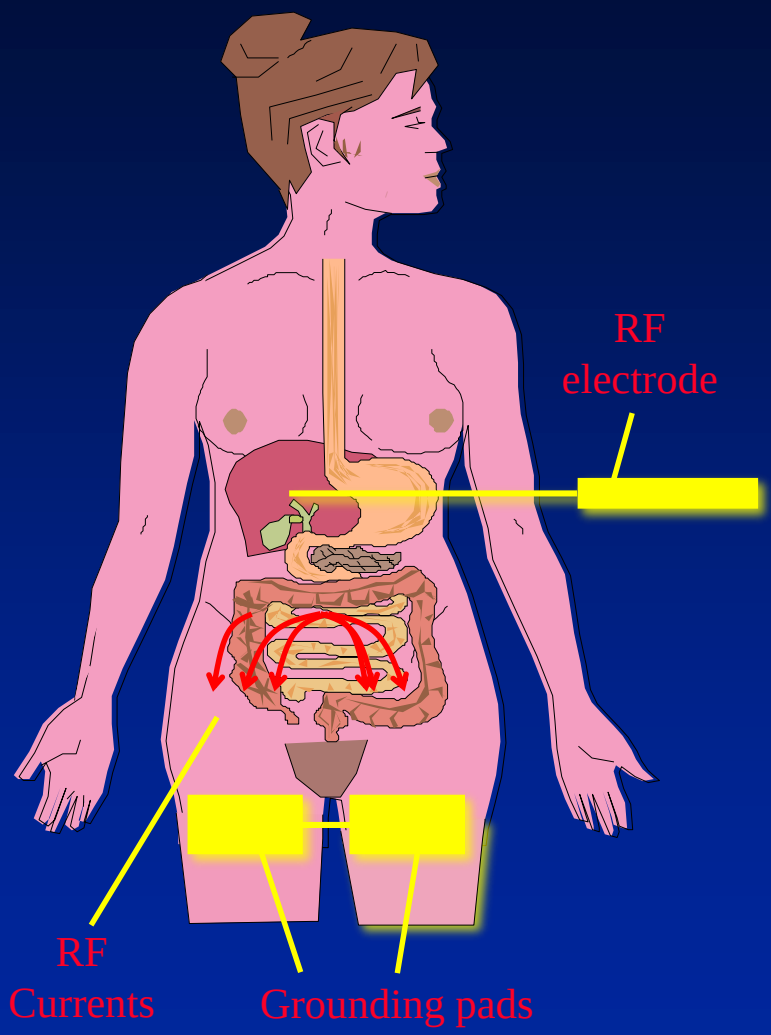
- **Bigger** ablation = Deeper penetration of energy
- **Hotter** = applicator temps. 120 - 140° C
- **Faster** ablation time

Rome, May 28th, 2013
University of Rome "La Sapienza
Dept. Of Electronic Engineering

"MW ablation: from theory to practice. Clinical rationale, technological development, performance characterization & optimization"

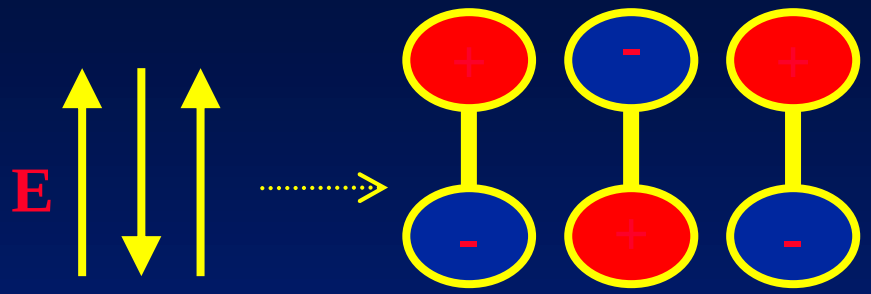
Ing. Nevio Tosoratti, PhD
R&D Manager
HS Hospital Service S.p.A.

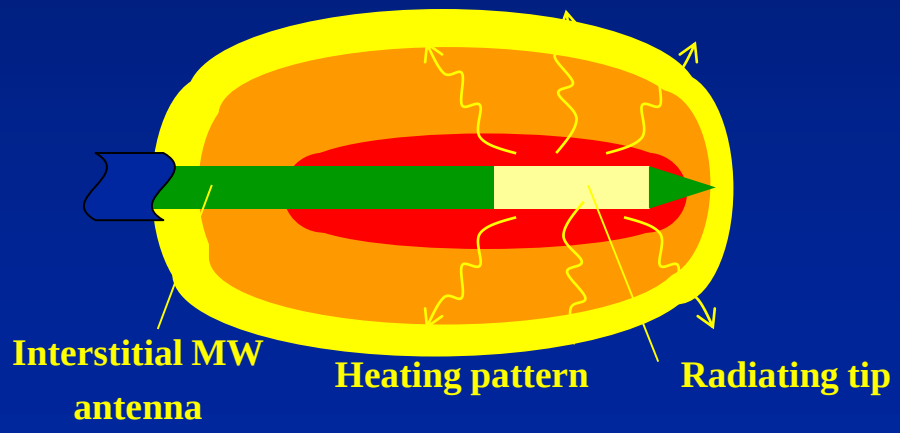
Limitations of RFA



- **Coagulation performance strongly correlated to tissue impedance**
- **Limitations on the maximum attainable temperatures (no charring should occur!) and, in turn, on the final ablation size**
- **Very limited extension of the direct heating zone (few mm around electrode exposed tip): sensitivity to heat sinking**
- **Long range distribution of delivered energy: poor treatment confinement**
  (risks in treating patients with pacemakers or metallic prosthesis, possible skin burns on return pads, possible overstimulation of nervous terminations)
- **Limitations on simultaneous use of multiple electrodes**

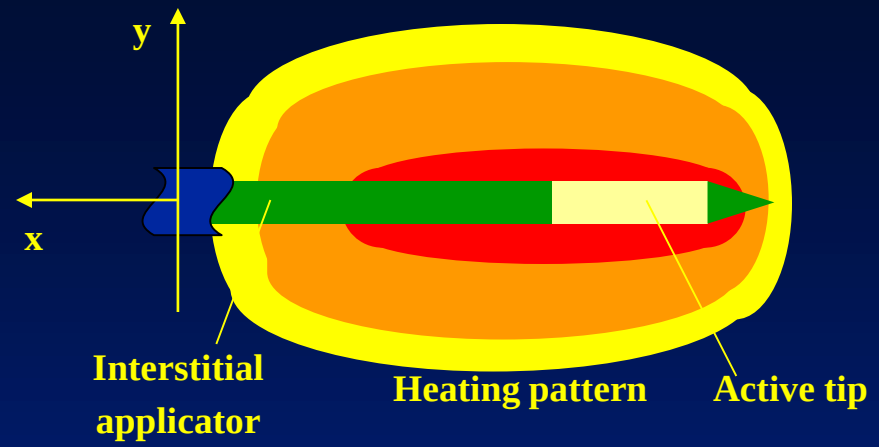
MWs: beyond limitations

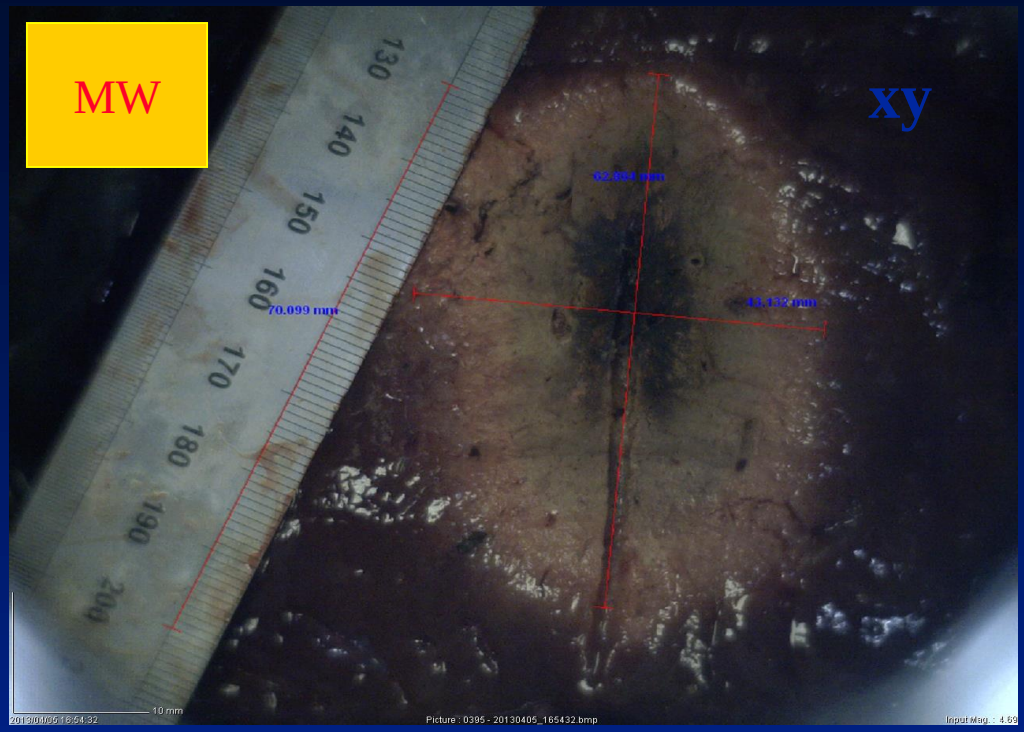


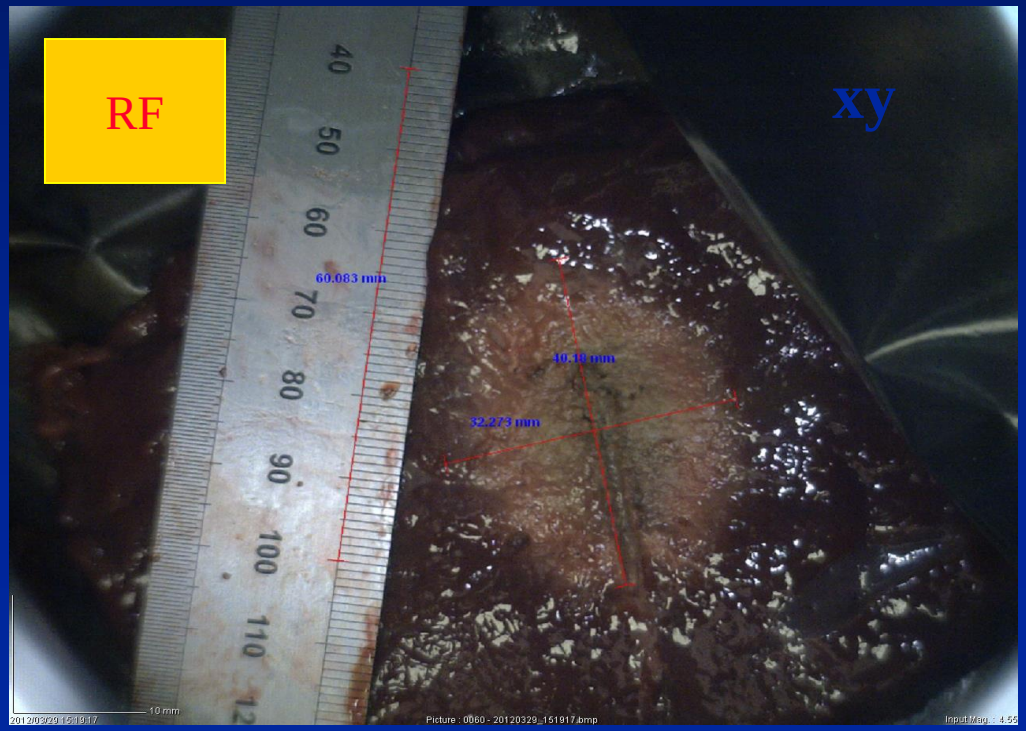


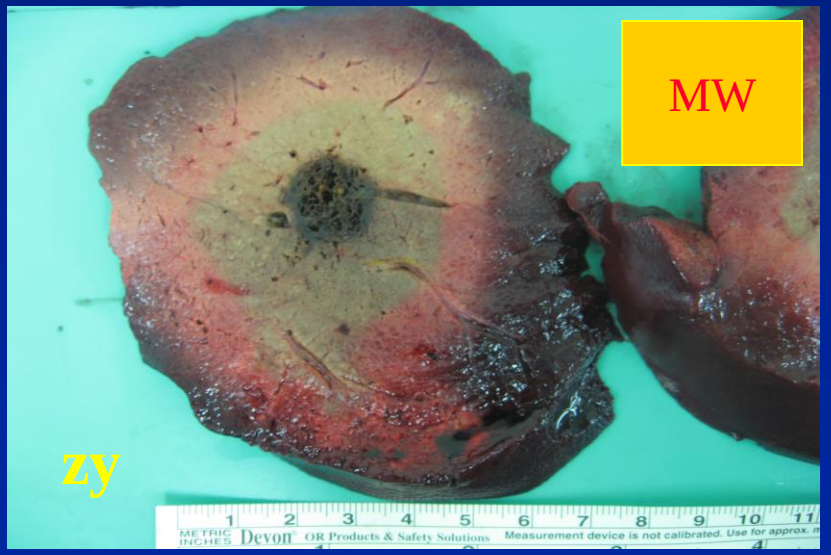
- **MWs are non ionizing EM radiations (frequency ~ 1 GHz for clinical use)**
- **MWs induce electric dipoles rotation at the atomic level, generating frictional heat.**
- **Remarkably larger active heating zone with respect to RFs, simultaneously heated with no propagation delay**
- **No current circulation! Poorly or non conductive targets still responsive to MW heating**
- **Enhanced response to MW heating in "polar" substances, such as water**

Appearance of RF or MW-ablated tissue



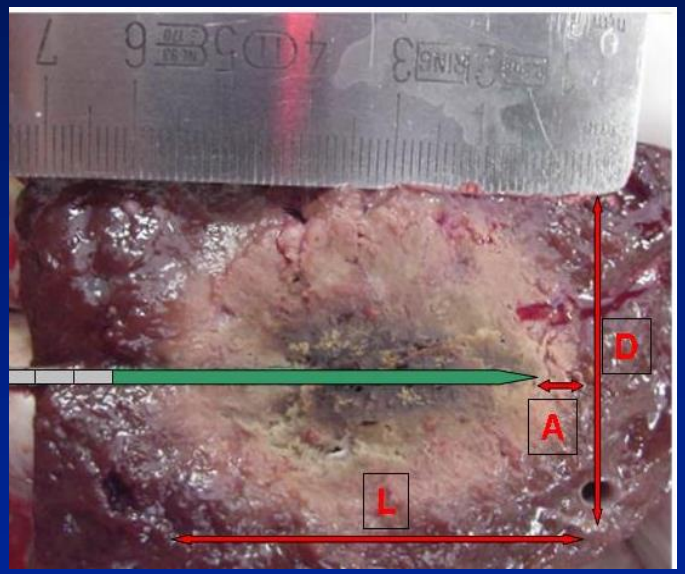


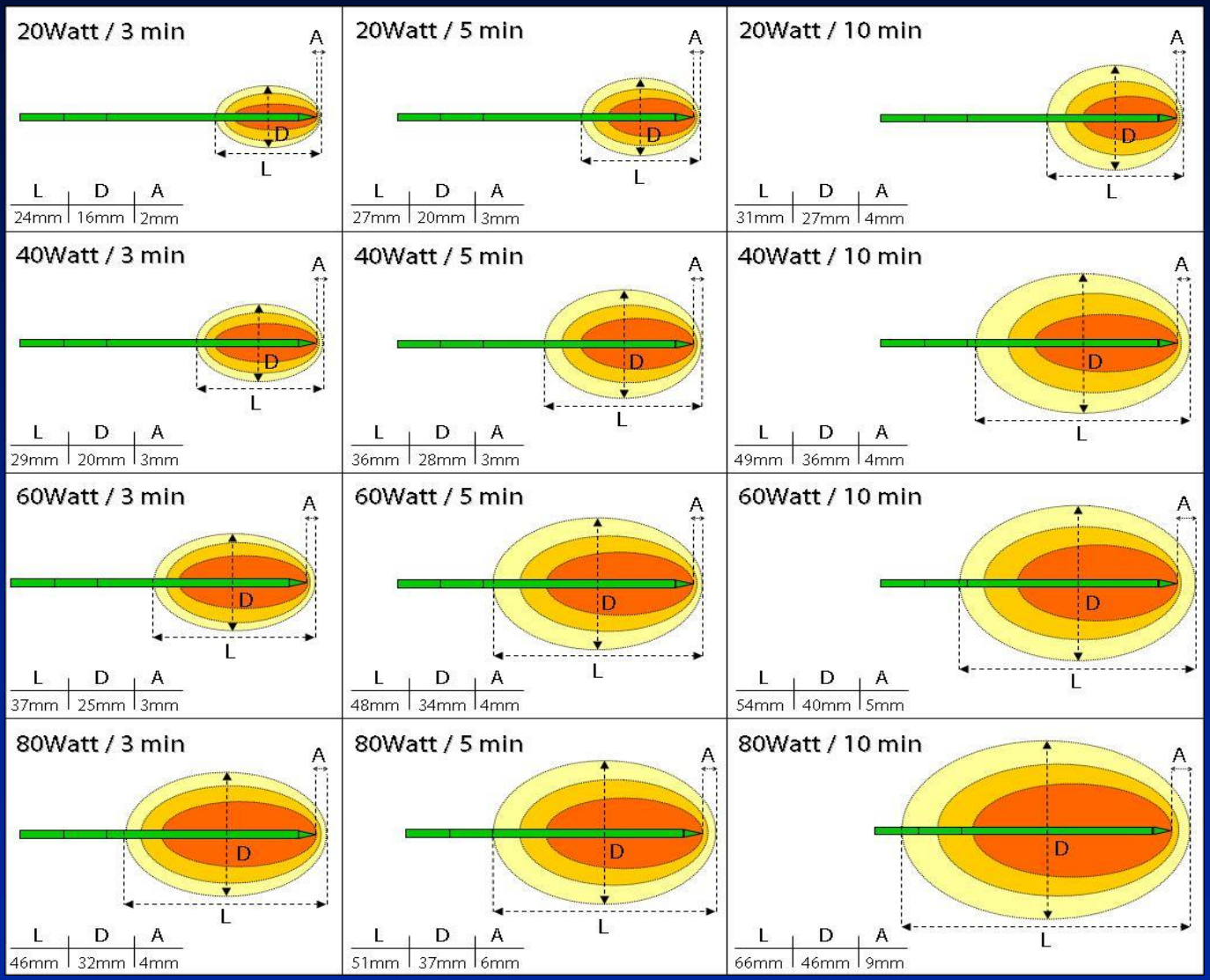




MWA: ex vivo coagulative performance

Ex vivo bovine liver, room temperature





MWA technology: critical issues

•**Cost and technical complexity**

Generating and controlling MW power effectively and safely for clinical use is more complicated and expensive than for RFA

•**Control over the heating pattern**

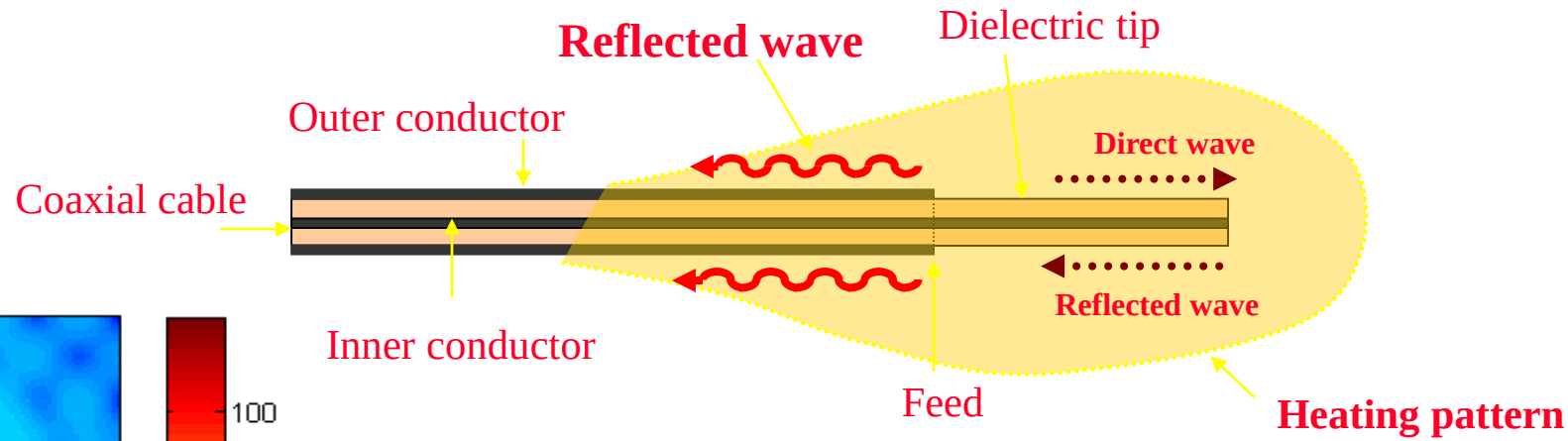
Conventional MWA probes are heavily affected by back heating phenomena (**COMET EFFECT**), both due to scarce control over reflected power (that is, the portion of MW power not absorbed by tissues and propagating backwards) and due to remarkable power loss along the antenna feeding cable, turning into severe shaft overheating.

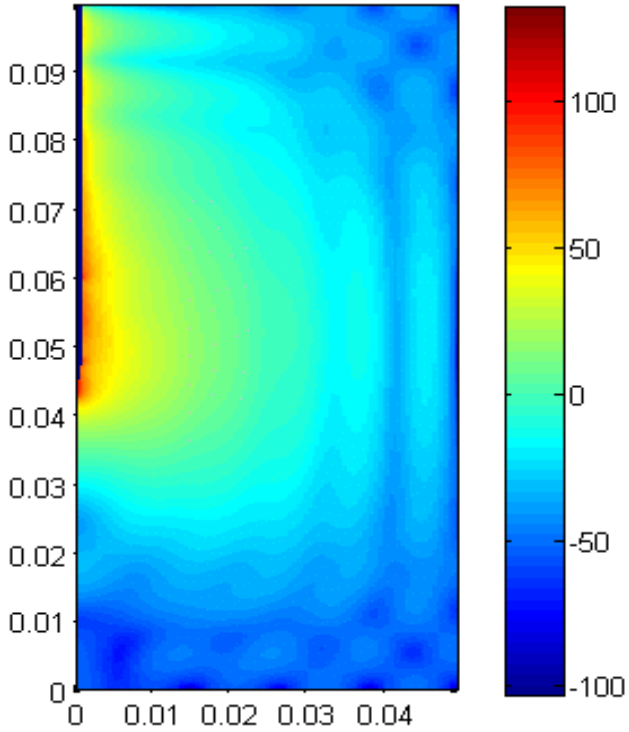
•**Invasiveness**

Common technical remedies to the heating pattern control issues bring to a significant enlargement of the probes size, making them unsuitable to percutaneous use.

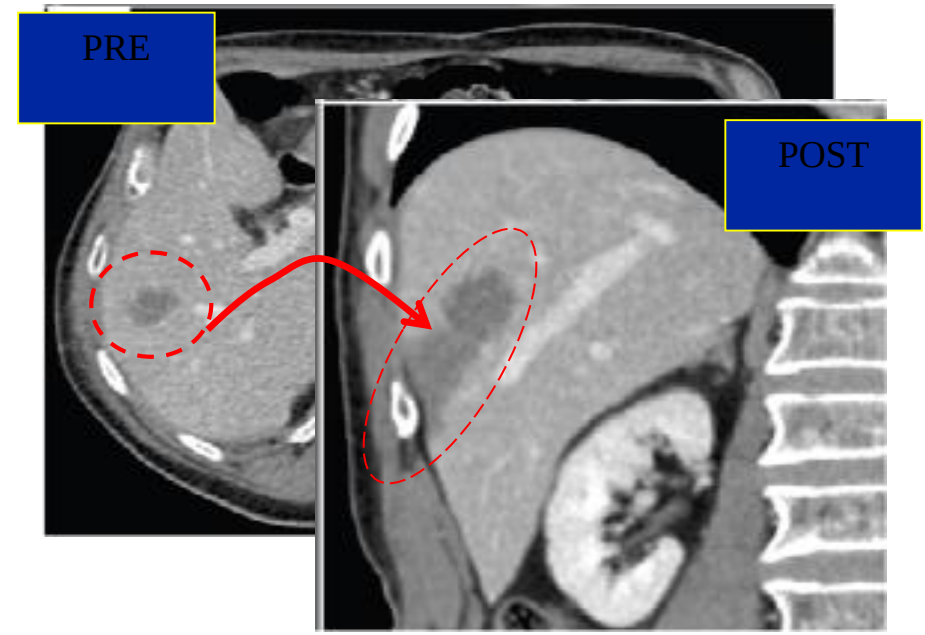
These critical issues have not been properly addressed until recently: therefore, MWA has so far played a minor role in IR, despite its huge potential.

Comet effect



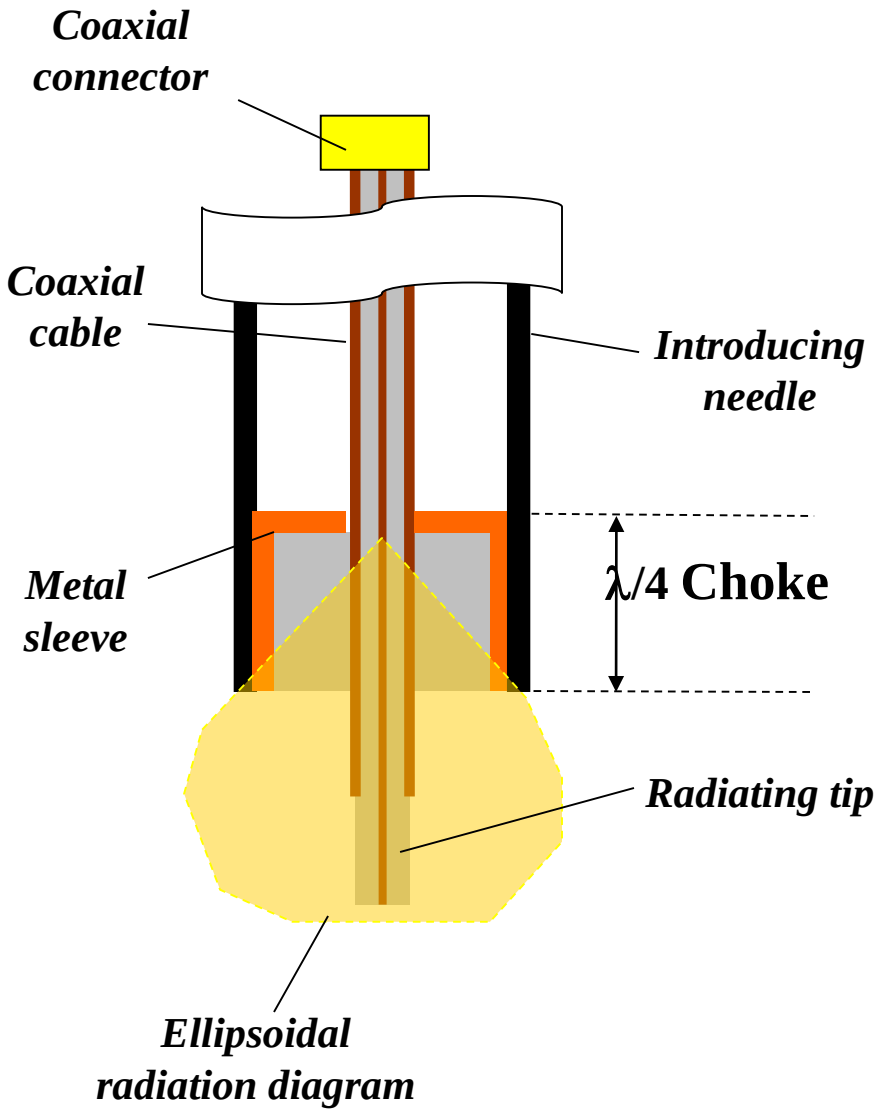


Picture courtesy of prof. M. Cavagnaro, University of Rome "La Sapienza", Dept. Electronic Engineering



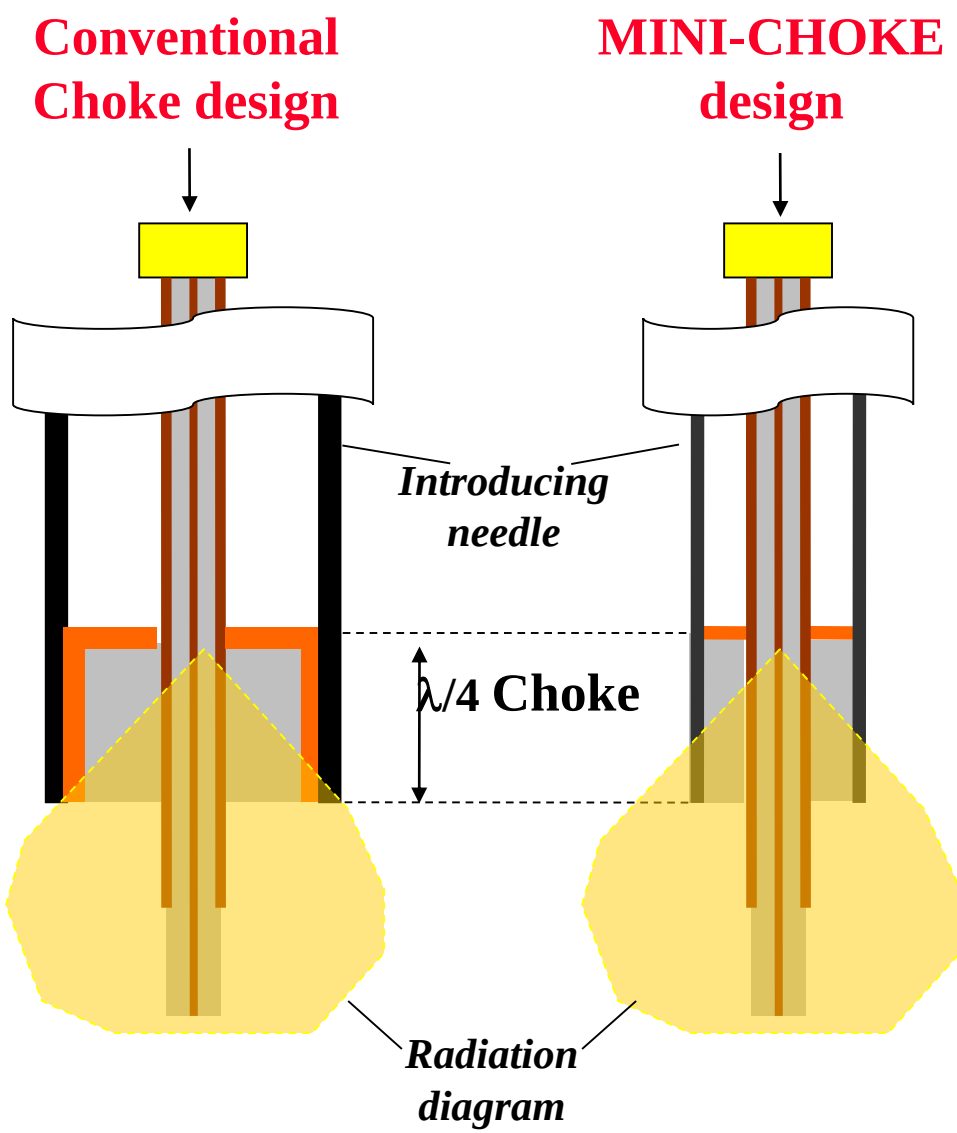
B. Topal et al., EJSO, 36, 8 (2010) 725

Choked applicators



- **Use of a quarter-wave impedance transformer**
- **Effective entrapment of reflected waves**
- **Heating pattern confined to the probe tip**
- **Transversal clearance remarkably increased**
- **<u>Not suitable for percutaneous use</u>**

The mini-choke concept

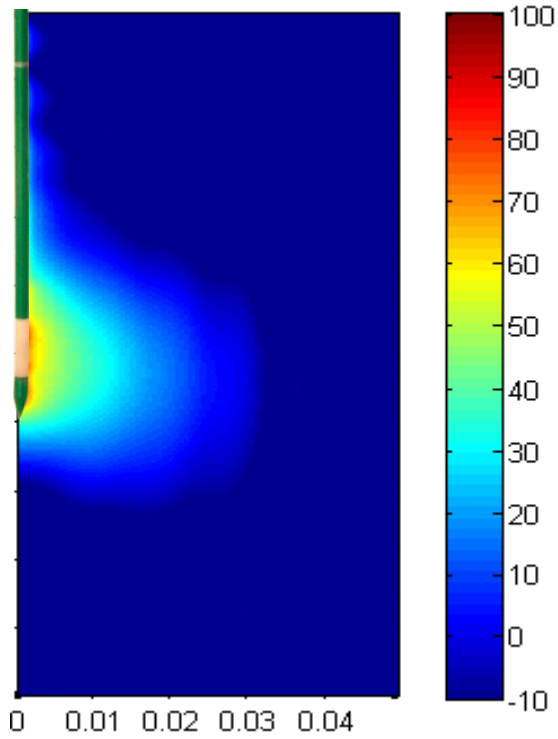


Consiglio Nazionale delle Ricerche

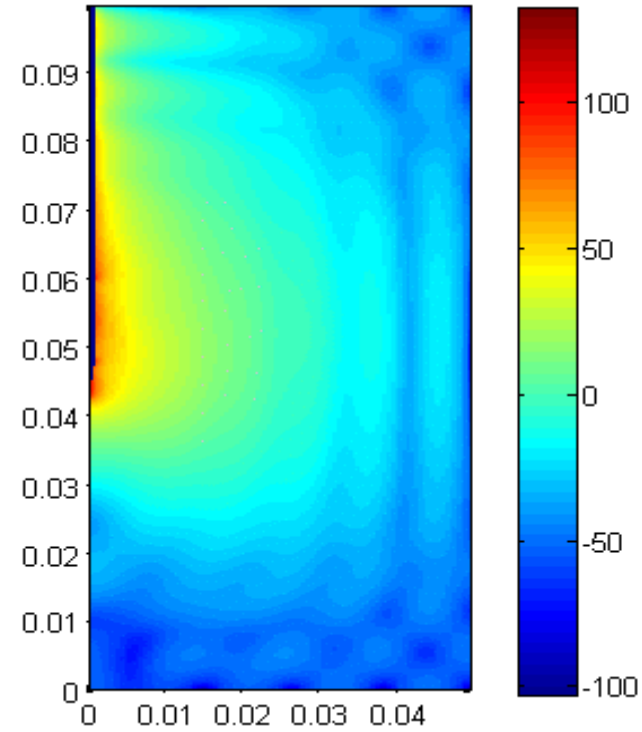
- **Worldwide patent (CNR, Dr I. Longo) licensed to HS**
- **Effective as an ordinary choke in trapping reflections, but with no gauge increase**
- **Minimum insertion depth required**

The mini-choke works!

Mini-choked applicator



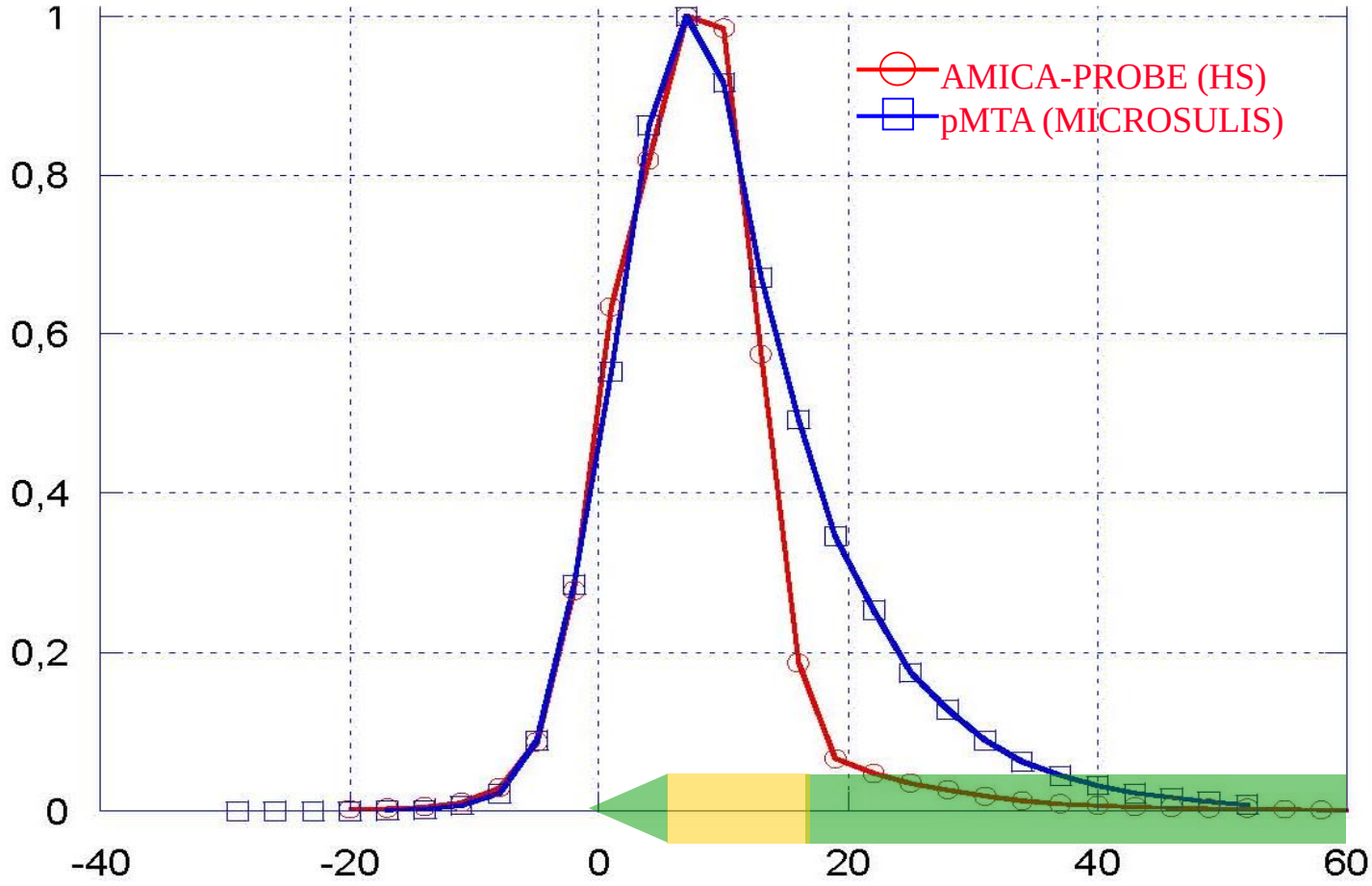
Unchoked applicator



Pictures courtesy of prof. M. Cavagnaro, University of Rome “La Sapienza”, Dept. Electronic Engineering

The mini-choke works!

Electric field (normalized)



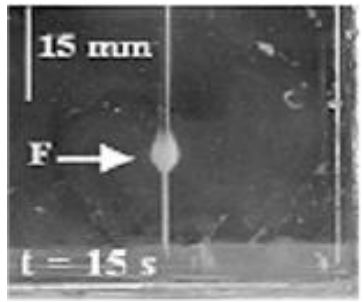
(mm)

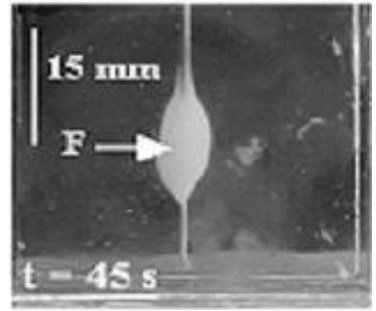
Courtesy of:

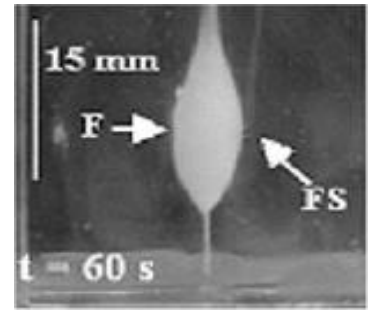
UT BIORAD
Dr Vanni Lopresto

The mini-choke works!

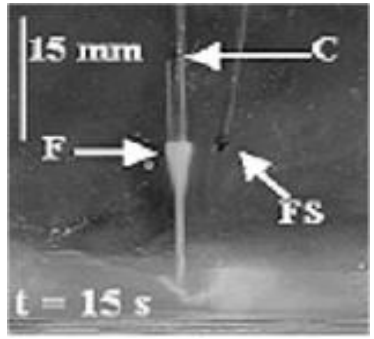
unchoked

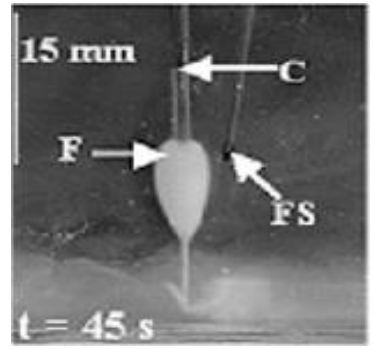


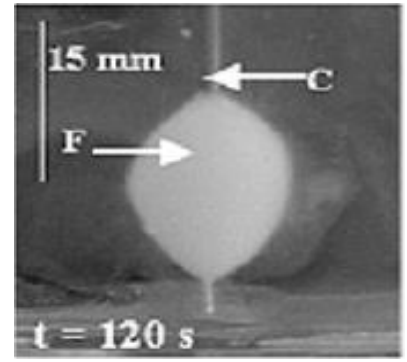




with mini-choke



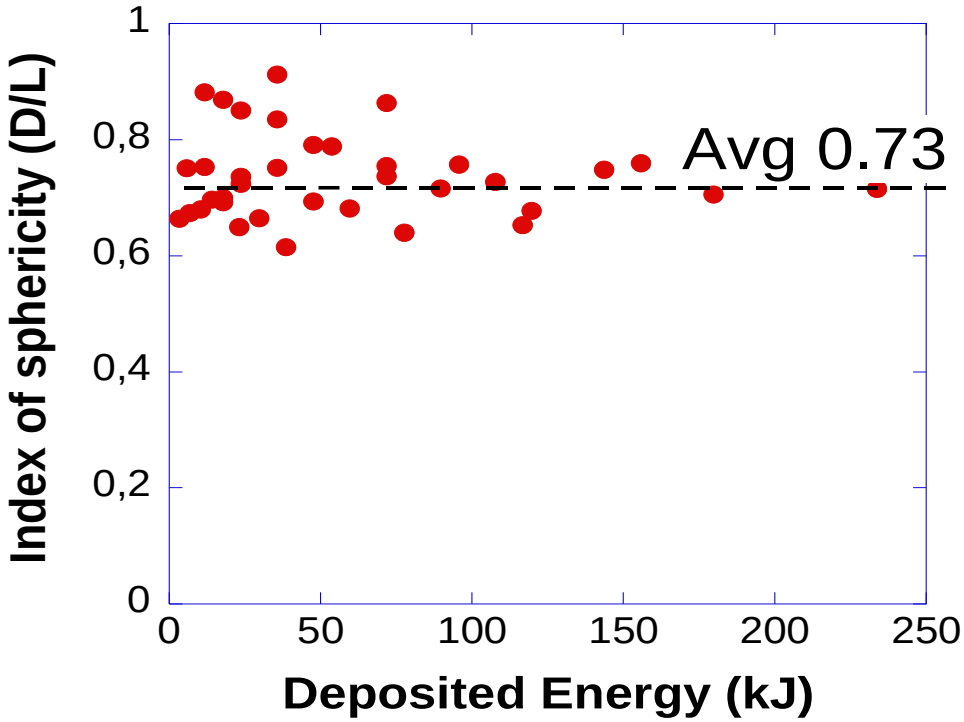


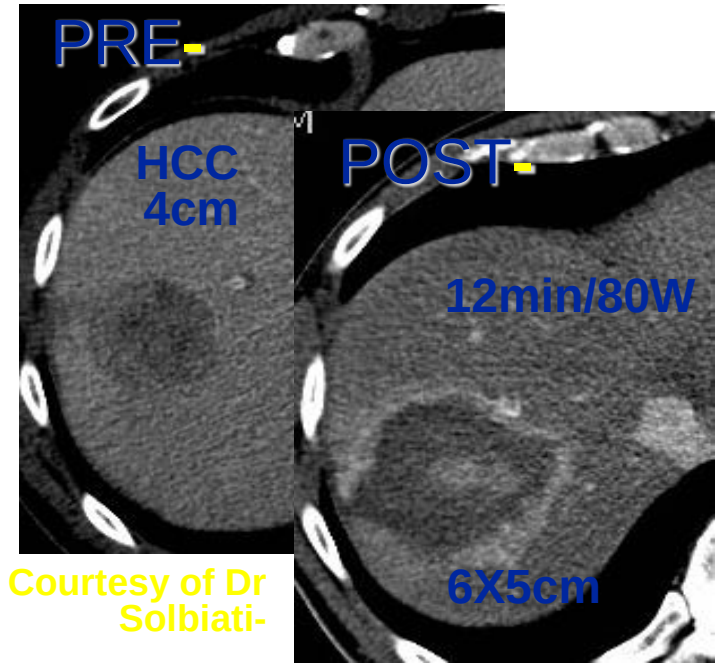


I. Longo, G. Biffi Gentili, M. Cerretelli, N. Tosoratti, “A coaxial Antenna with Miniaturized Choke for Minimally Invasive Interstitial Heating”. IEEE Trans. on Biomed. Eng. Vol 50 N. 1; 2003.

The mini-choke works!

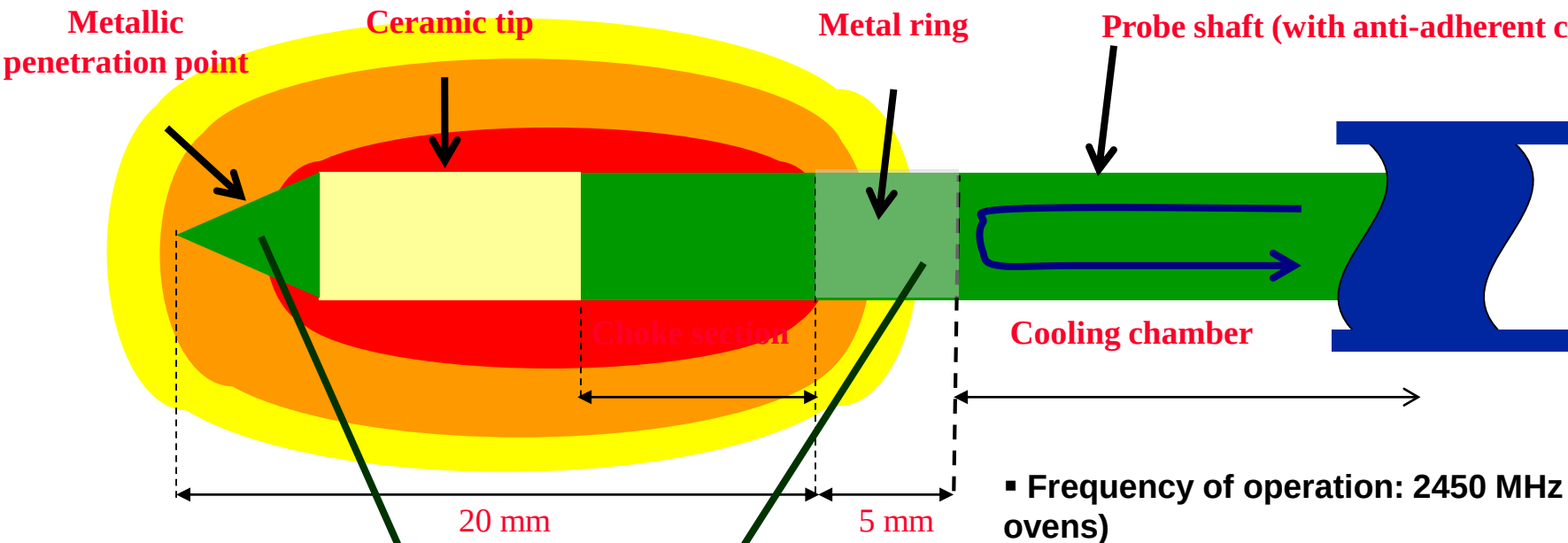
Enhanced control over the probe radiation and heating pattern:
improved sphericity index, reduced risk of overheating damage

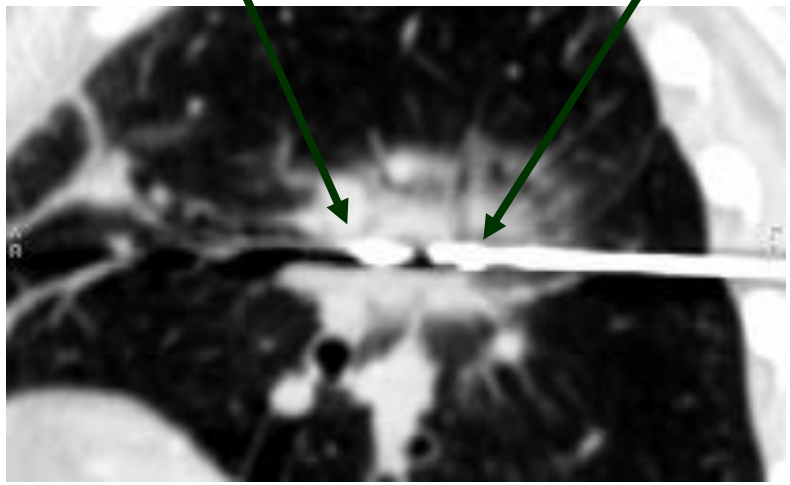




Courtesy of Dr Solbiati-

AMICA-PROBE: beyond the mini-choke





Picture courtesy of Dr T. De Baere, IGR, Villejuif, France

- **Frequency of operation: 2450 MHz (same as MW ovens)**
- **Interstitial 11G, 14G, 16G models**
- **150, 200, 270mm shaft lengths**
- **Mini-choke for reflections trapping**
- **Internal cooling to avoid shaft overheating: pre-assembled hydraulic lines**
- **Lesions from 2cm to >5cm attainable through different ablation time and power settings (up to 100W/net on probe)**

New Ablation Device: Key ??

- What can it do ?
- Is it safe ?
- Is it better than other alternatives ?

Typical Results: Satisfaction of Search

Them ?!?!

(4.9 ± 0.2 x 7.8 ± 0.4 cm)

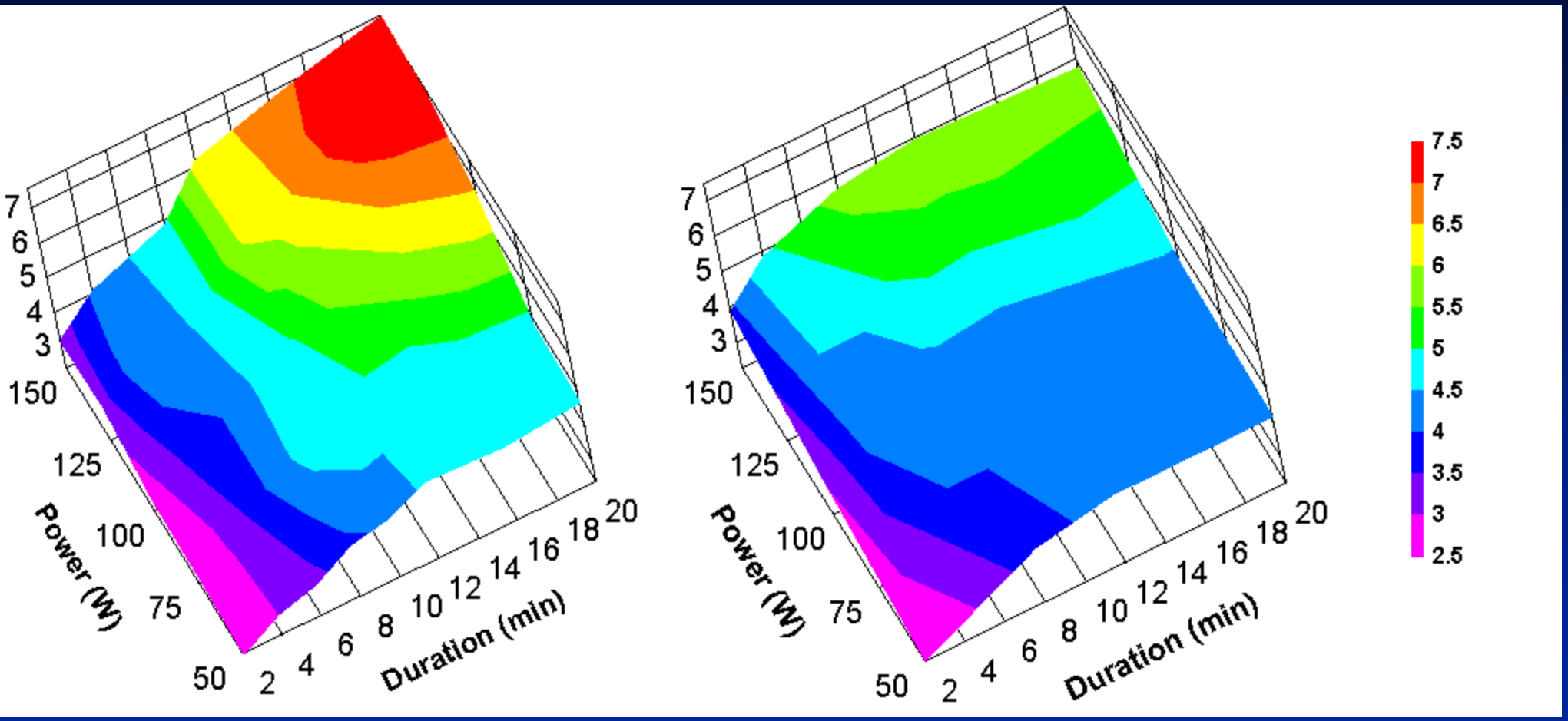
US !!!!

(5.7 ± 0.2 x 6.5 ± 1.7 cm)

New Ablation Device: Key ??

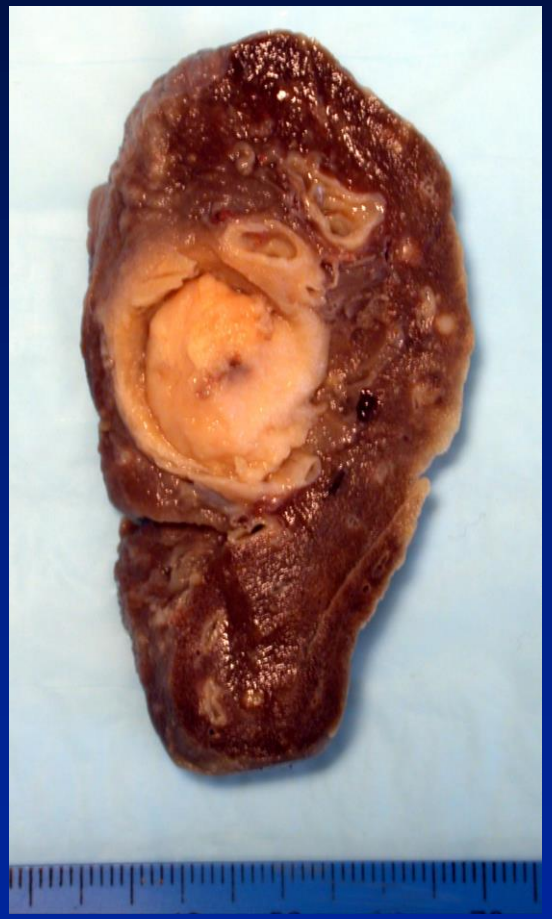
- **What can it do ?**
  - » Systematic application-specific characterization and optimization
- **Is it safe ?**
- **Is it better than other alternatives ?**

MWA: Systematic Characterization



Ex-vivo **In-vivo**

RF Ablation: Effect of Tumor Environment



Kidney **Subcutaneous** **Lung**

CVS; RF @90˚ C; 5 min

Ahmed; Radiol 2004

Systematic Evaluation !!!

Materials and Methods:

- **110 ablations performed in *ex-vivo bovine liver***
  - » HS R&D
- **Representative settings in *in-vivo porcine liver***
  - » Hadassah (n=20)
- **26 patients with *small focal HCC nodules* (2.3±0.9cm; 1.3-4.5 cm) receiving single applications of MW energy**
  - » Solbiati / Meloni groups

Ex-vivo Studies:

- **Systematically varied to create grids:**
  - » Power (20 – 130 Watt net on antenna)
  - » Time (3 - 30 min) of energy application

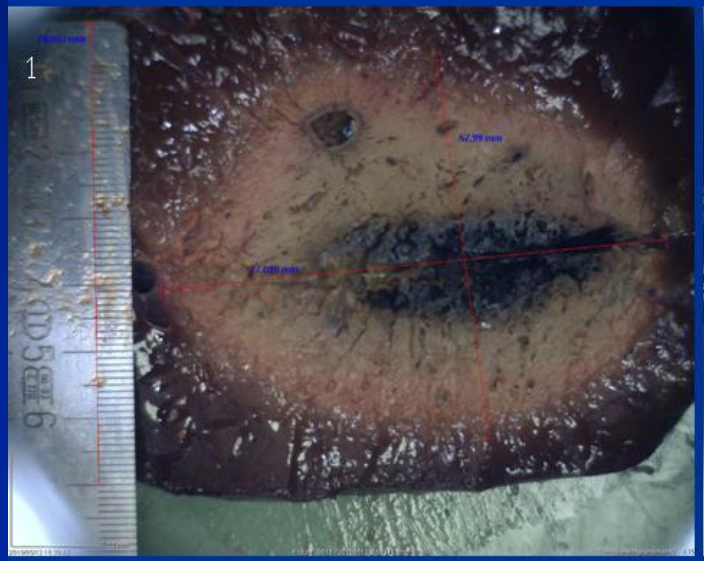
- **Key End-points:**
  - » ablation diameter
  - » length
  - » sphericity index

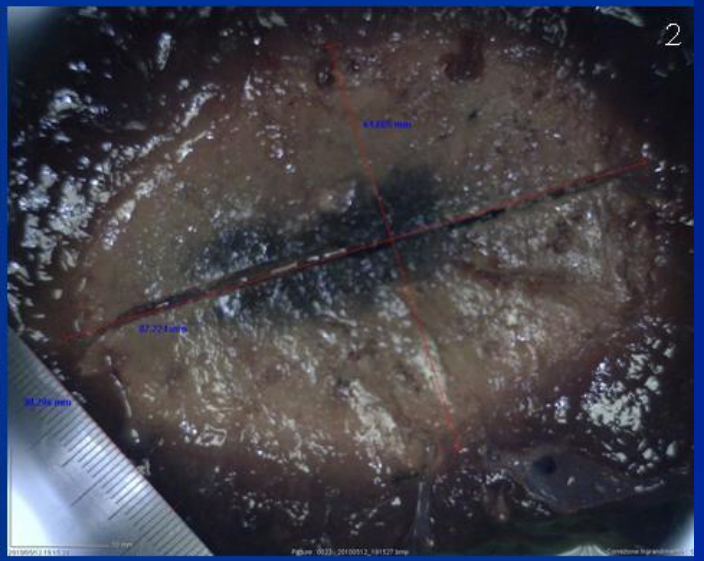
HS Evaluation Means Business !!

Coagulation Measurement:

HS AMICA –MV coagulation system

Ablation parameters				Measurements	
Image No'	Power (W)	Time (MIN)	S	Height (cm)	Width (CM)
1	100	15	4.7	7.7	5.8
2	100	20	5.0	8.7	6.1





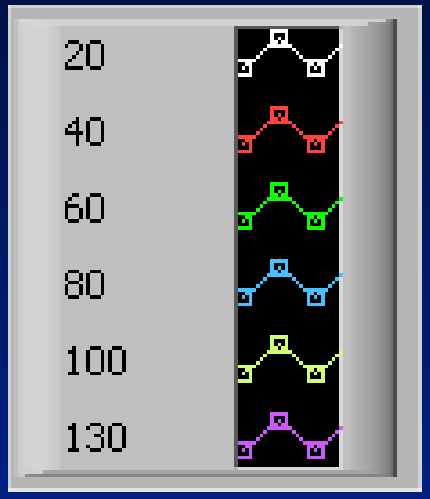
Results summary:

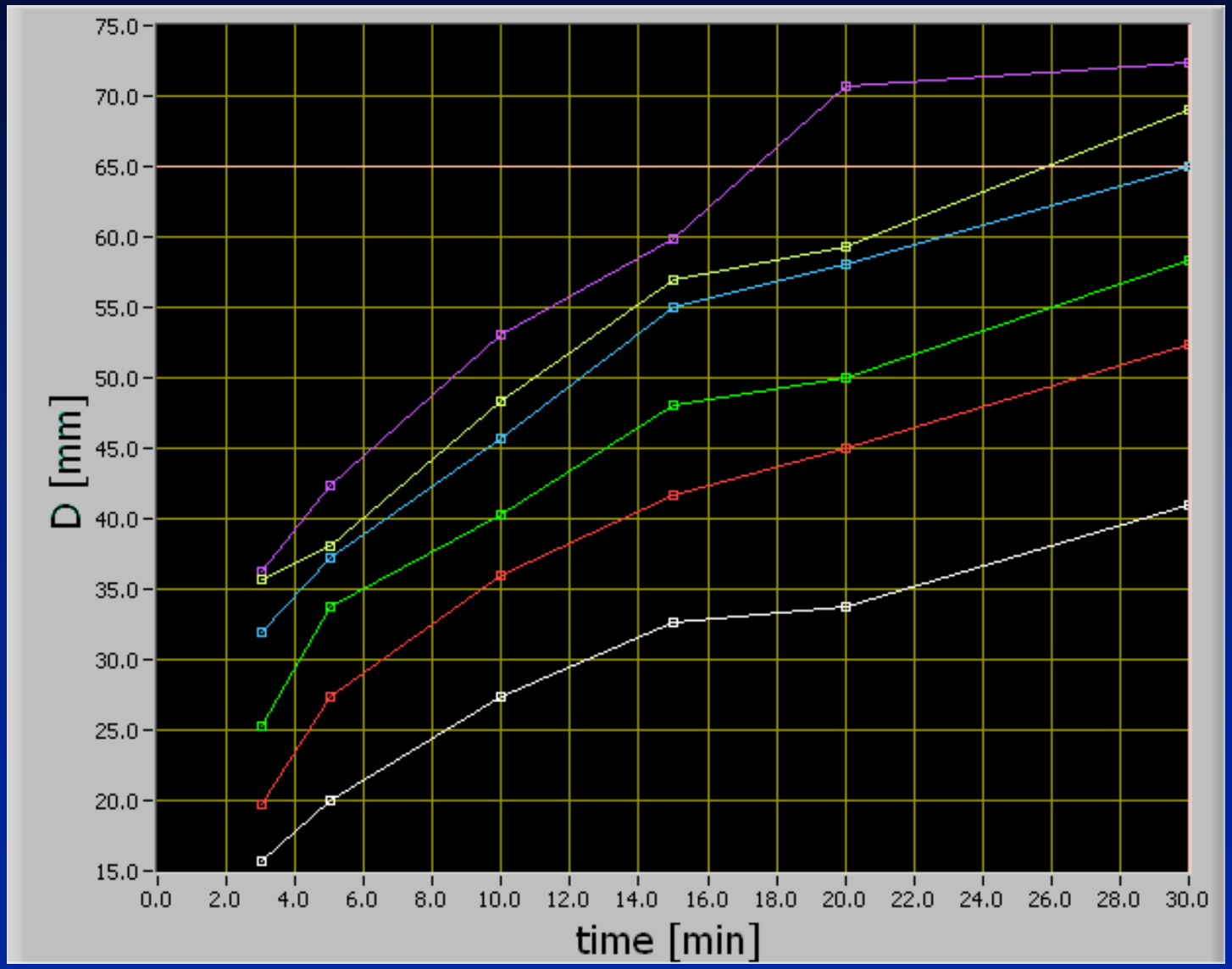
Ablation Size: Average Diameter (mm)

Ablation Time (min)	Ablation Power (W)					
	20	40	60	80	100	130
3	15.7	19.7	25.3	32.0	35.7	36.3
5	20.0	27.3	33.7	37.2	38.0	42.3
10	27.3	36.0	40.3	45.7	48.3	53.0
15	32.7	41.7	48.0	55.0	57.0	59.8
20	33.7	45.0	50.0	58.0	59.3	70.7
30	41.0	52.3	58.3	65.0	69.0	72.3

Ex-vivo: Diameter vs. Time

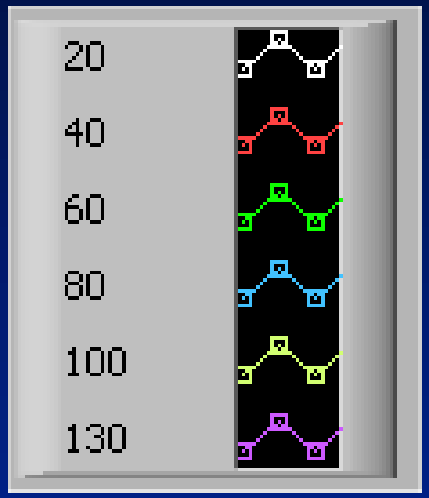
POWER (W)

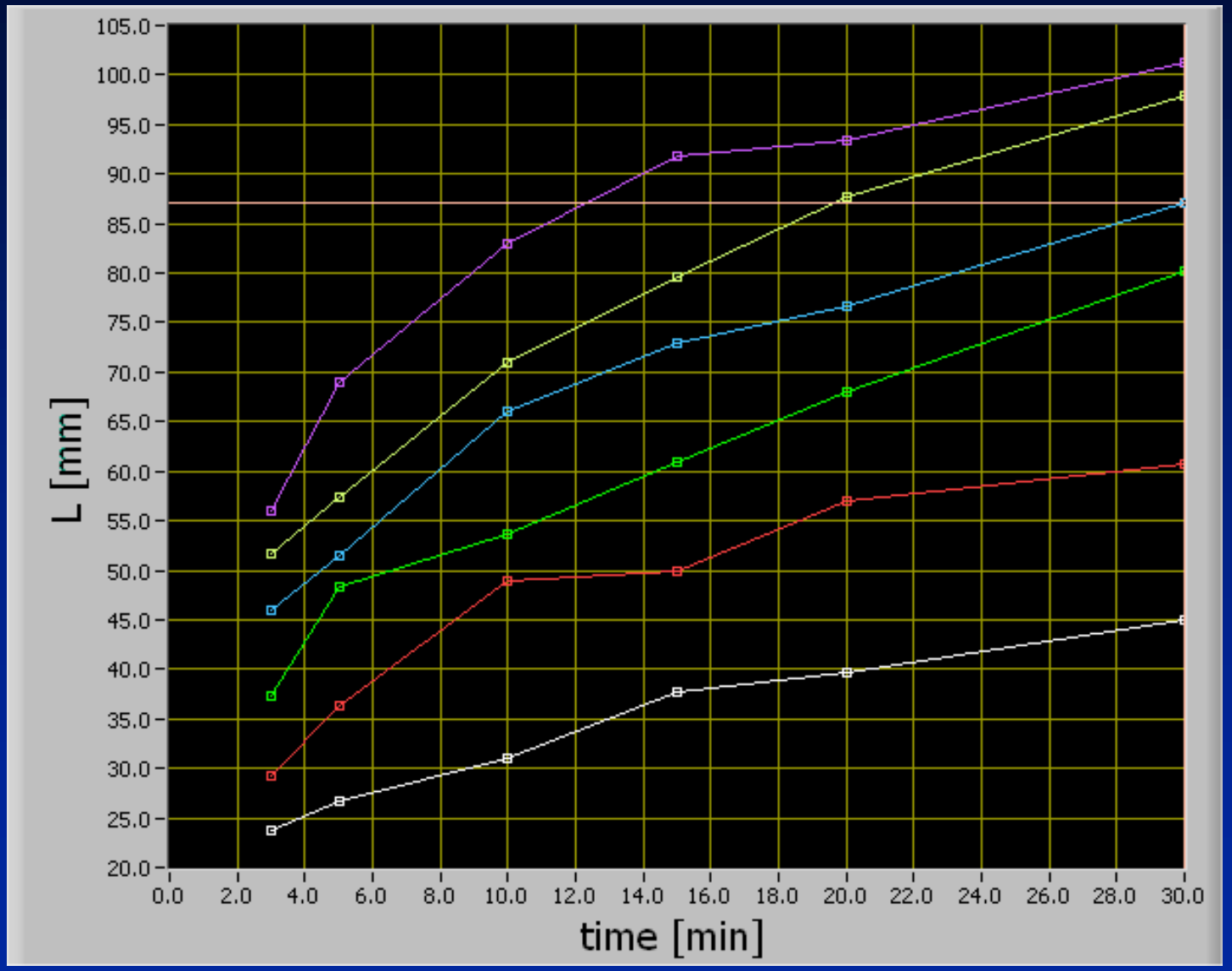




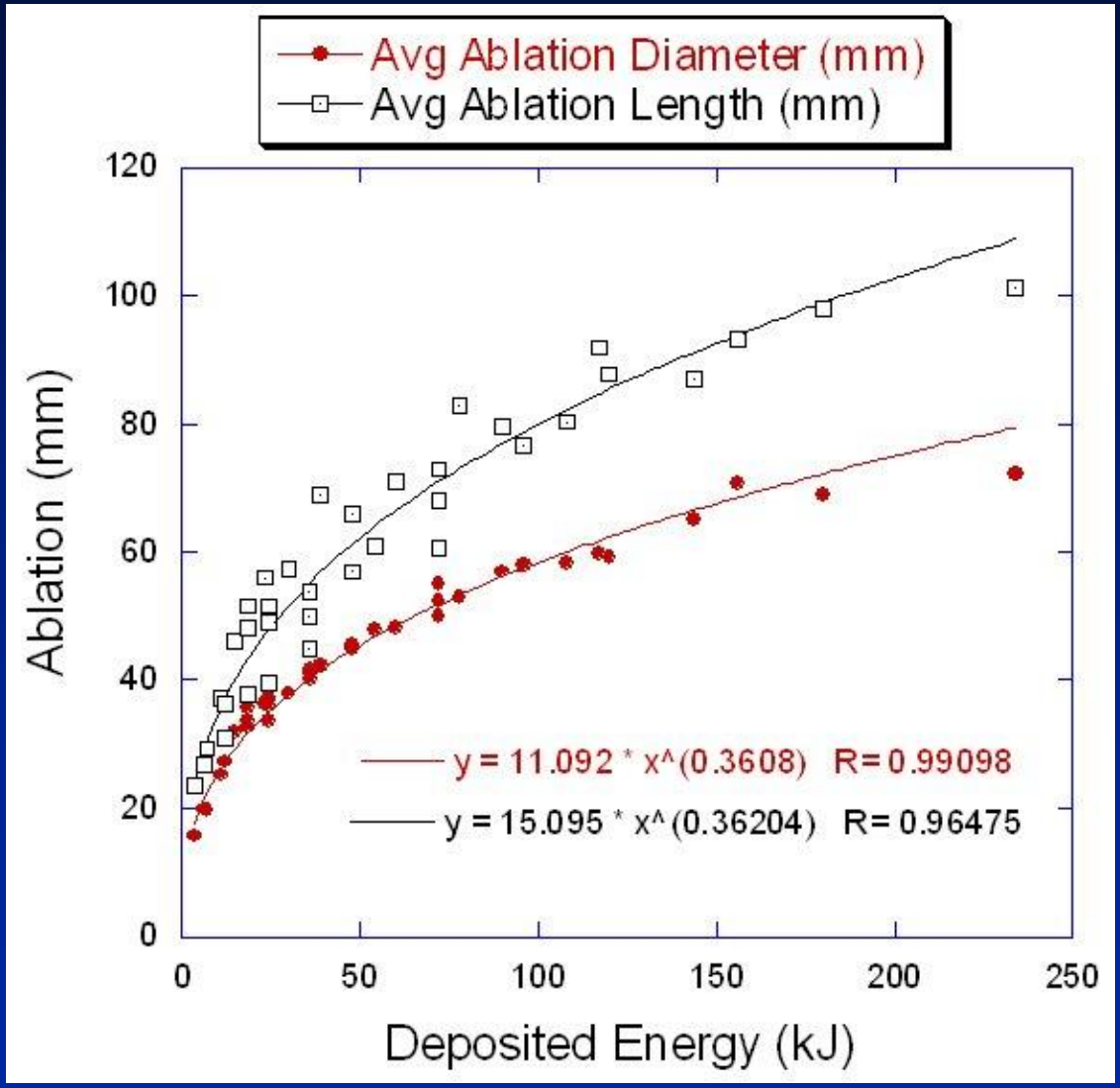
Ex-vivo: Length vs. Time

POWER (W)





For the Mathematicians:

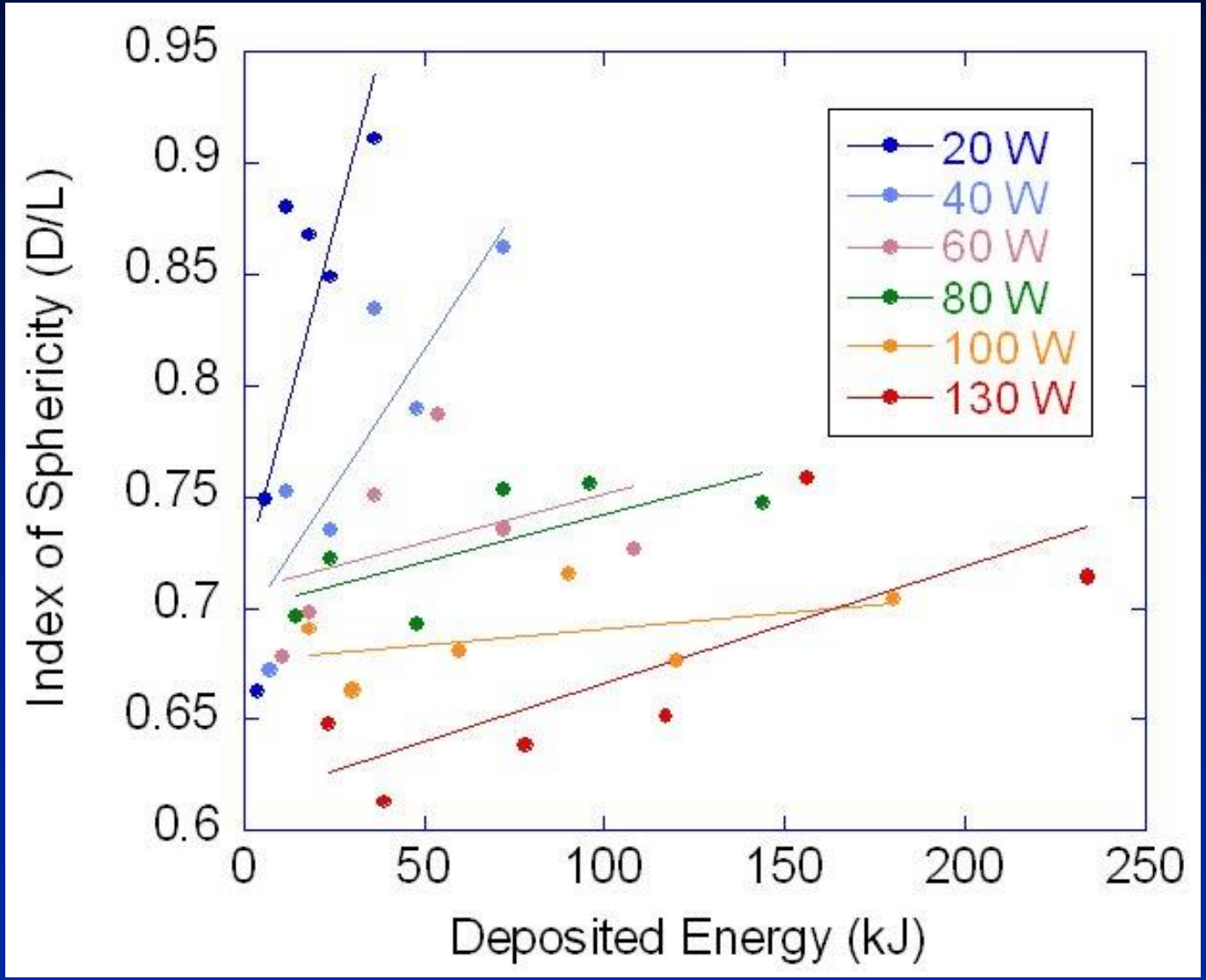


Results summary:

Index of Sphericity: Average(D/L) (mm)

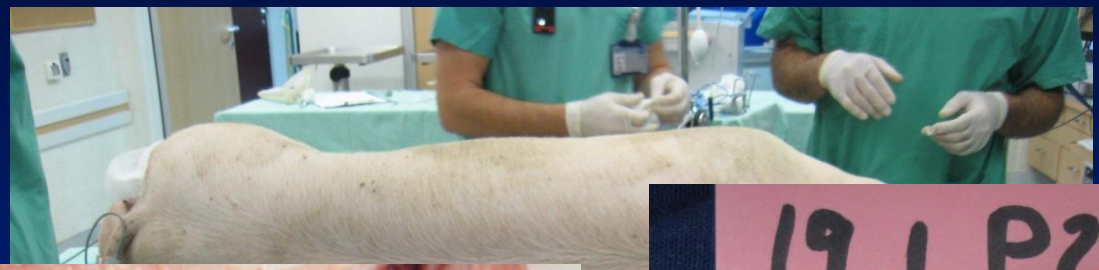
Ablation Time (min)	Ablation Power (W)					
	20	40	60	80	100	130
3	0.7	0.7	0.7	0.7	0.7	0.6
5	0.8	0.8	0.7	0.7	0.7	0.6
10	0.9	0.7	0.8	0.7	0.7	0.6
15	0.9	0.8	0.8	0.8	0.7	0.6
20	0.9	0.8	0.7	0.8	0.7	0.8
30	0.9	0.9	0.7	0.7	0.7	0.7

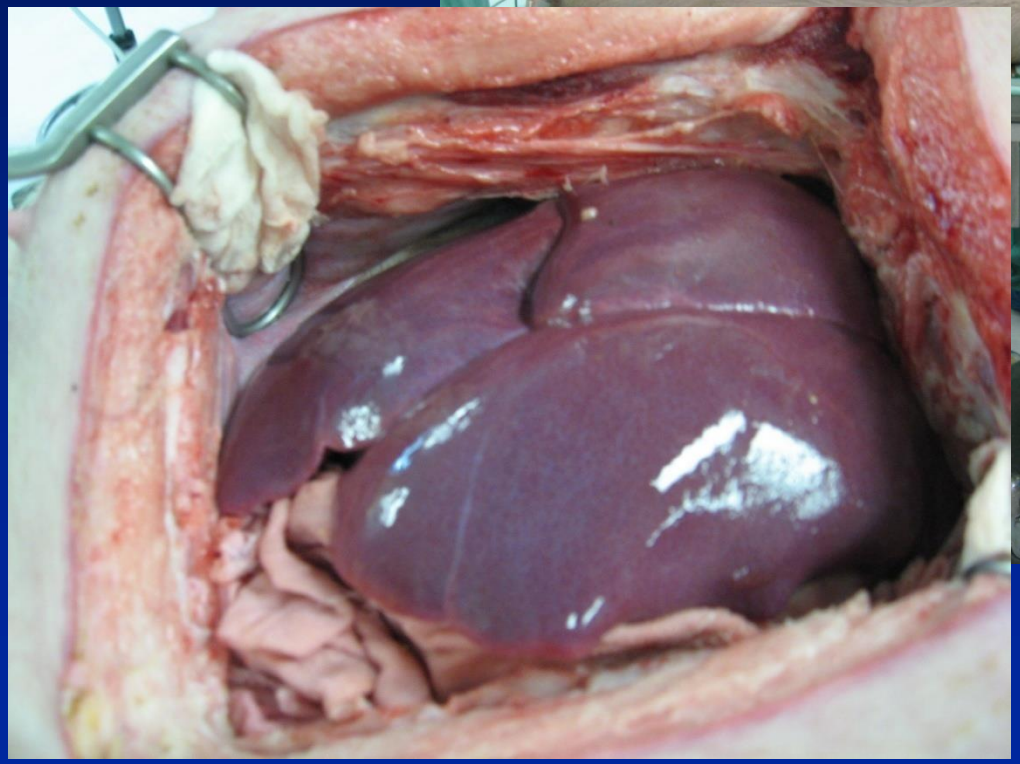
MW Sphericity vs. Power & Time:



In-vivo Results:

(The Fate of All Good Swine in Israel)





Results: In-vivo

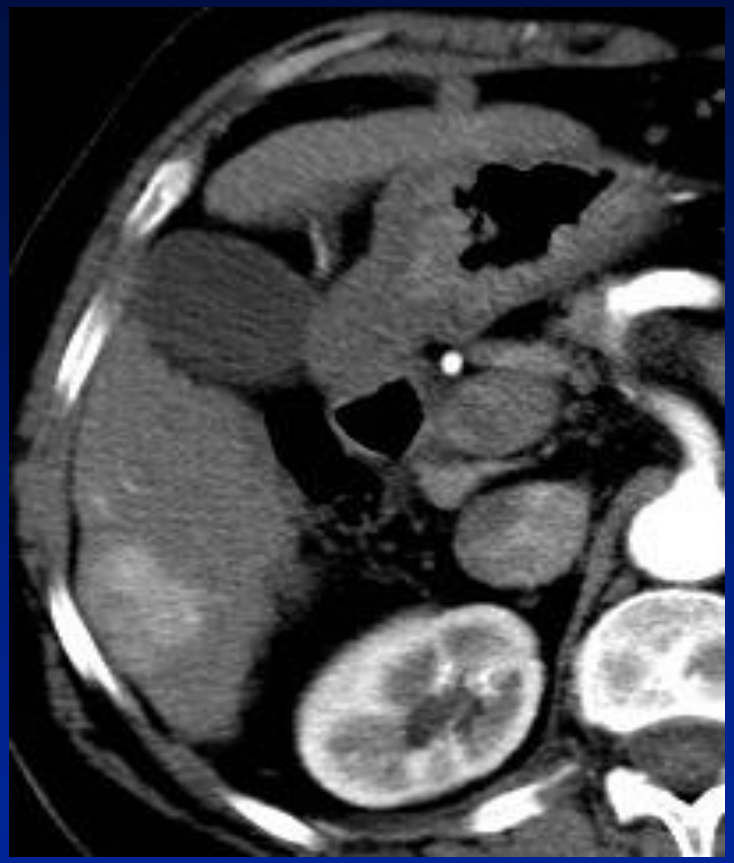
Ablation power (W)	Ablation time (min)	Diameter (cm)	Length (cm)	Index of sphericity	(N)
100	10	5.0 ± 0.3	8.5 ± 0.4	0.59	5
100	5	3.3 ± 0.5	5.9 ± 0.6	0.57	4
60	10	3.1 ± 0.5	4.9 ± 1.0	0.64	8

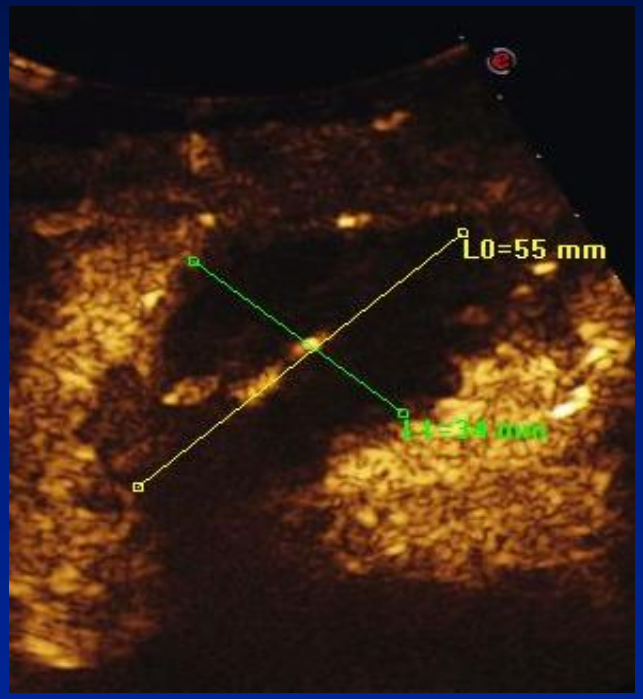
Mining Relevant Clinical Data:

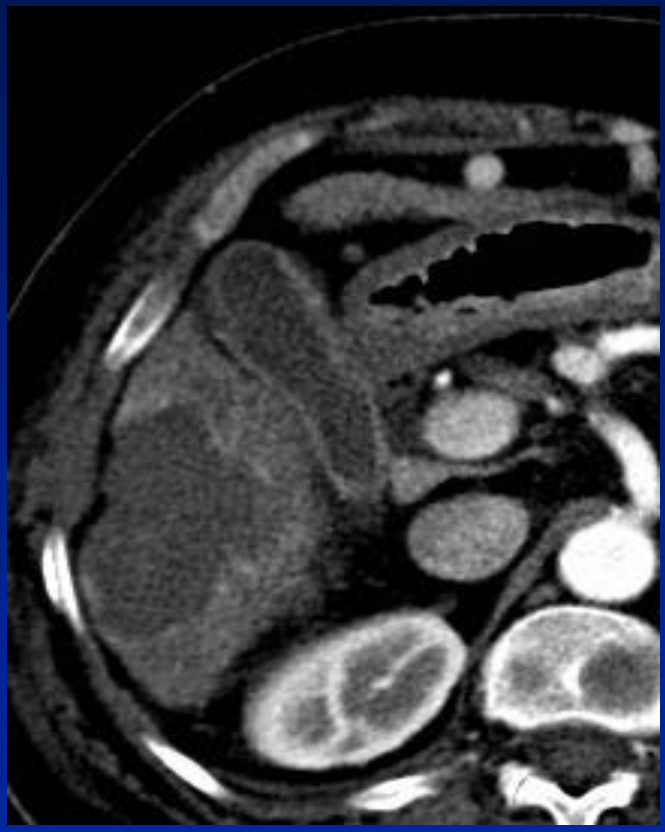
- ***Local control of focal hepatic malignancies treated with microwave ablation with a novel high-power applicator system: 108 ni ecneirepxe htnom-14patients***
  - » L. Solbiati et al.
- ***Thermal ablation of primary and secondary liver tumors using microwave energy: evaluation of technique effectiveness and complications in 54 patients***
  - » Meloni F, et al.

Pt. AV HCC VI cm 3.0 03/08/2010

MW: 14G, 10 min, 70 W

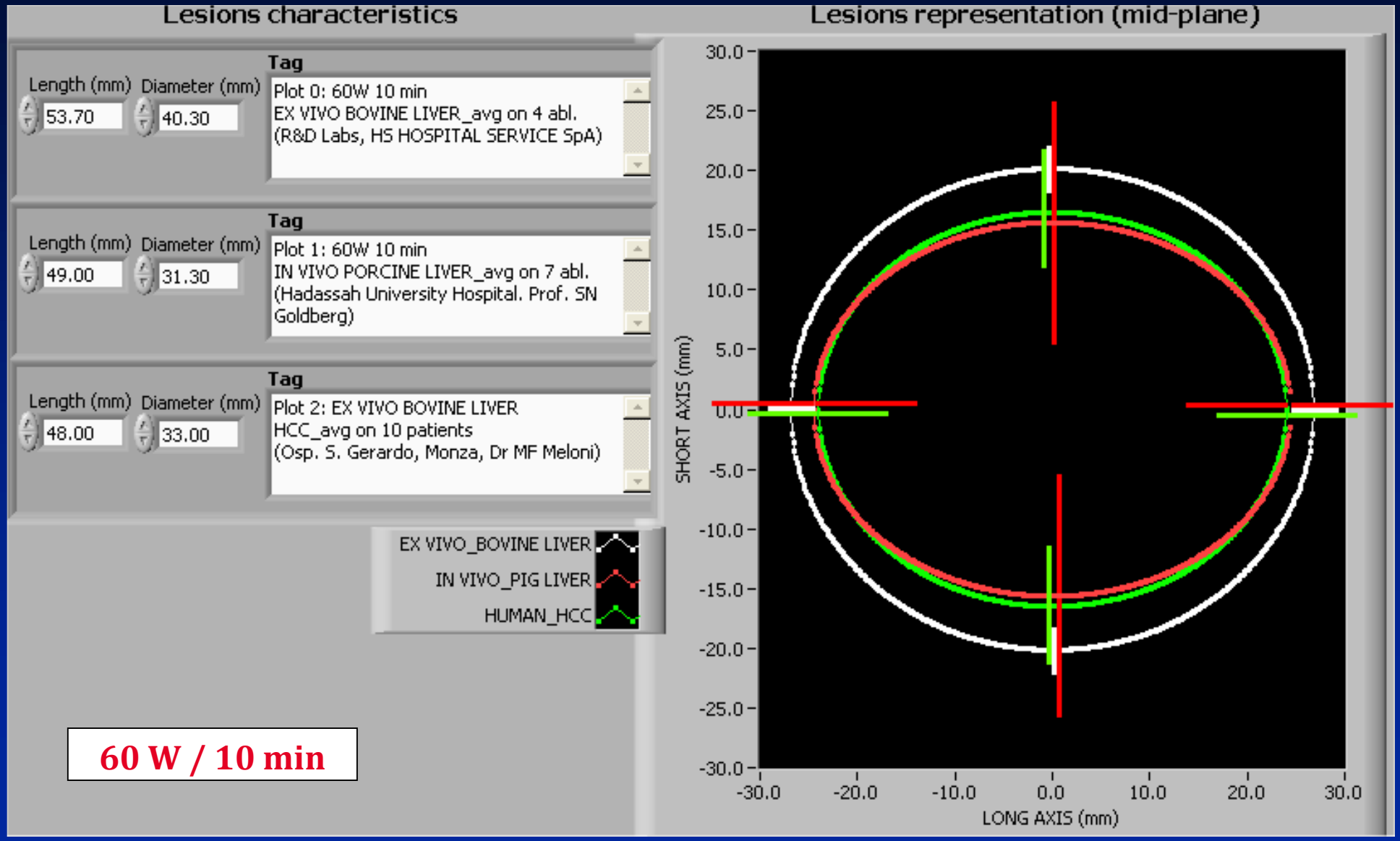




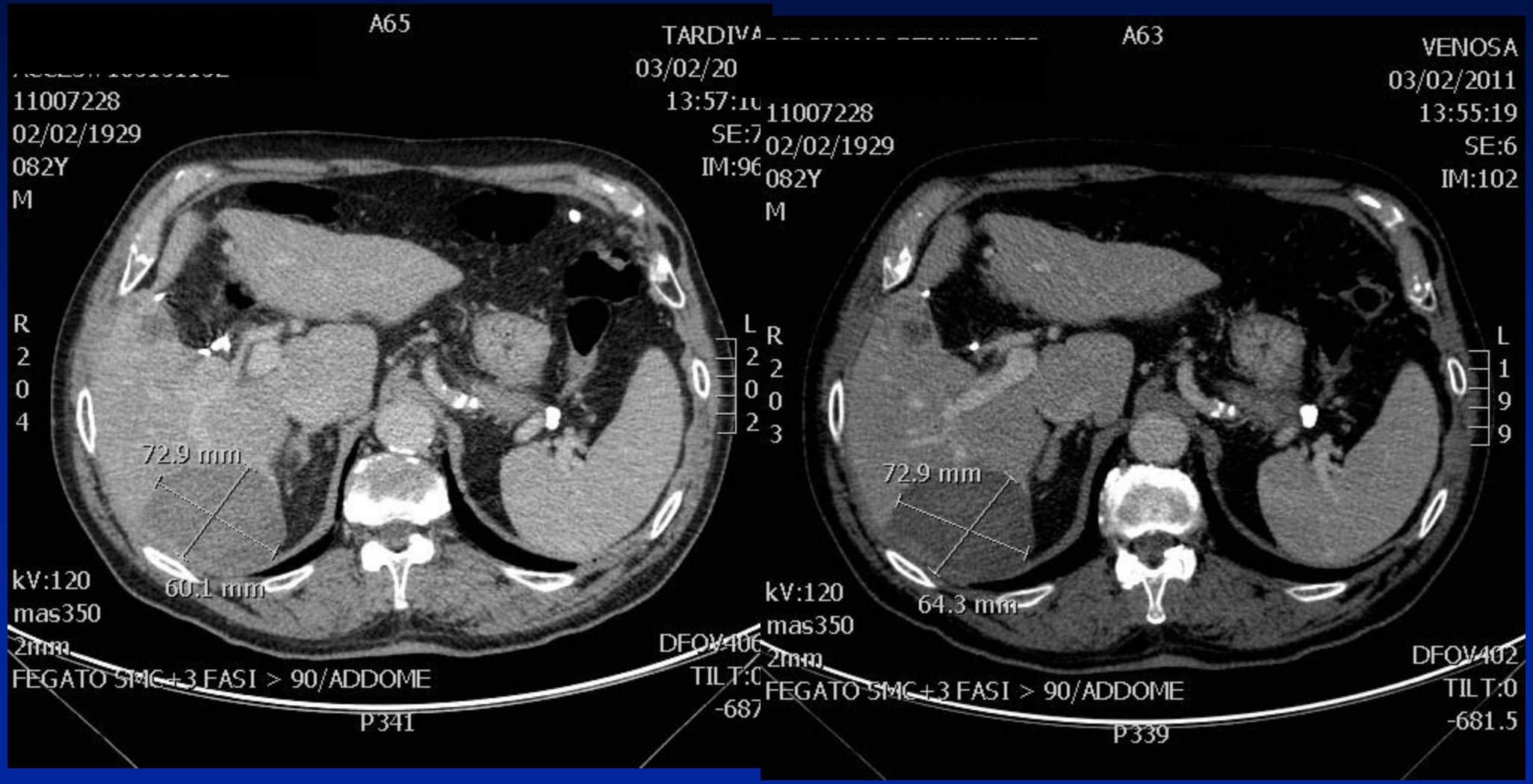


Necrosis : cm 5.7 x 3.7 x 4.2

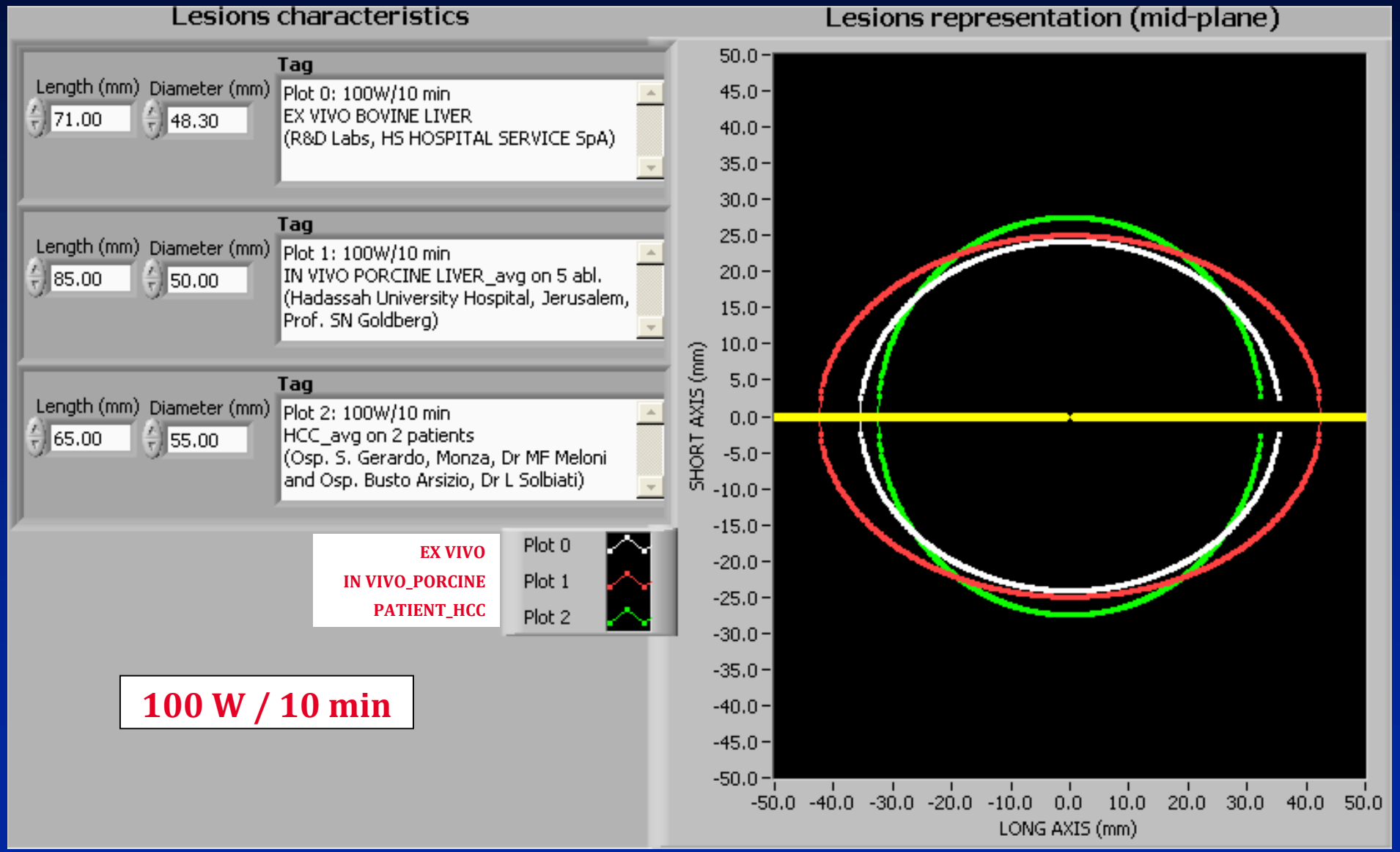
Results: Summary



HCC: 100 W / 10 min



Results: Summary



New Ablation Device: Key ??

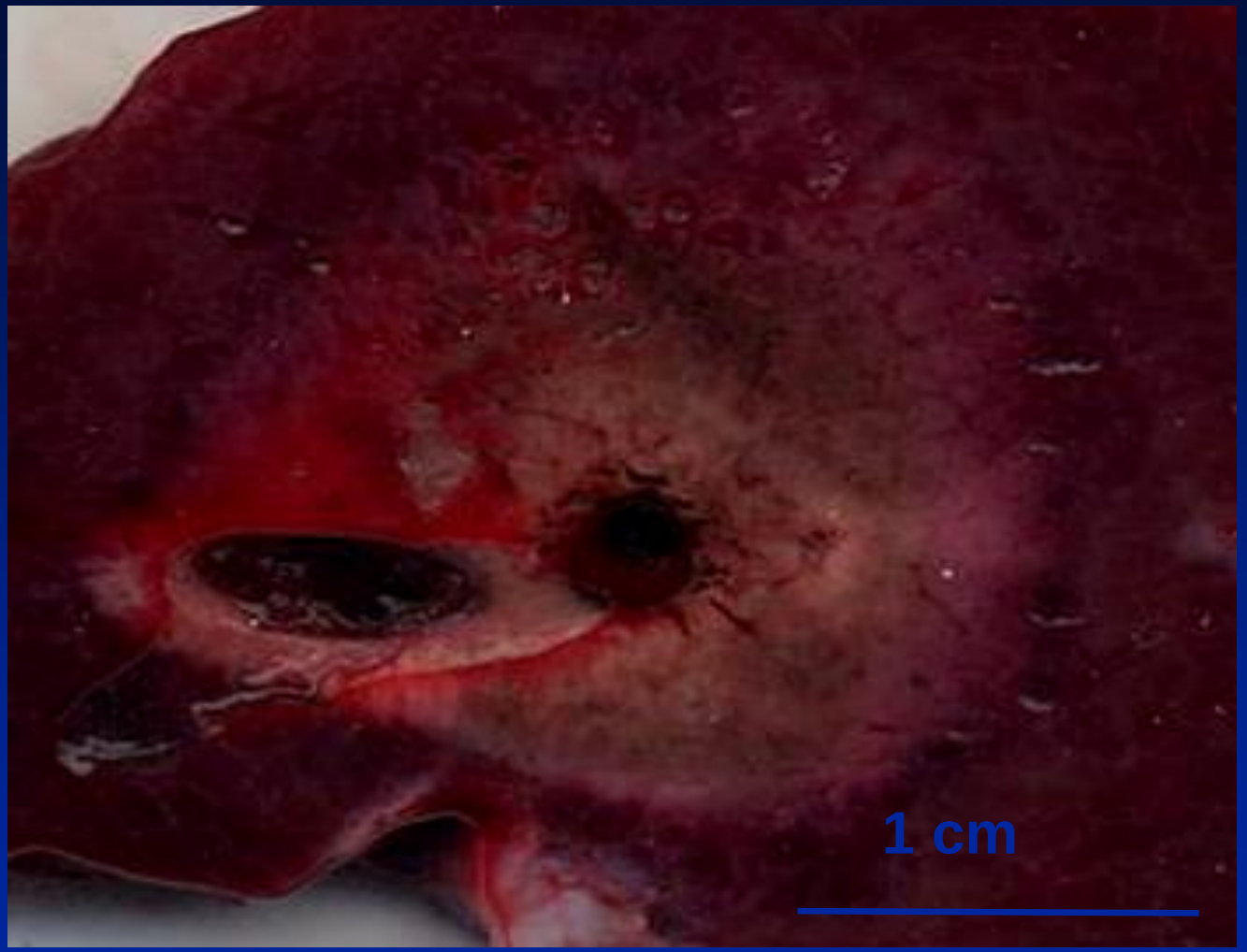
- **What can it do ?**
  - » Systematic application specific characterization and optimization
- **Is it safe ?**
  - » Understand technology and perform appropriate pre-clinical and clinical studies
- **Is it better than other alternatives ?**

MW Ablation: Safety

- **Fact: MW ablation can proceed at temperatures measuring 120 - 140° C**

- **Question: Is this a good thing or a bad thing ?**

MWA: Ablation Around Vessels



T=12 minutes; P=65 watts
Micrablate Triaxial antenna

Case Courtesy of Fred Lee Jr. MD

MWA: Conduction of Steam

T=6 minutes; P=100 watts
Microsulis 5.7 mm antenna

MW Ablation: Safety

- **Fact: MW ablation can proceed at temperatures measuring 120 - 140° C**

- **Question: What does this mean to adjacent tissues ?**

MW Ablation: Safety

- **<u>High temperature Effecting Adjacent Tissues</u>**

- **What is the safe distance to prevent perforation of:**
  - Vessels
  - Bronchi
  - Gut (colon / small bowel / stomach)
  - Ureters
  - Bile ducts / GB

New Ablation Device: Key ??

- **What can it do ?**
  - » Systematic application specific characterization and optimization
- **Is it safe ?**
  - » Understand technology and perform appropriate pre-clinical studies and initial beta-site series
  - » Post-launch data accrual - registry
- **Is it better than other alternatives ?**

Initial Clinical Series:

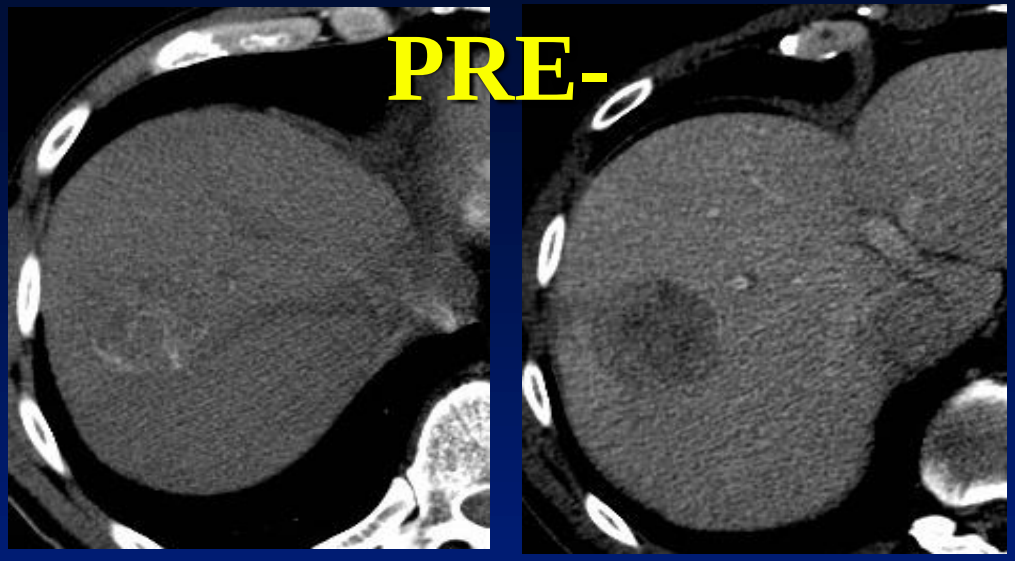
- ***Local control of focal hepatic malignancies treated with microwave ablation with a novel high-power applicator system: 108 ni ecneirepxe htnom-14patients***
  - » L. Solbiati et al.

- ***Thermal ablation of primary and secondary liver tumors using microwave energy: evaluation of technique effectiveness and complications in 54 patients***
  - » Meloni F, et al.

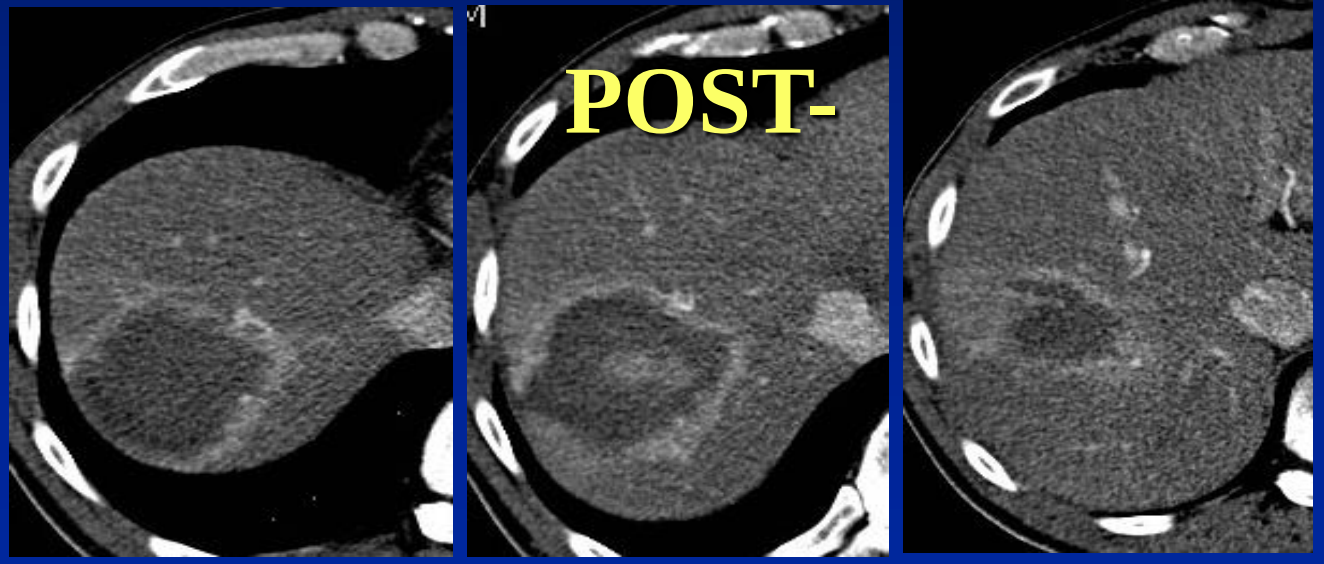
LARGE LESIONS (>3cm)

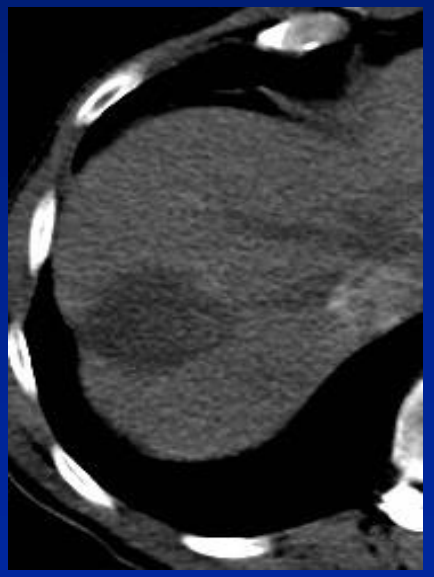
MW

B. A. HCC VIII cm 4.0



MW: 14G, 12 min, 80 W





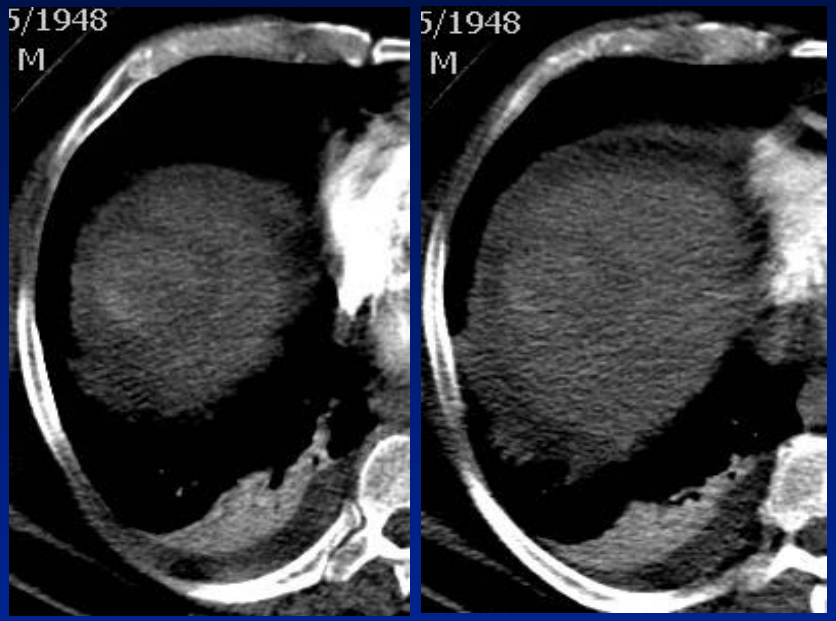
Necrosis : cm 6.6 x 5.1 x 4.9

7-month f/u

B.M. HCC IV-VIII cm 4.9

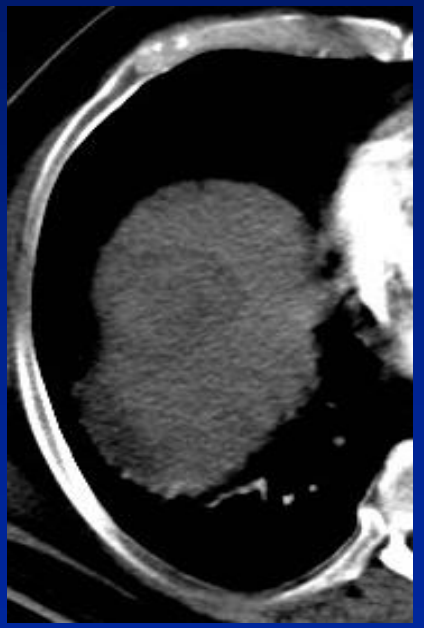
MW: 14G, 13 min, 60 W

PRE -



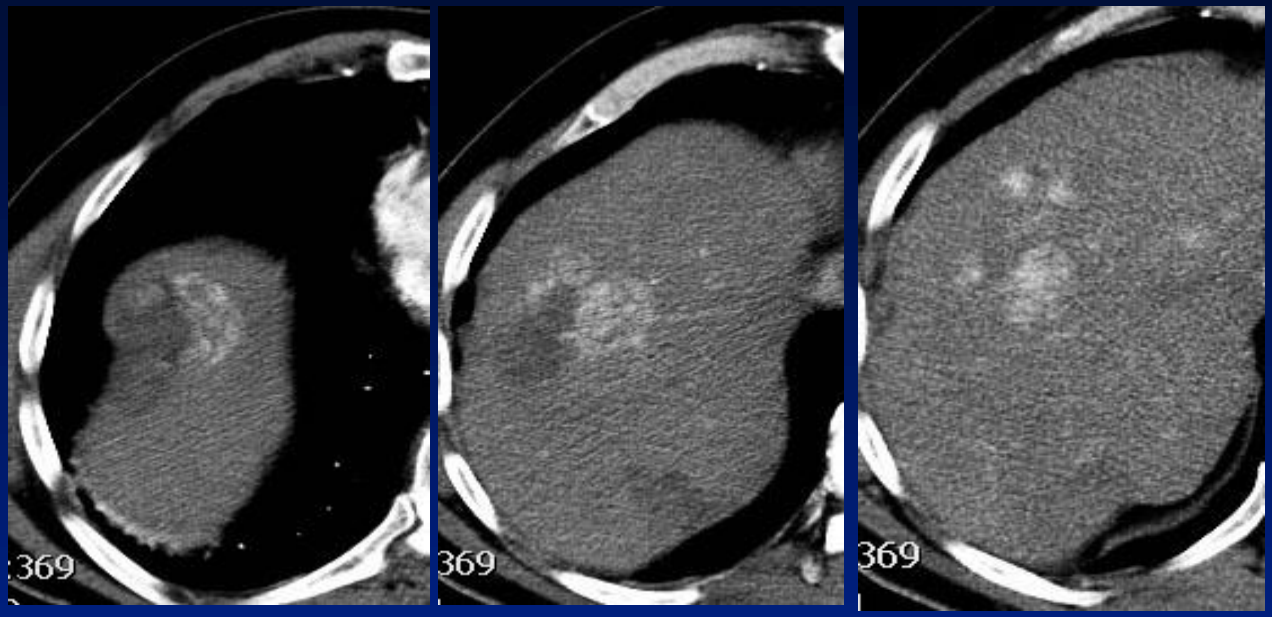
POST-

Necrosis : cm 5.4 x 5.1



8-month f/u

L.M. HCC 6 x 4.5 cm



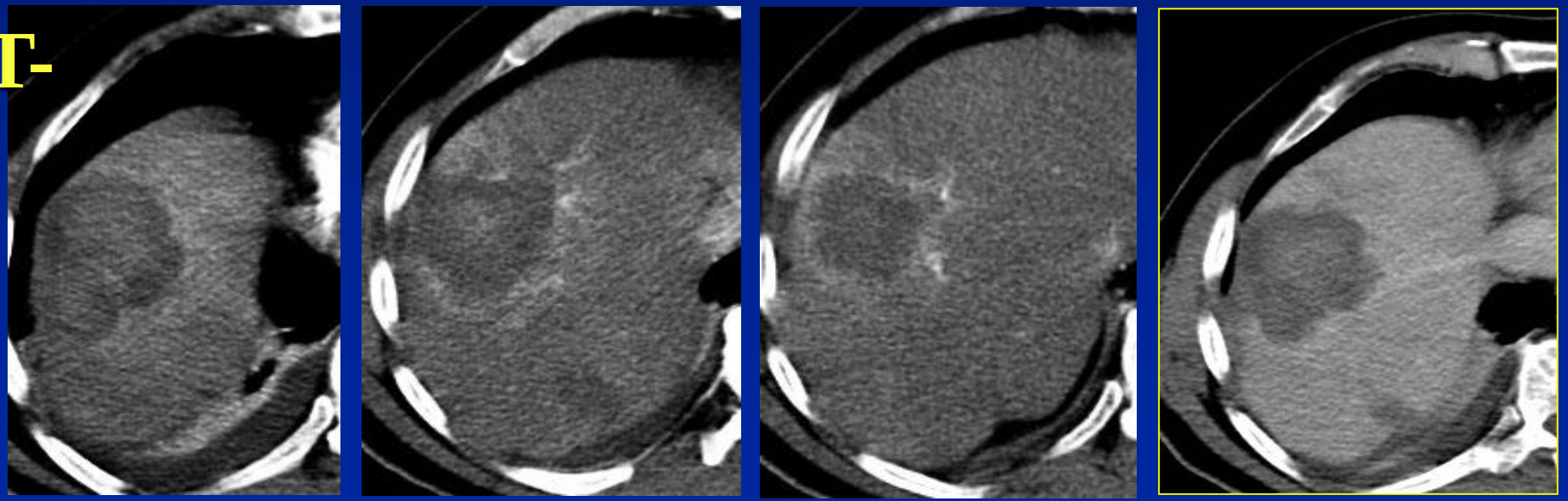
PRE-

2 antennas (3 cm spaced)

MW 14 G 10 min 50 W

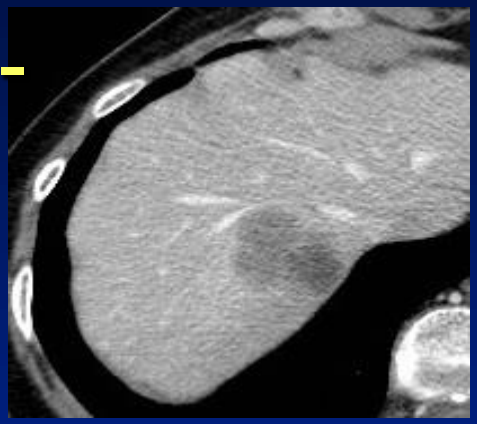
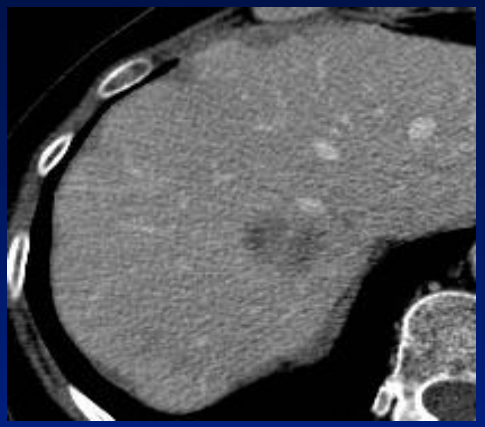
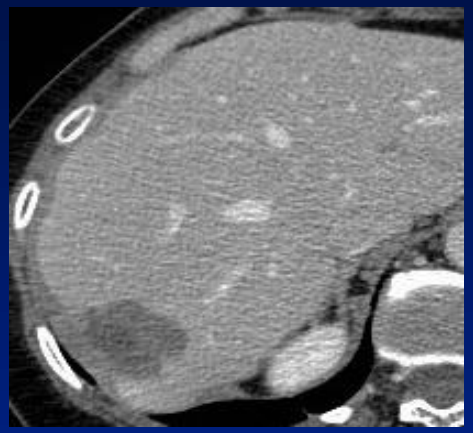
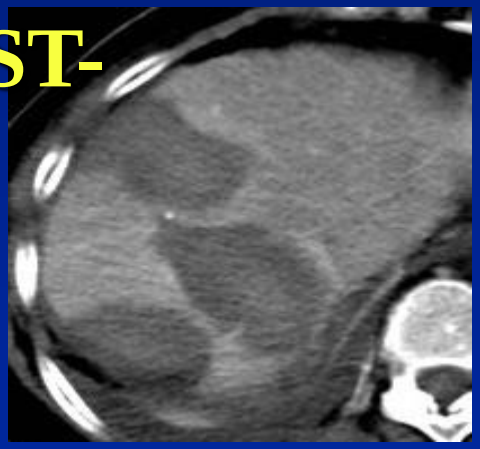
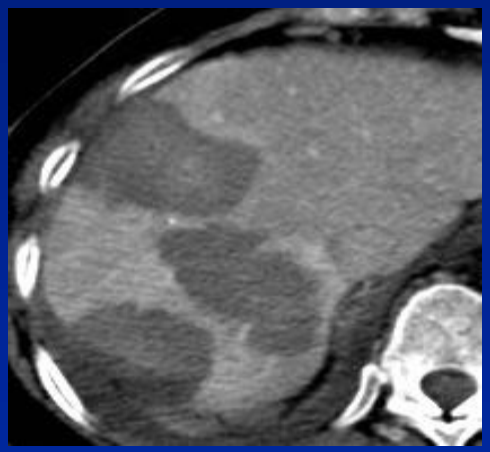
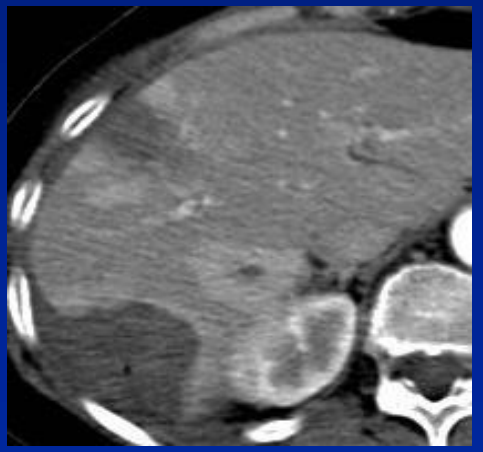
Necrosis: 7.1 x 5.5 x 5.3 cm

POST-



V. C. 3 metastases from colon CA

MW 14G

Met VIII 3.9 cm 60 W 11 min	Met VIII 1.4 cm 45 W 10 min	Met LTP VII 3.0 cm 45 W 9 min
PRE- 		
POST- 		
Necrosis: 5.3 x 4.3 cm	5.1 x 3.9 cm	4.6 x 3.5 cm

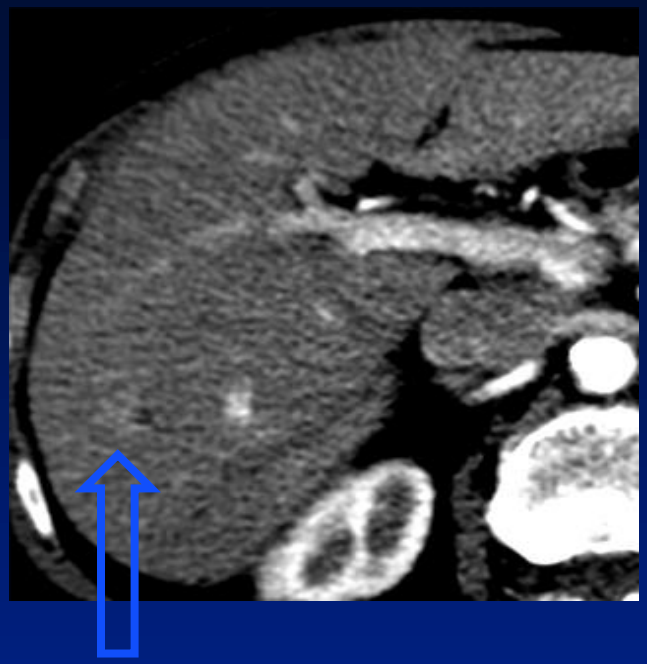
LESIONS ADJACENT to LARGE BLOOD VESSELS

MW

Pictures courtesy of Dr Luigi Solbiati,

Head of the Radiology Dept., Hospital of Busto Arsizio

T.C. HCC VII cm 2.1



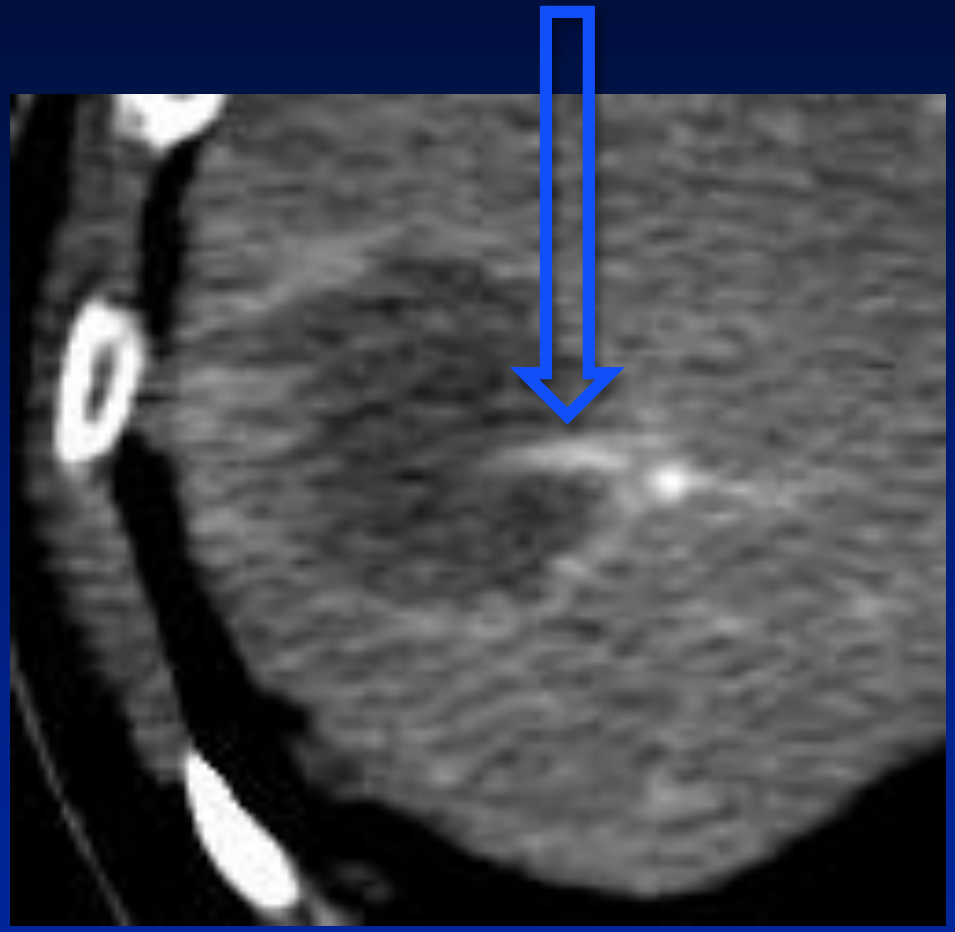
MW 14G

7 min, 50 W

PRE-

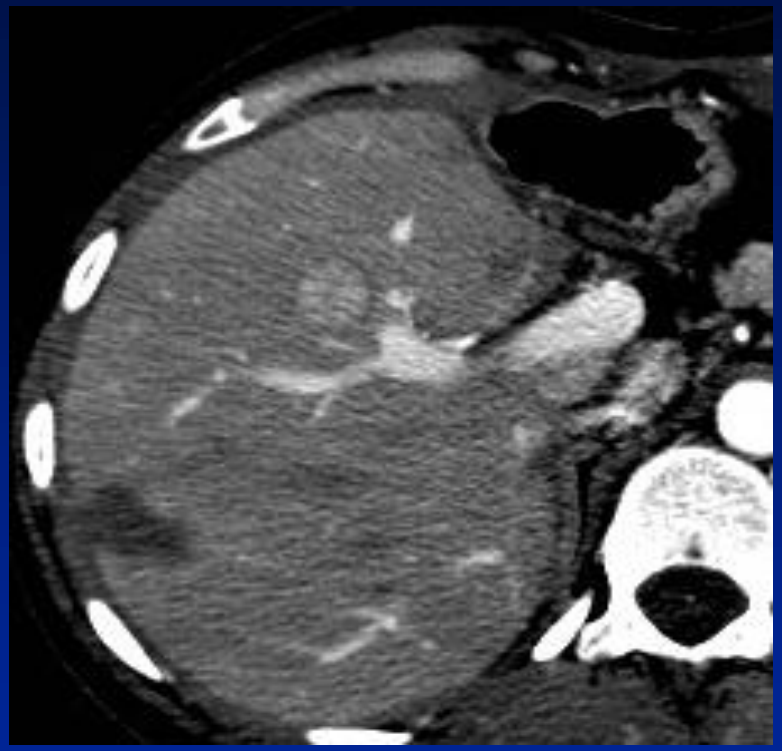
POST-

Necrosis : cm 4.6 x 4.0 x 4.2



R. M. HCC IV-VIII cm 1.6

MW 14G 4 min, 40 W



PRE-

POST-

Necrosis : cm 4.0 x 3.0 x 3.6

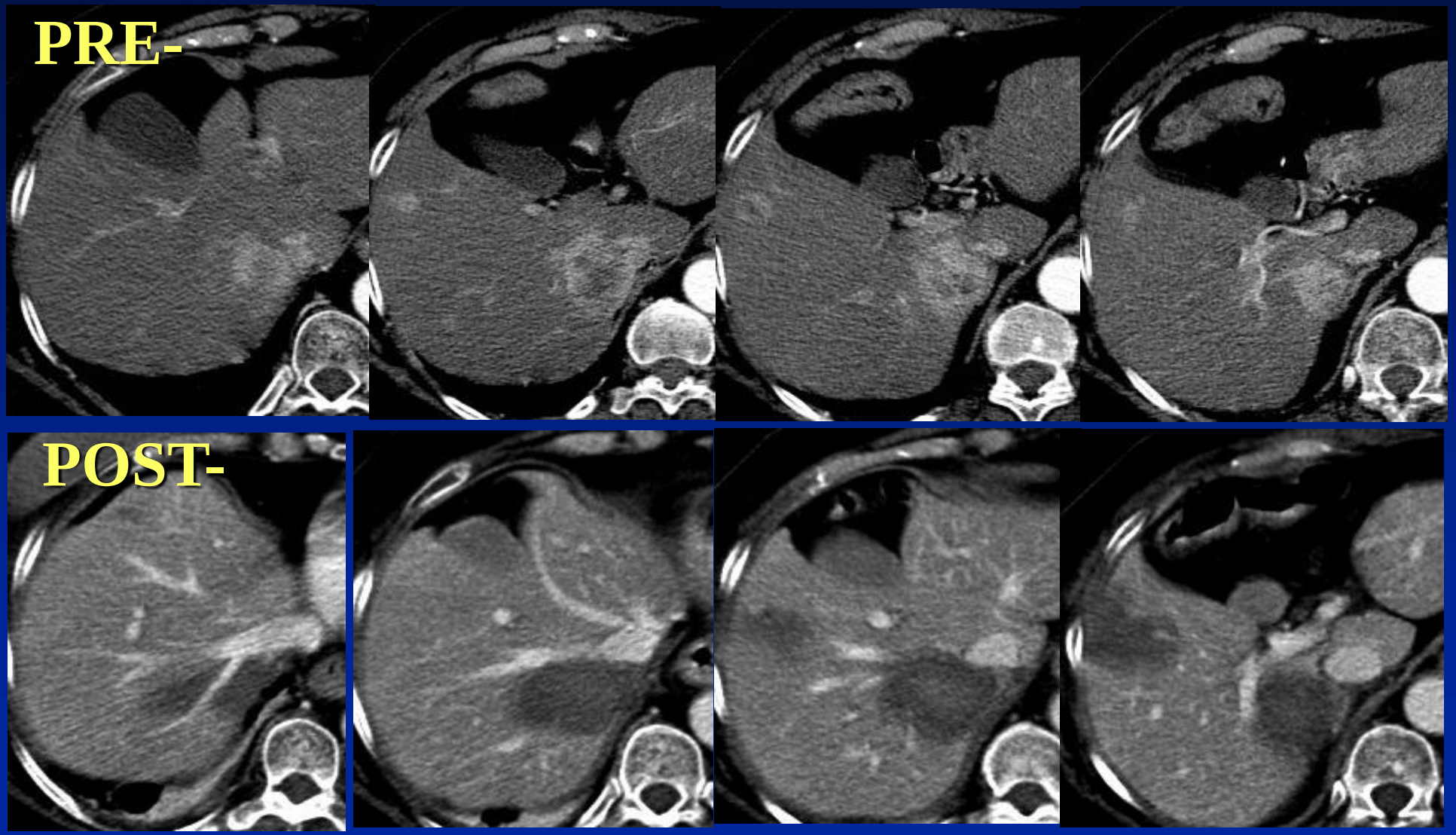
S. C.

14/07/2010

metastases from breast CA

VII cm 4.5 **MW 14G** 16 min (2) 60 W 4.7 x 3.4 cm

V cm 1.7 **MW 14G** 6 min 40 W 4.2 x 3.8 cm



New Ablation Device: Key ??

- **What can it do ?**
- **Is it safe ?**
- ***Is it better than other alternatives ?***

New Ablation Device: Key ??

- *Is it better than other alternatives ?*

“If you ain’t the first kid on the block, they’ll hold you to higher standards.”

Philosopher Eric von Sonnenberg

Tumor Ablation Registry:

- **Pooling of data**
  - Efficacy in different organ systems
  - Assessment of complications
  - Differences in technique
- **Identifying areas requiring / providing fertile further research**
- **Helping design pivotal randomized trials**
  - Best parameters / technique
  - Most likely to succeed patient populations
- **Caveat - asking the right questions**

Ablation Evaluation: Doing It Right

- **Systematic, tissue specific optimization:**
  - Ex-vivo tissues ⇒ In-vivo animal studies ⇒ clinical validation
- **Demonstration of safety**
  - Animal studies ⇒ Registry
- **Application specific clinical validation**
  - Registry ⇒ Comparative clinical trials

HS AMICA: making a long story short…

•**2001**: Mini-choke patent deposited by CNR
•**2003**: Mini-choke patent exclusively licensed to HS.
•**2004**: First prototypes of mini-choked, internally cooled MWA probes realized by HS.
• **2005**: First prototype of a solid state, programmable 2450MHz/100W generator for clinical use realized by HS
• **2006**: HS AMICA receives CE approval. Available probes: 14G and 17G, mini-choke+internal cooling, ***open-ended*** structure
• **2007/2008**: First clinical trial on BPH patients. Probe re-engineering: moving to a ***closed-point*** structure
• **2009:** HS AMICA receives FDA approval. Early clinical experience in liver, lung, kidney and bone ablation

2013:

Over 10,000 procedures performed worldwide with HS AMICA (percutaneous, laparoscopic, intra-surgical).
Almost 300 HS AMICA systems installed in more than 20 countries in Europe, Middle East

and America

AMICA-PROBE: technical validation

1) I.Longo, G. Biffi Gentili, M.Cerretelli, N.Tosoratti; "*A Coaxial Antenna With Miniaturized Choke for Minimally Invasive Interstitial Heating*", IEEE Trans. on Biomed. Eng., 50 82 (2003)

2) M. Cavagnaro, C. Amabile , P. Bernardi, S. Pisa, N. Tosoratti; "*Design and Realization of a New Type of Interstitial Antenna for Ablation Therapies*", Proceedings of the 39th European Microwave Conference (2009)

3) M. Cavagnaro, C. Amabile , P. Bernardi, S. Pisa, N. Tosoratti; "*A Minimally Invasive Antenna for Microwave Ablation Therapies: Design, Performances, and Experimental Assessment*", IEEE Trans. on Biomed. Eng. 58 949 (2011)

4) V. Lopresto, R. Pinto, G. A. Lovisolo, M. Cavagnaro; "*Changes in the dielectric properties of ex vivo bovine liver during microwave thermal ablation at 2.45 GHz*", Phys. Med. Biol. **57** 2309 (2012)

AMICA-PROBE: pre-clinical validation

1) Bartoletti, T.Cai, N.Tosoratti, C.Amabile, A.Crisci, G.Tinacci, N.Mondaini, P.Gontero, S.Gelsomino, G.Nesi; “In vivo microwave-induced porcine kidney thermoablation: results and perspectives from a pilot study of a new probe”, BJU Int., 106 1825 (2010)

2) F.Meloni, A.Andreano,G.Bovo, B.Chiarpotto,C. Amabile, S.Gelsomino, S.Lazzaroni, S.Sironi; “Acute Portal Venous Injury After Microwave Ablation in an In Vivo Porcine Model: A Rare Possible Complication”, J Vasc Interv Radiol, 22 947 (2011)

3) O. Planche, C. Teriitehau, S. Boudabous, J. M. Robinson, P. Rao, F. Deschamps, G. Farouil, T. de Baere; “In Vivo Evaluation of Lung Microwave Ablation in a Porcine Tumor Mimic Model”, Cardiovasc. Intervent. Radiol., 2013 Feb; 36(1):221-8.

4) R Hoffmann, H Rempp, L Erhard, G Blumenstock, PL Pereira, CD Claussen, S Clasen; “Comparison of Four Microwave Ablation Devices: An Experimental Study in ex Vivo Bovine Liver”, Radiology 121127; published online February 25, 2013

AMICA-PROBE: clinical validation

1) R.Bartoletti, T.Cai, G.Tinacci, I.Longo, A.Ricci, M.P.Massaro, N.Tosoratti, E.Zini, N.Pinzi; “Transperineal Microwave Thermoablation in Patients with Obstructive Benign Prostatic Hyperplasia: A Phase I Clinical Study with a New Mini-Choked Microwave Applicator”, J of Endourol. 22 1509 (2008)

2) G. Zanus, R. Boetto, E. Gringeri, A. Vitale, F. D’Amico, A. Carraro, D. Bassi, P. Bonsignore, G. Noaro, C. Mescoli, M. Rugge, P. Angeli, M. Senzolo, P. Burra, P. Feltracco, and U. Cillo; “Microwave Thermal Ablation for Hepatocarcinoma: Six Liver Transplantation Cases”, Transplantation Proceedings, 43 1091 (2011)

3) O. M. Hetta, N. H. Shebrya, S. K. Amin; “Ultrasound-guided microwave ablation of hepatocellular carcinoma: Initial institutional experience”, The Egyptian Journal of Radiology and Nuclear Medicine, 42 343 (2011)

4) T.Livraghi, F.Meloni, L.Solbiati, Giorgio Zanus; “Complications of Microwave Ablation for Liver Tumors: Results of a Multicenter Study”, Cardiovasc. Intervent. Radiol., 35 868 (2012)

5) R Bartoletti, E Meliani, A Simonato, P Gontero, G Berta, P Dalla Palma, E Leonardi, T Cai, G Carmignani. “Microwave-induced thermoablation with Amica-probe is a safe and reproducible method to treat solid renal masses: results from a phase I study”. Oncol Rep. 2012 Oct; 28(4):1243-8

6) G Poggi, B Montagna, P Di Cesare, G Riva, G Bernardo, M Mazzucco, A Riccardi. “Microwave Ablation of Hepatocellular Carcinoma Using a New Percutaneous Device: Preliminary Results”. Anticancer Res. 2013 Mar;33(3):1221-1227