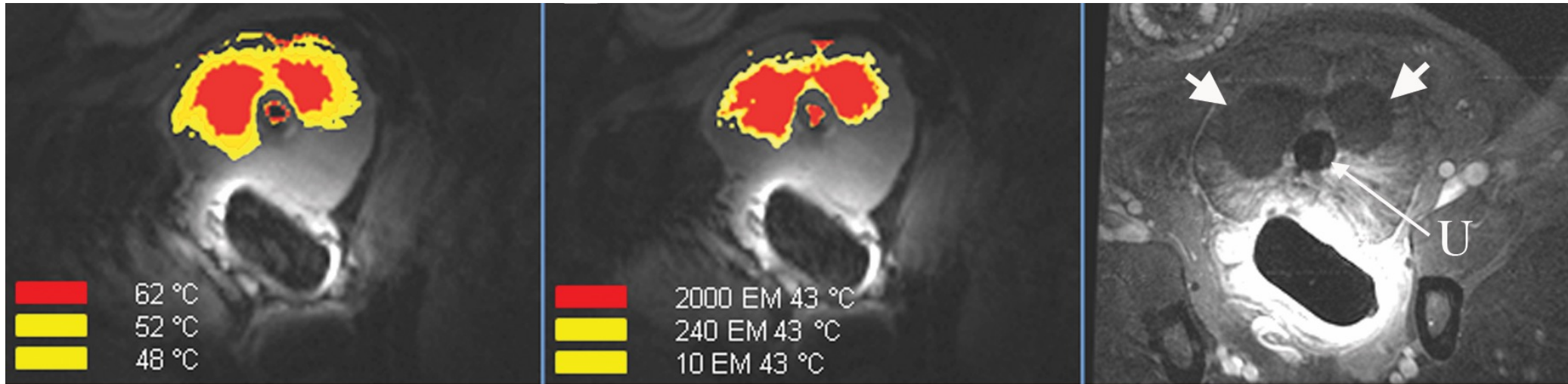


Physics of Ultrasound Thermal Therapy



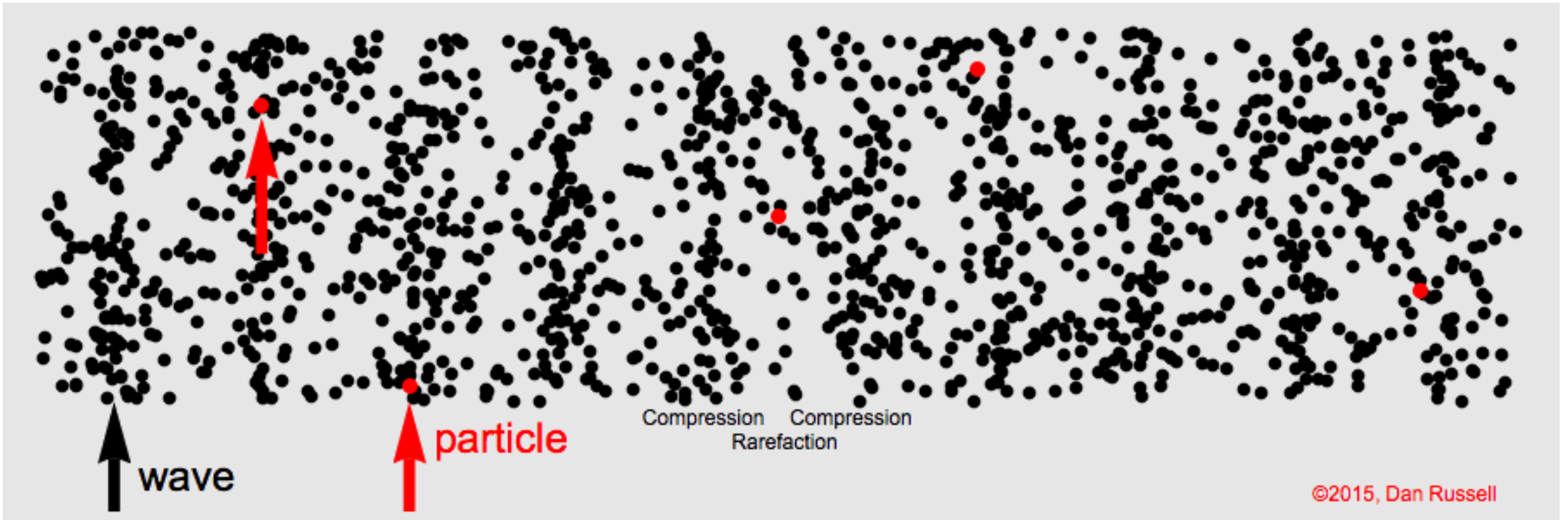
Punit Prakash

Dept. of Electrical and Computer Engineering

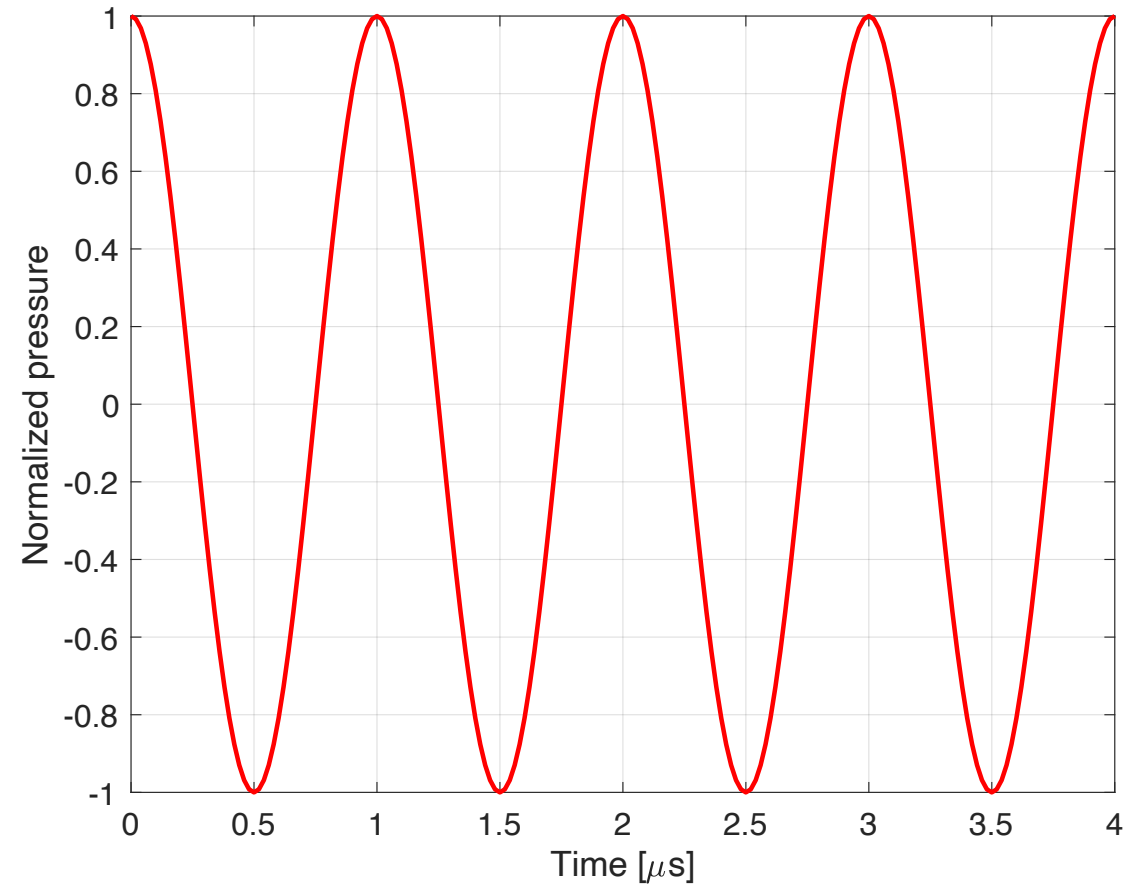
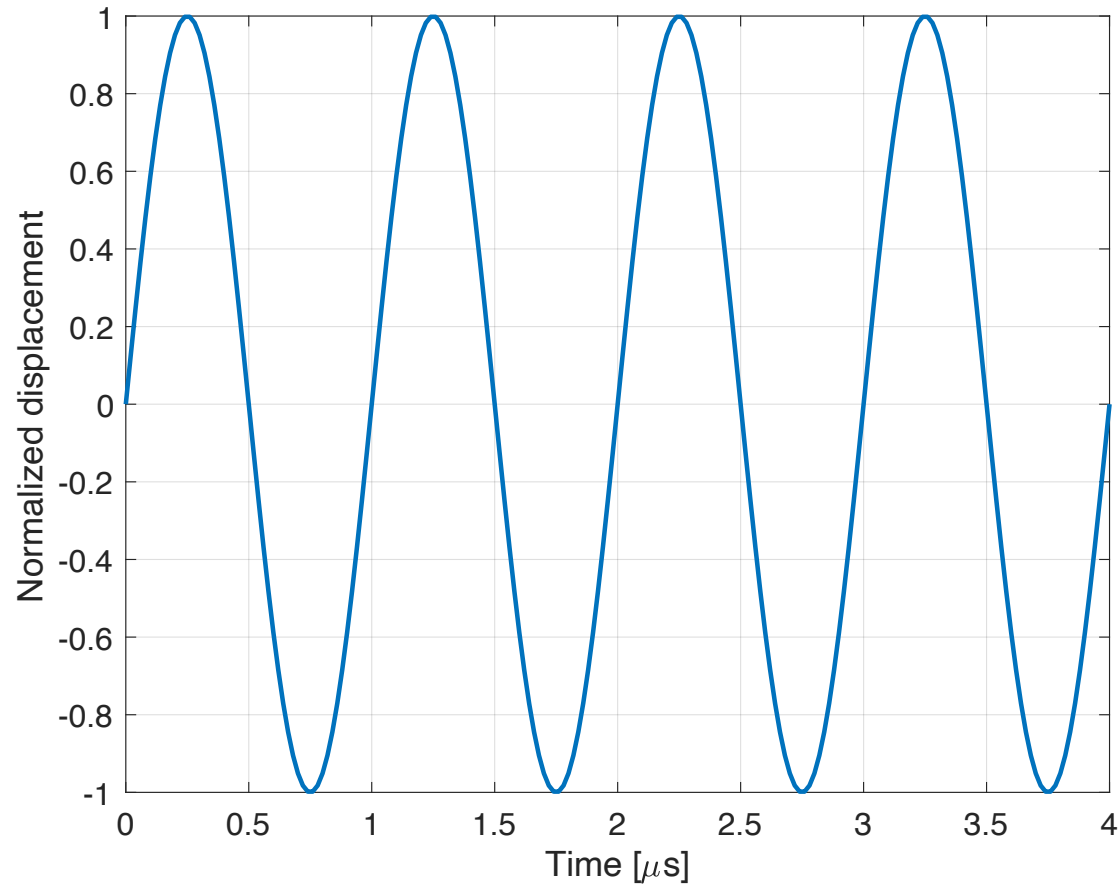
Kansas State University

prakashp@ksu.edu

Particle displacement and wave propagation



Particle displacement, velocity, and pressure



Speed of sound

Pressure

Particle velocity

Density

$$p = \rho cv$$

Acoustic properties of tissue

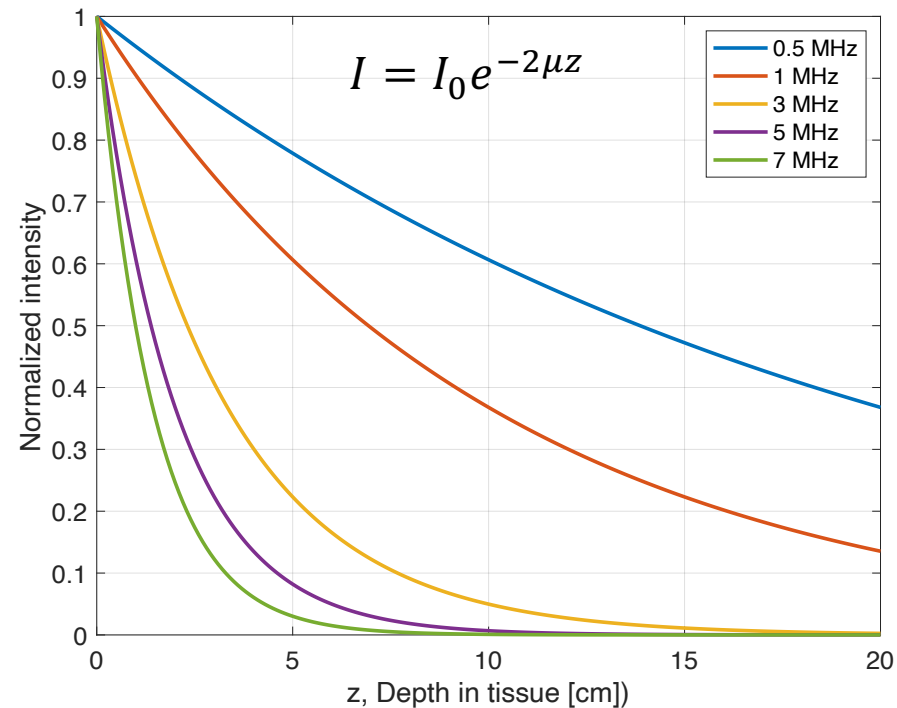
Selected tissues	Attenuation coefficient [Np m ⁻¹ MHz]	Penetration depth @ 1 MHz [cm]	Wavelength @ 1 MHz [mm]	Speed of sound [m/s]	Density [kg/m ³]	Acoustic impedance [M Rayl]
Liver	6.9	14.5	1.6	1586	1079	1.71
Muscle	7.1	14.1	1.6	1588	1090	1.73
Cortical bone	54.5	1.8	3.5	3515	1908	6.71

Time-averaged power absorption:

$$q = 2\alpha I$$



Absorption coefficient
(~attenuation coefficient)



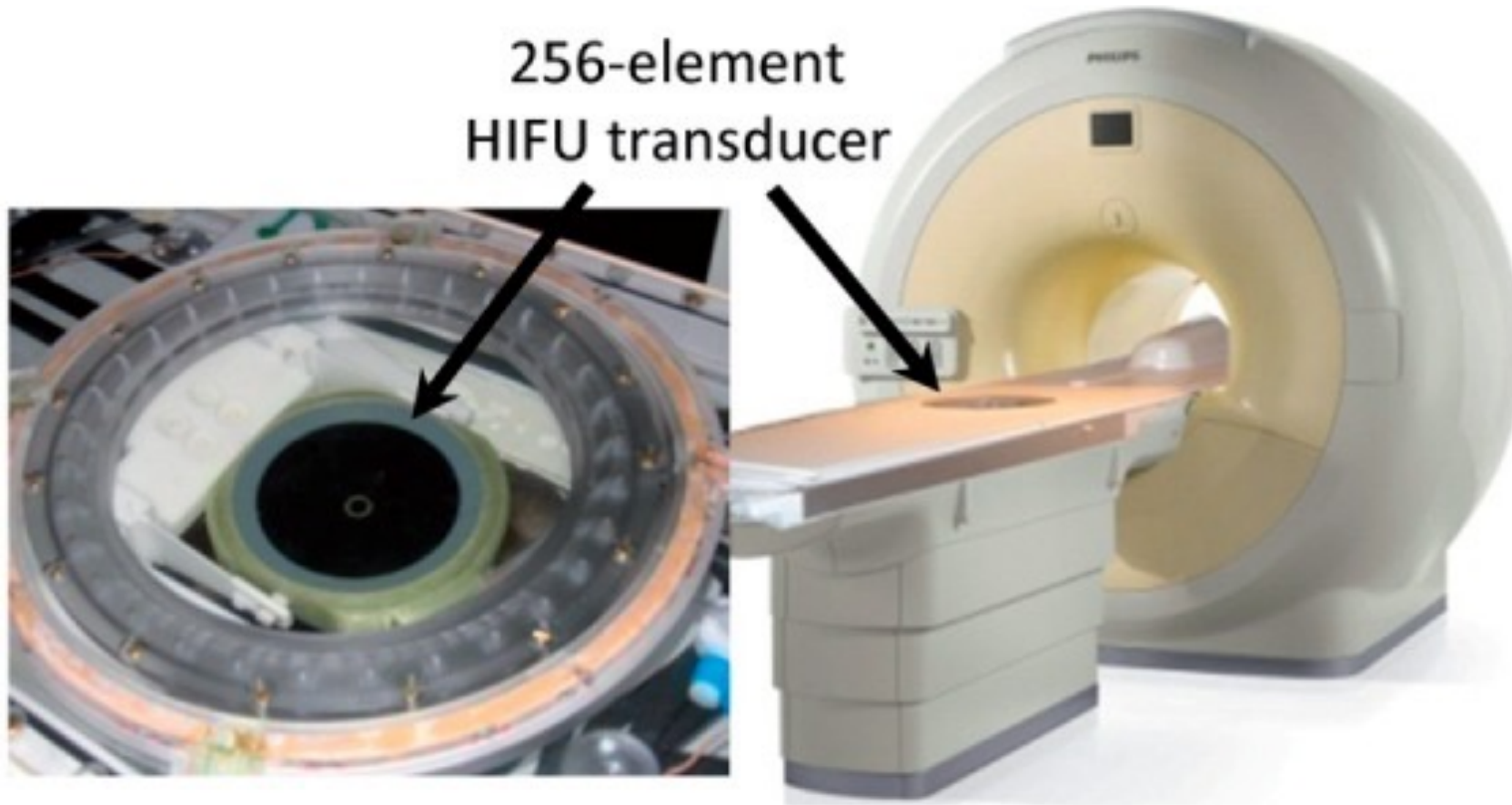
Acoustic intensity:

$$I \propto p^2$$

Reflection at interfaces:

$$\Gamma = \frac{Z_2 - Z_1}{Z_2 + Z_1}$$

Ultrasound thermal therapy systems



From: Wiljemans et al, *Cancer Imaging*, 12(2), 2012

- 1-1.5 MHz operating frequency for most non-invasive ultrasound thermal therapy systems
 - Deep penetration in to issue & short wavelengths for small focal spots
 - Considerably separated in frequency from 1.5 T (64 MHz) and 3 T (128 MHz) MRI scanners

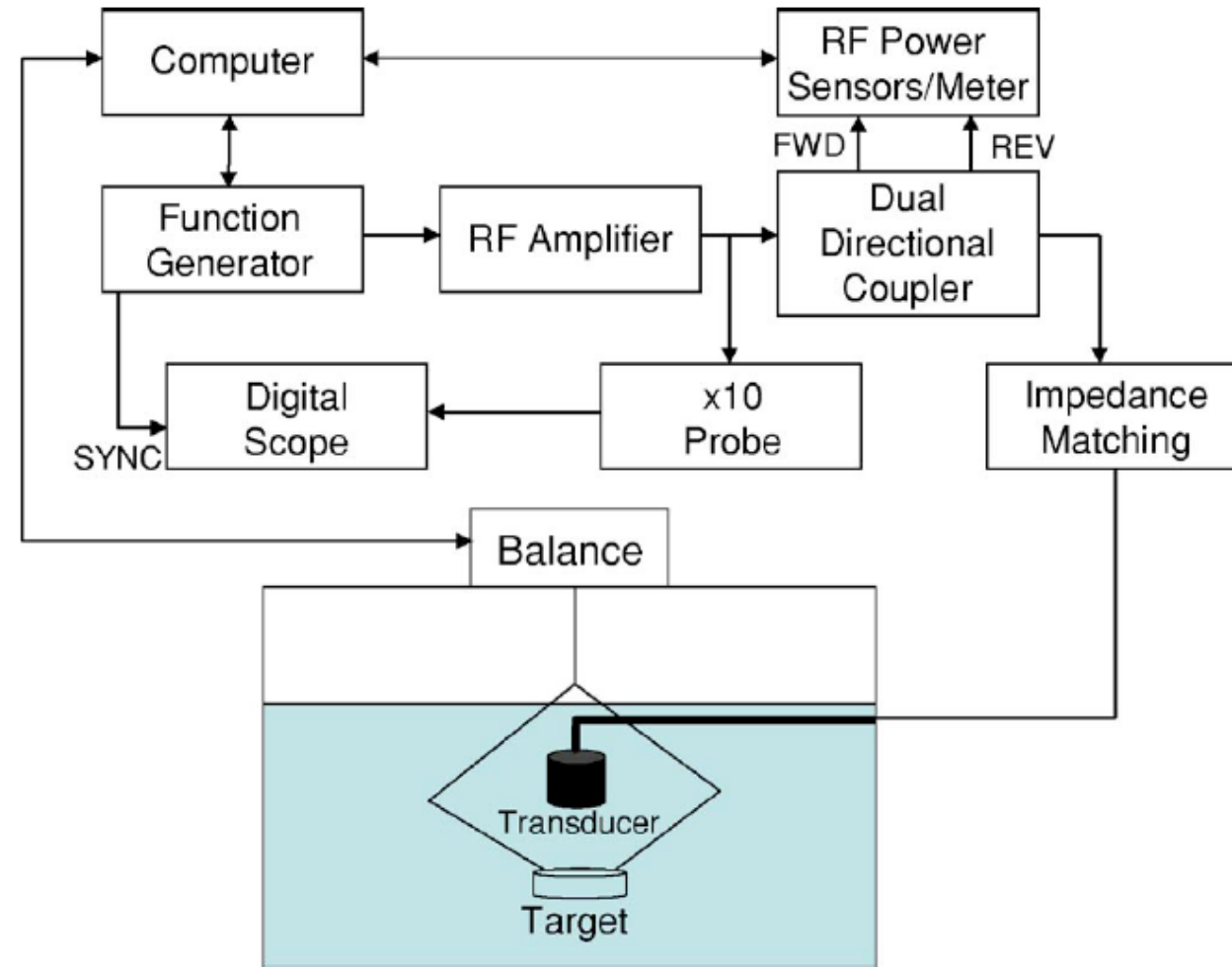
Electro-acoustic efficiency assessment

Time-averaged power:

$$P_{TA} = cF$$

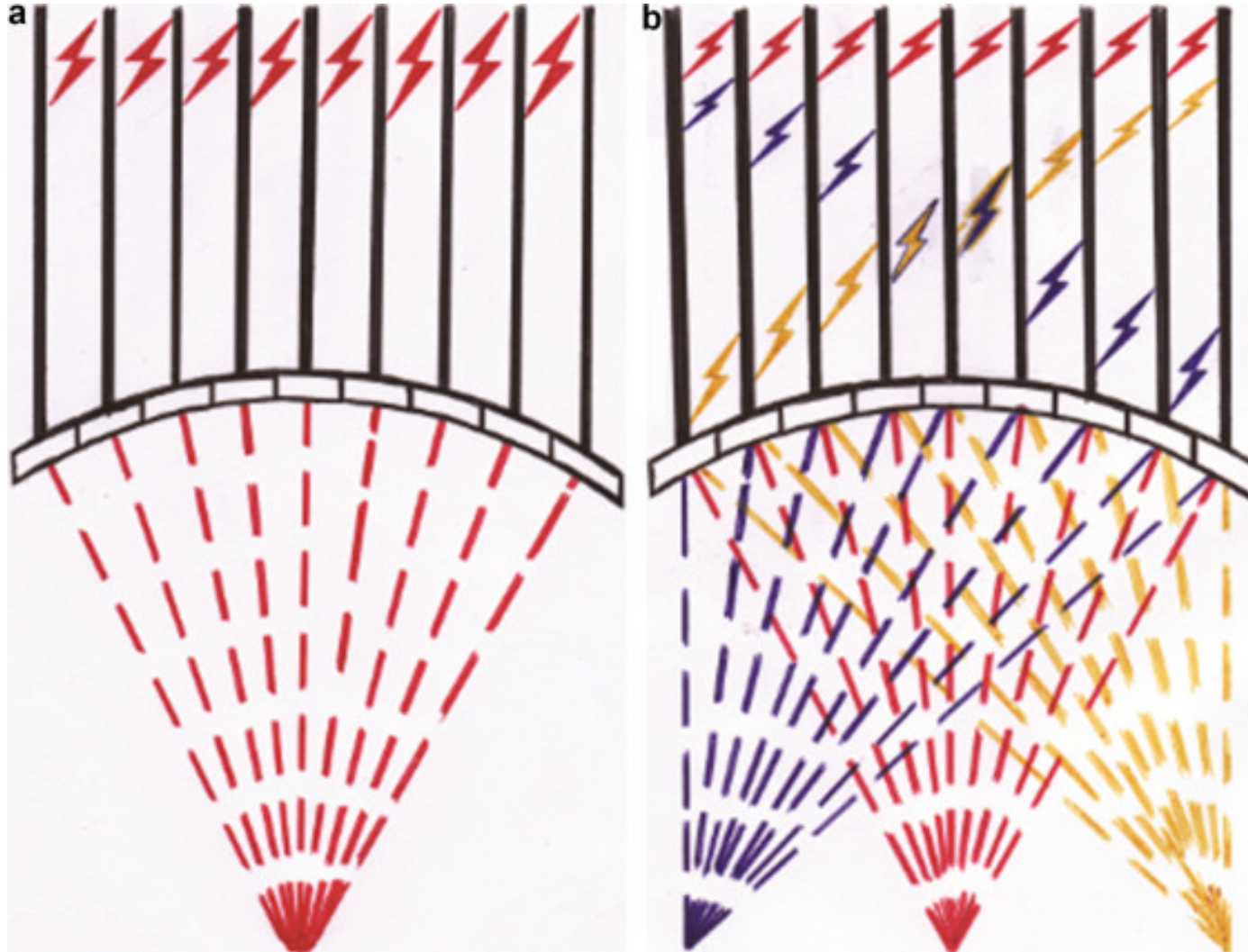
Speed of
sound

Radiation force

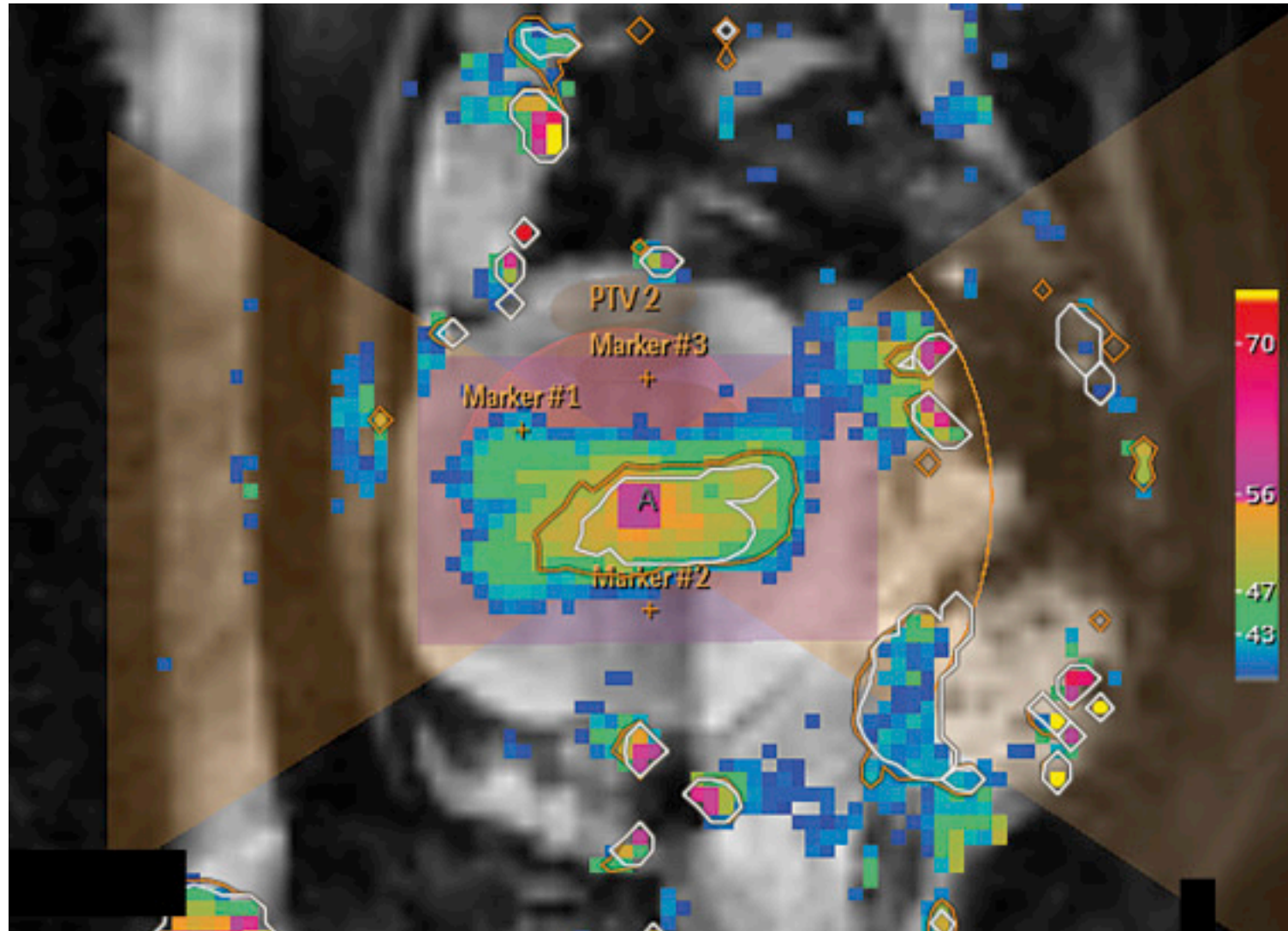


From: Maruvada et al, *J Acoust Soc Am*, 121(3), 2007

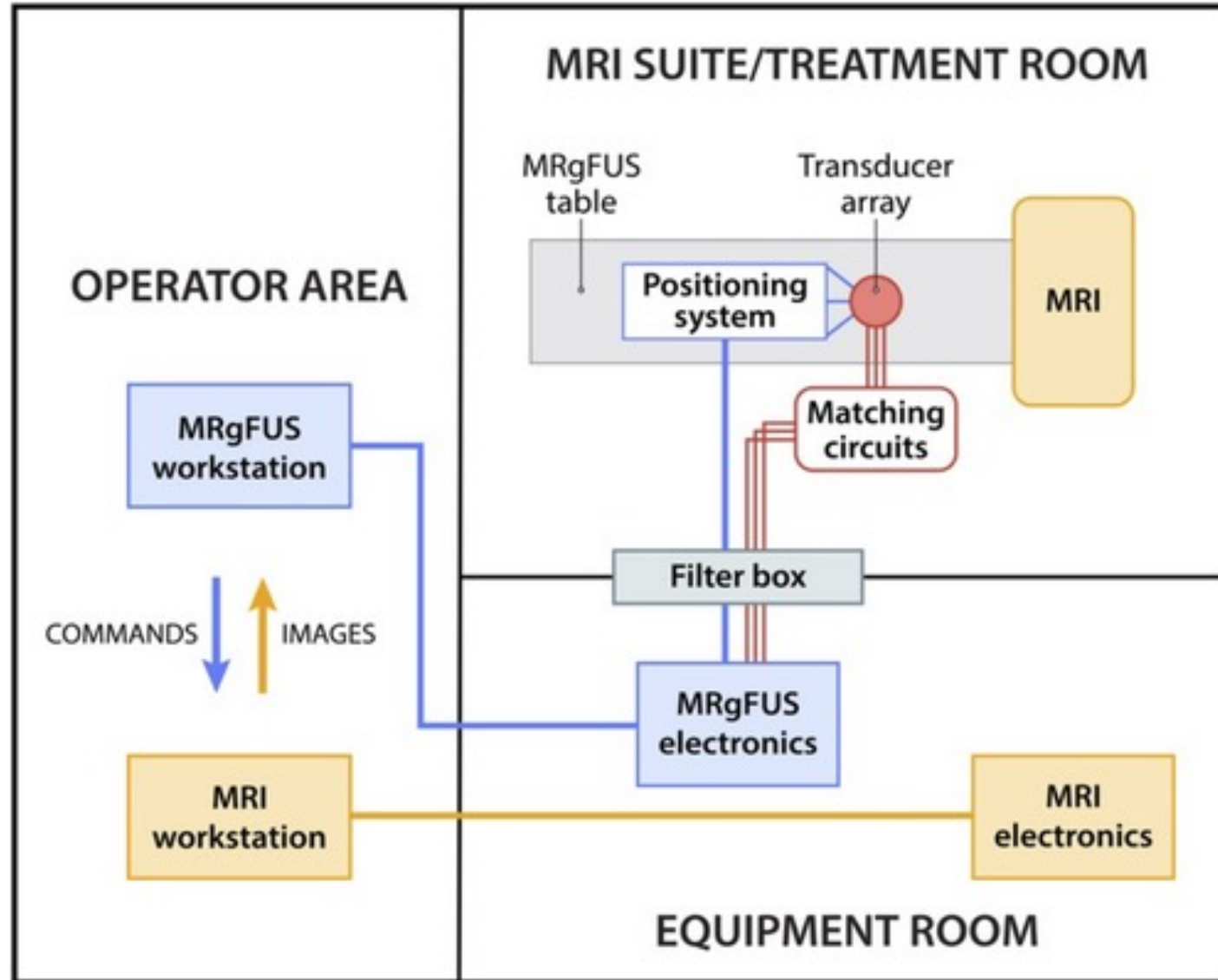
Electronic beam steering with phased array transducers



Integration with MRI thermometry



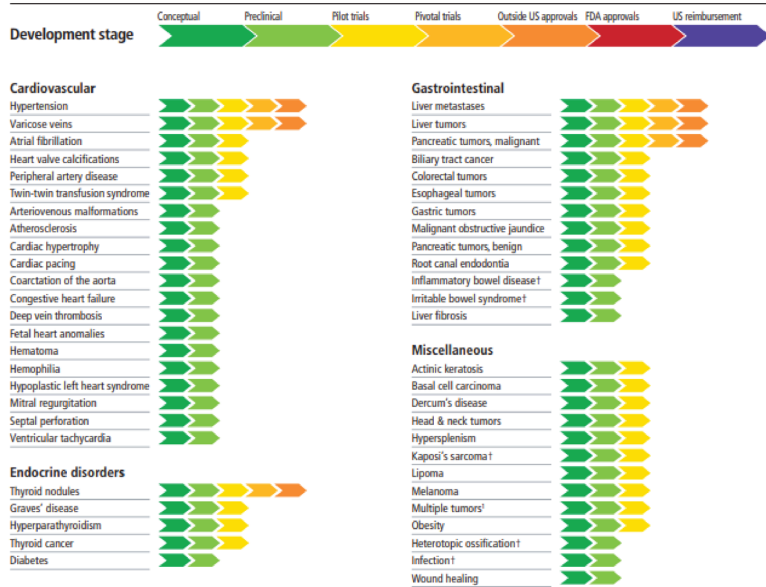
Treatment room setup for MRgFUS system



Treatment sites under investigation for ultrasound based therapy

FIELD OVERVIEW

State of Research and Regulatory Approvals by Body System



There are 152 distinct indications for 2020.

1 Protocols inclusive of more than one indication

† New in 2020

FIELD OVERVIEW

State of Research and Regulatory Approvals by Body System continued



There are 152 distinct indications for 2020.

2 Multiple myeloma approval is based on bone metastases.

3 Treatment of the underlying cause of the disease

† New in 2020

FIELD OVERVIEW

State of Research and Regulatory Approvals by Body System continued



There are 152 distinct indications for 2020.

4 FDA approval is for prostate tissue ablation.

5 Reimbursement is for salvage therapy in radiorecurrent prostate cancer.

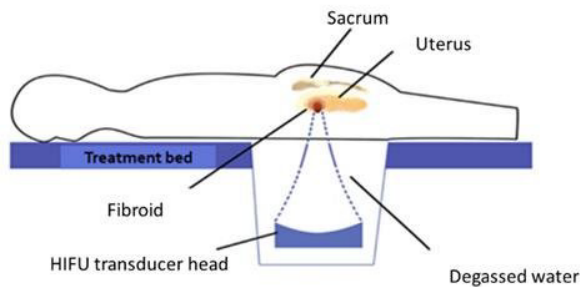
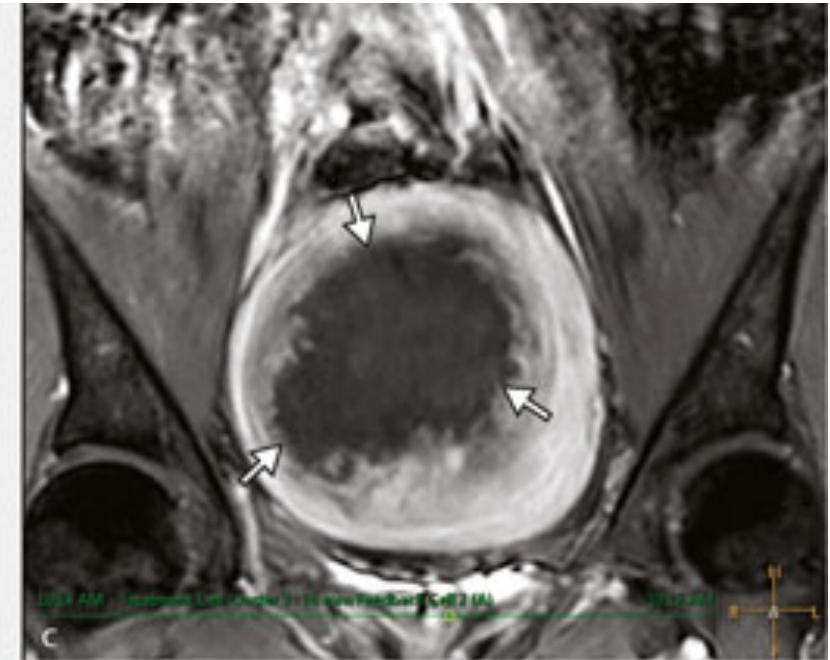
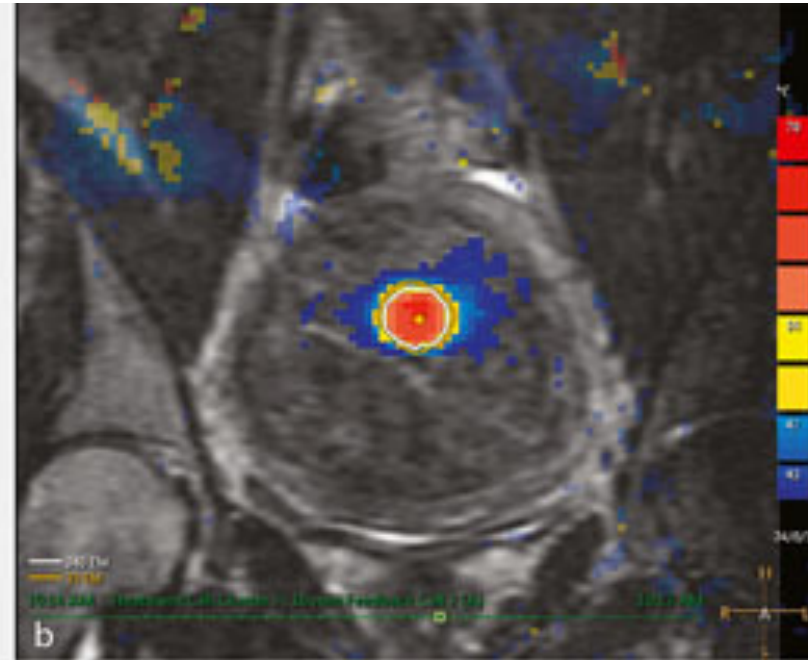
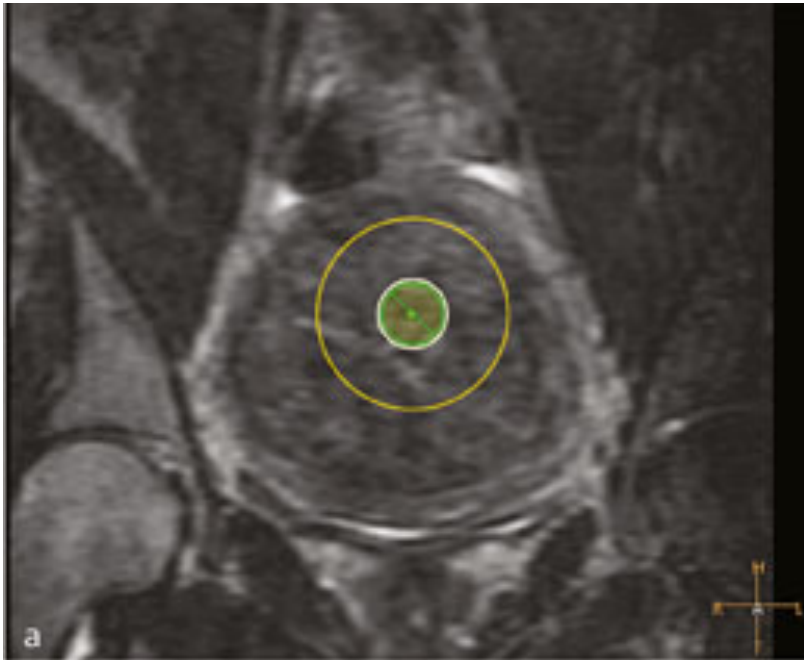
† New in 2020

Focused ultrasound ablation: uterine fibroids

MR-imaging based pre-treatment planning

Real-time MR thermometry feedback to monitor ablation progress

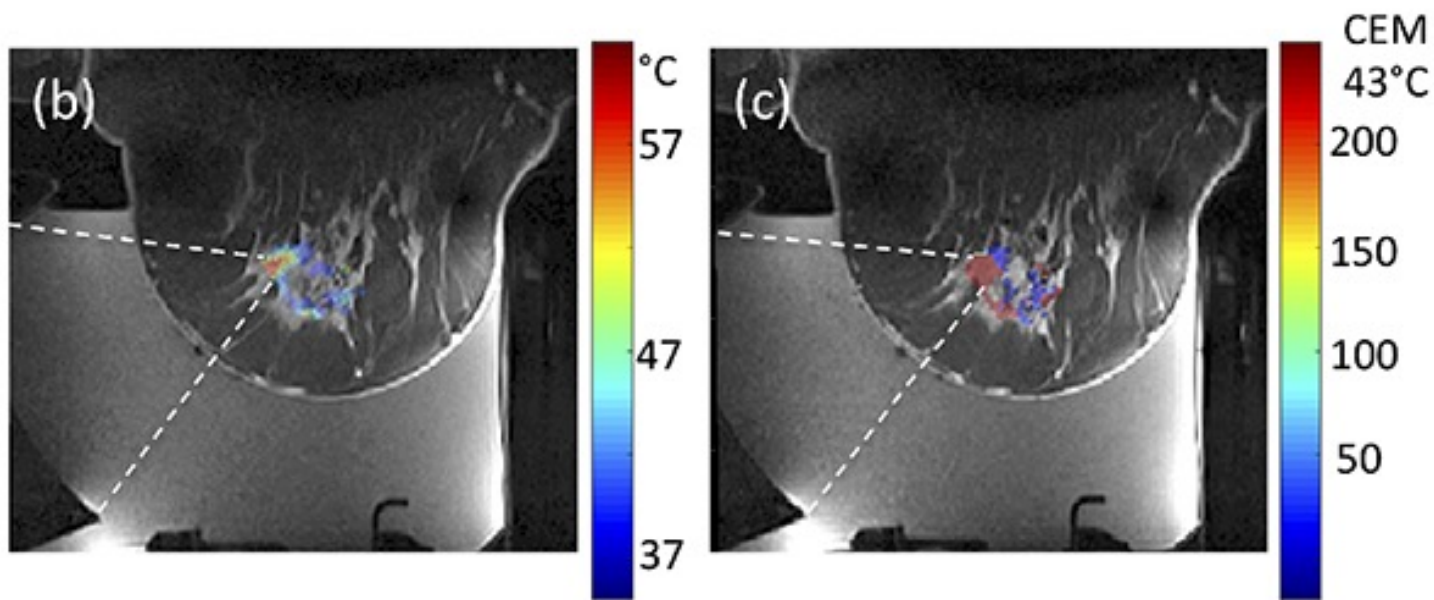
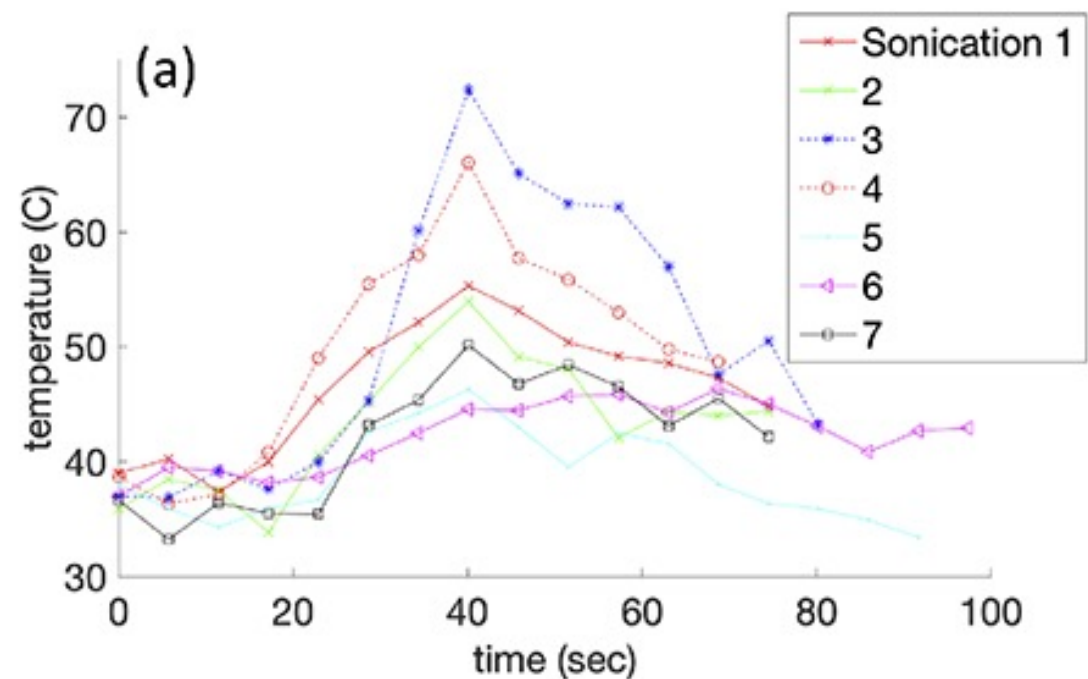
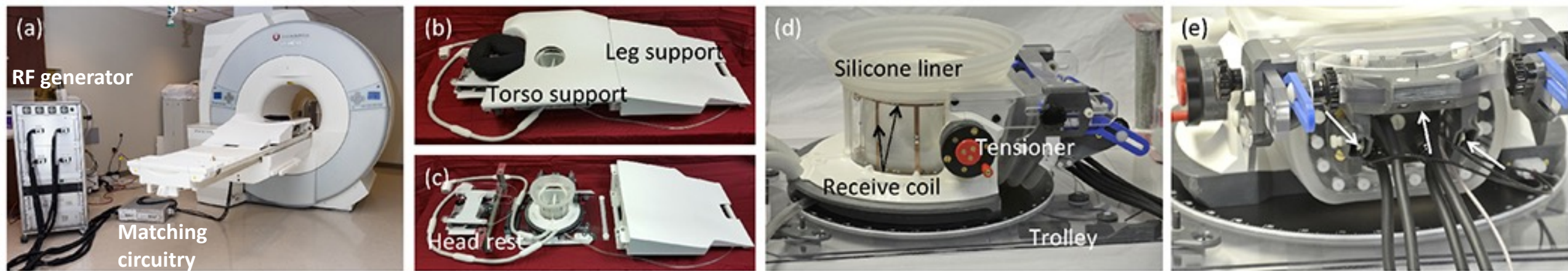
Non-perfused volume (NPV) provides a means for assessing ablation effect



From: Wong, *WJARR*, 2021

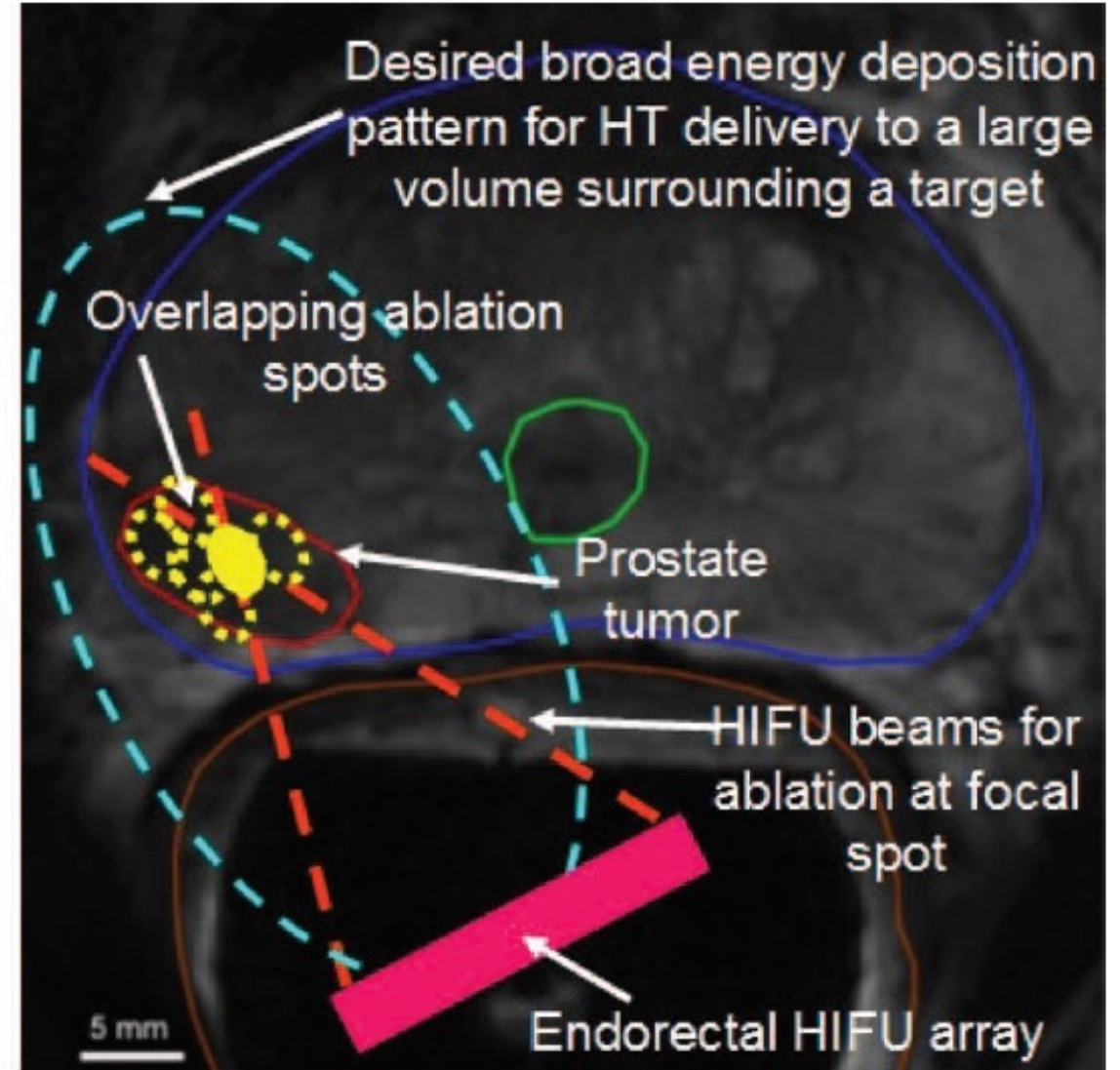
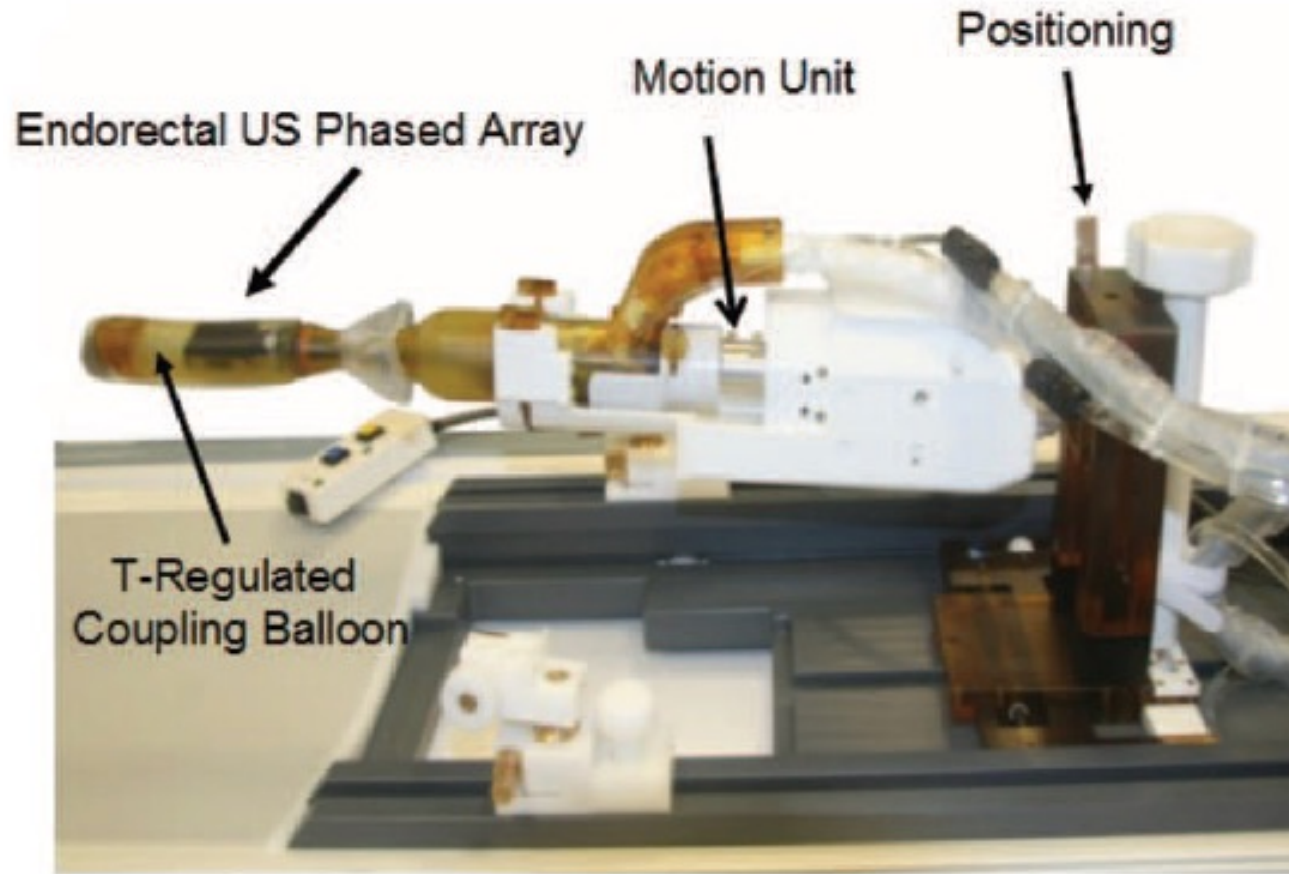
From: Siedek et al, *Rofo*, 191(6), 2019

MRgHIFU system for breast ablation



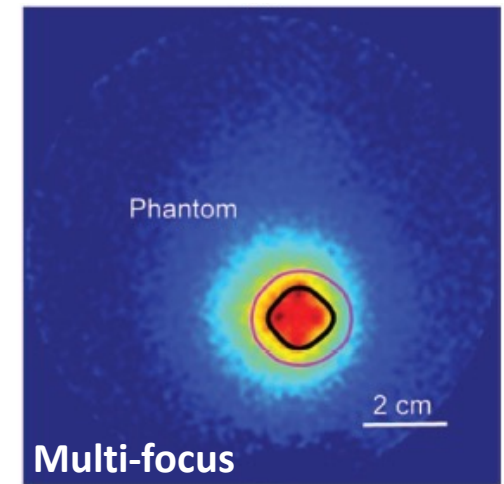
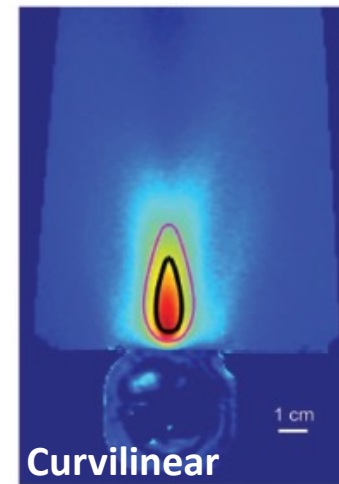
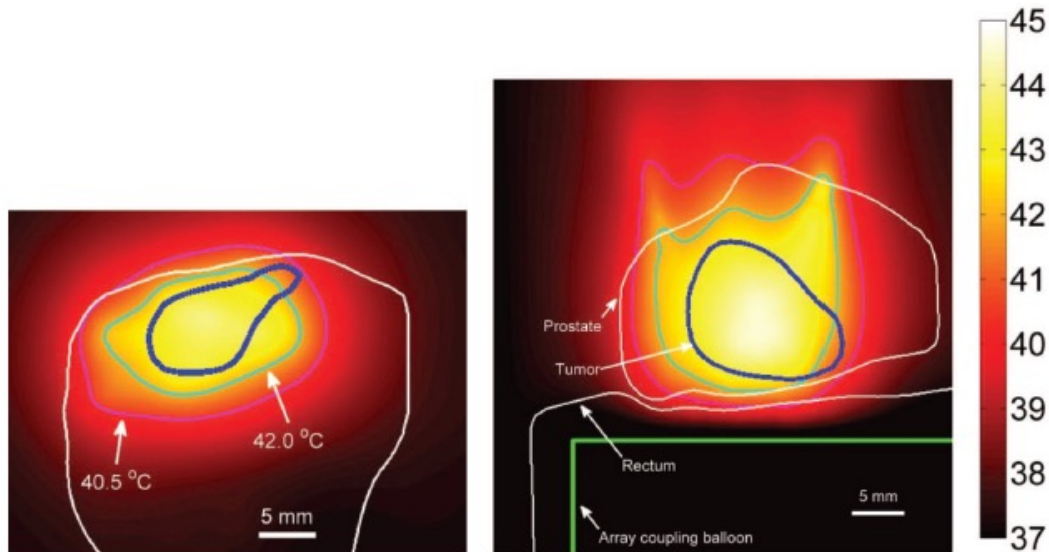
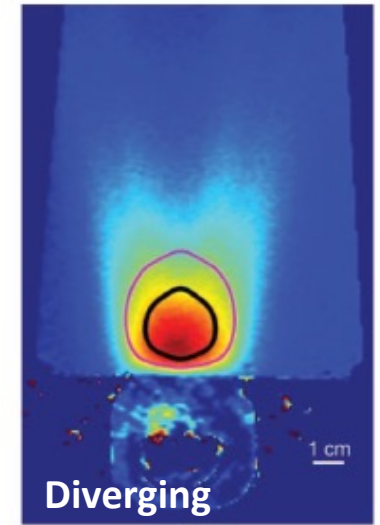
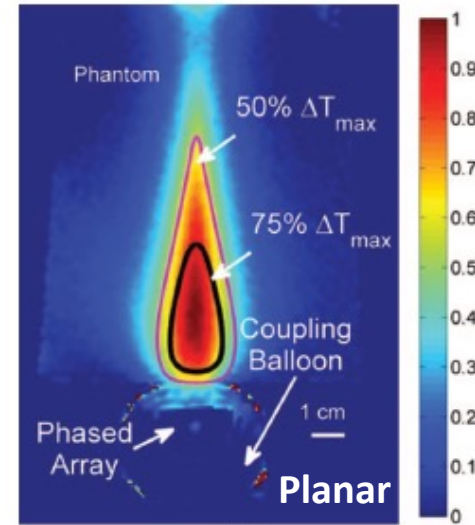
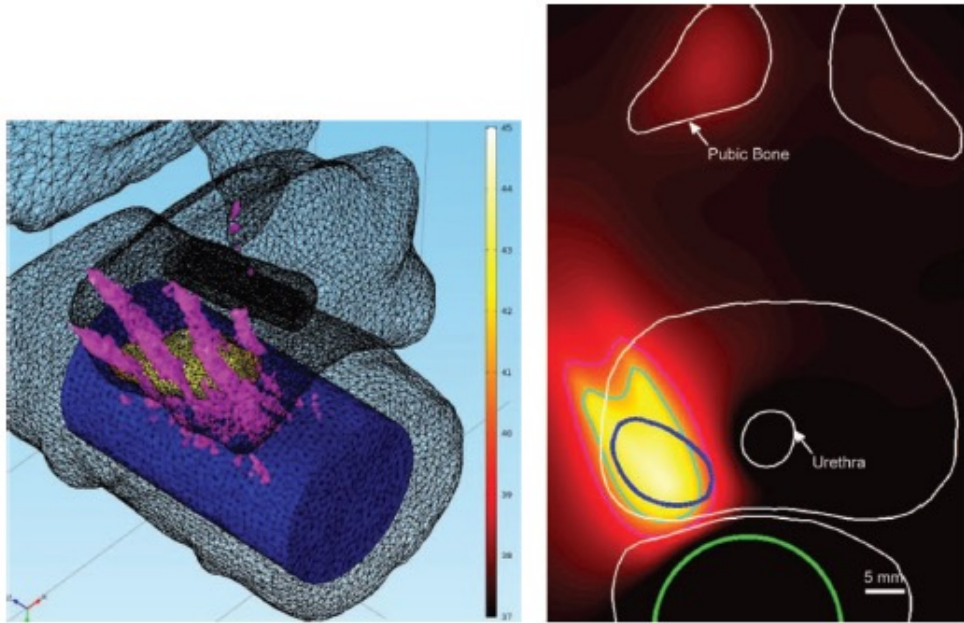
Adapting HIFU ablation systems for large volume hyperthermia

2.3 MHz endorectal ultrasound applicator



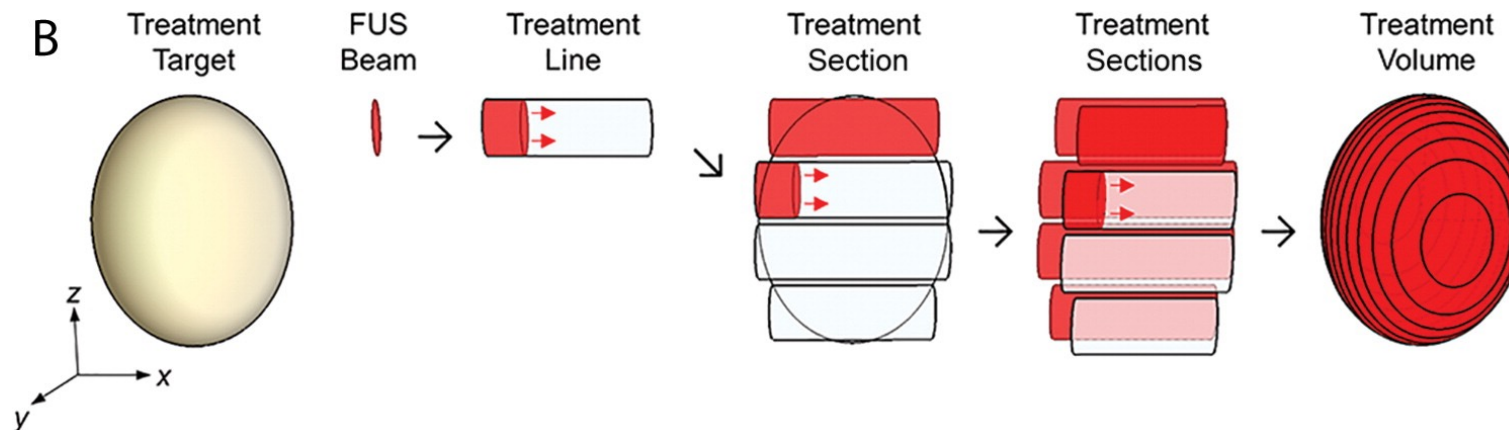
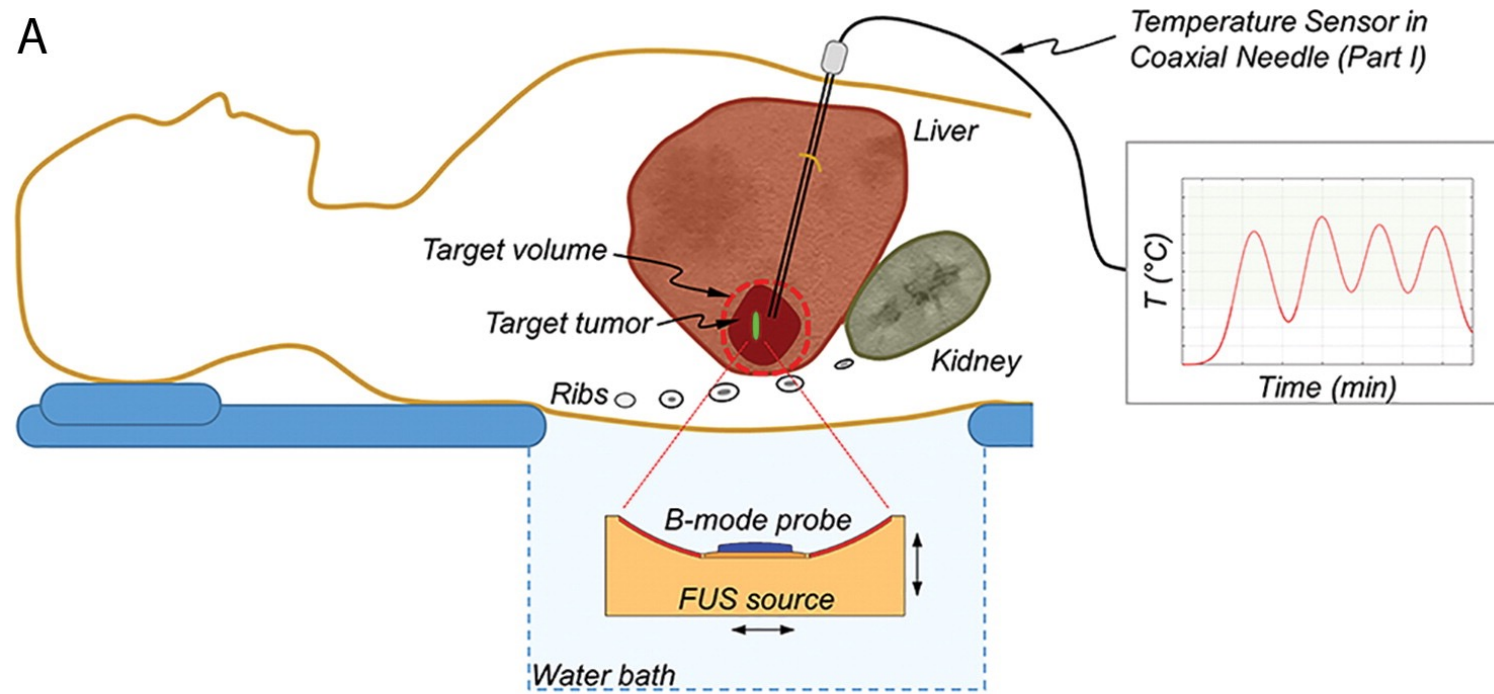
From: Salgaonkar *et al*, *Med Phys*, 41(3), 2014

Adapting HIFU ablation systems for large volume hyperthermia

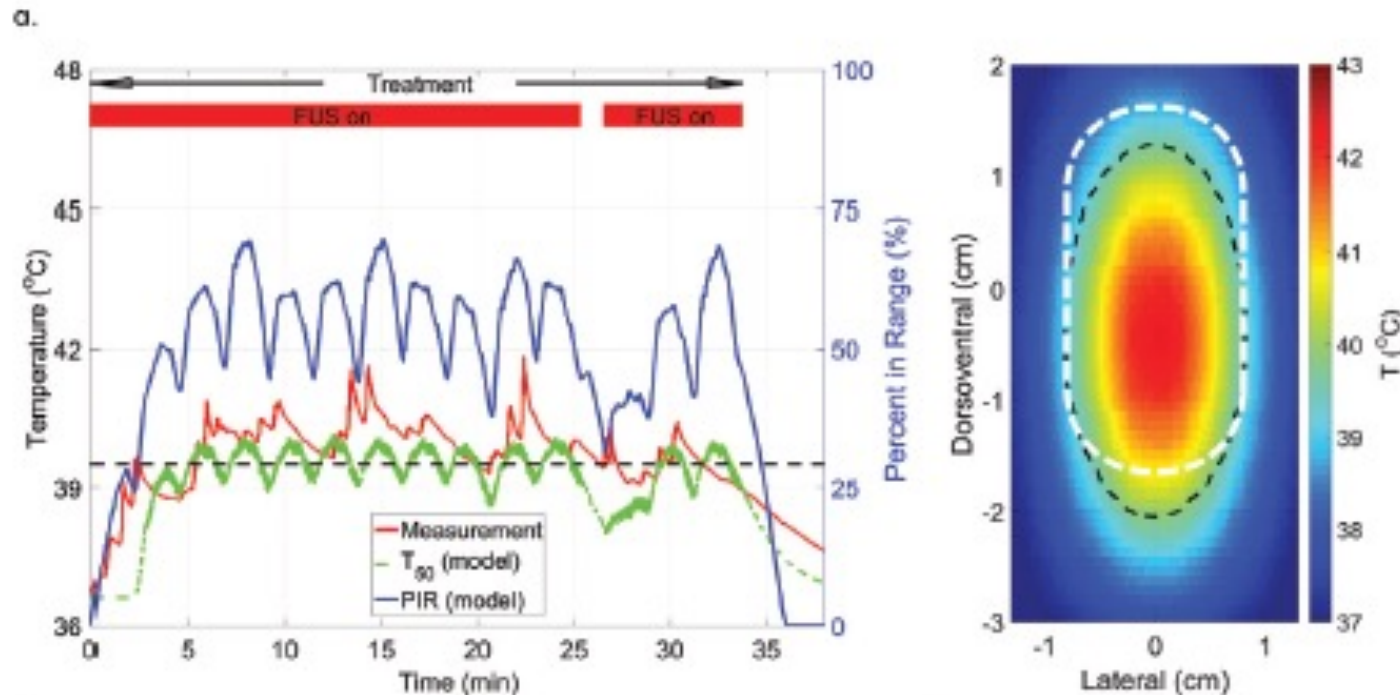
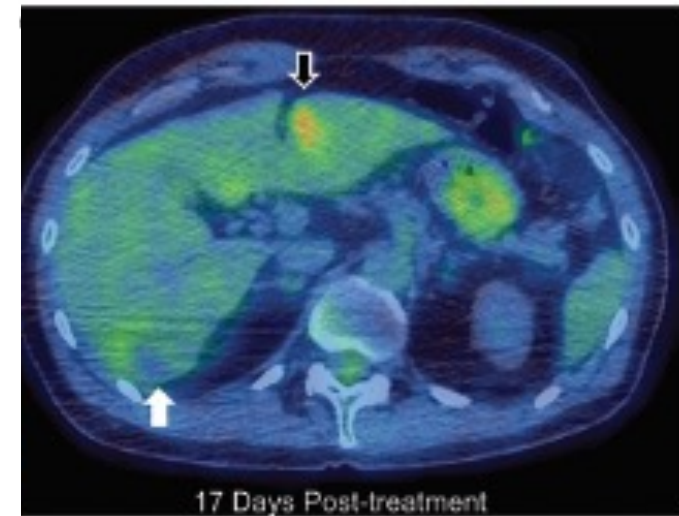
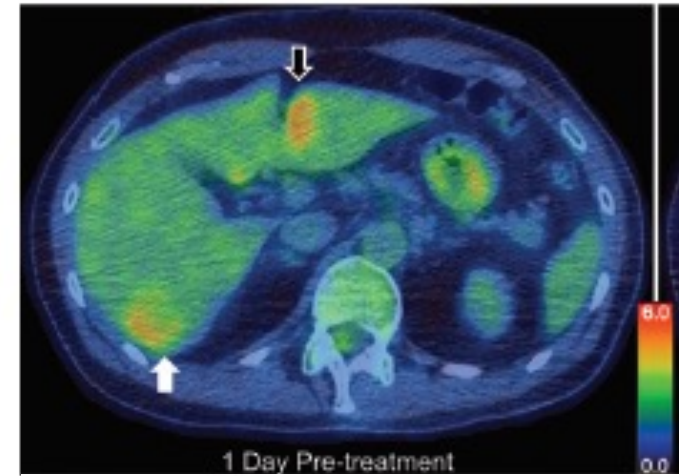
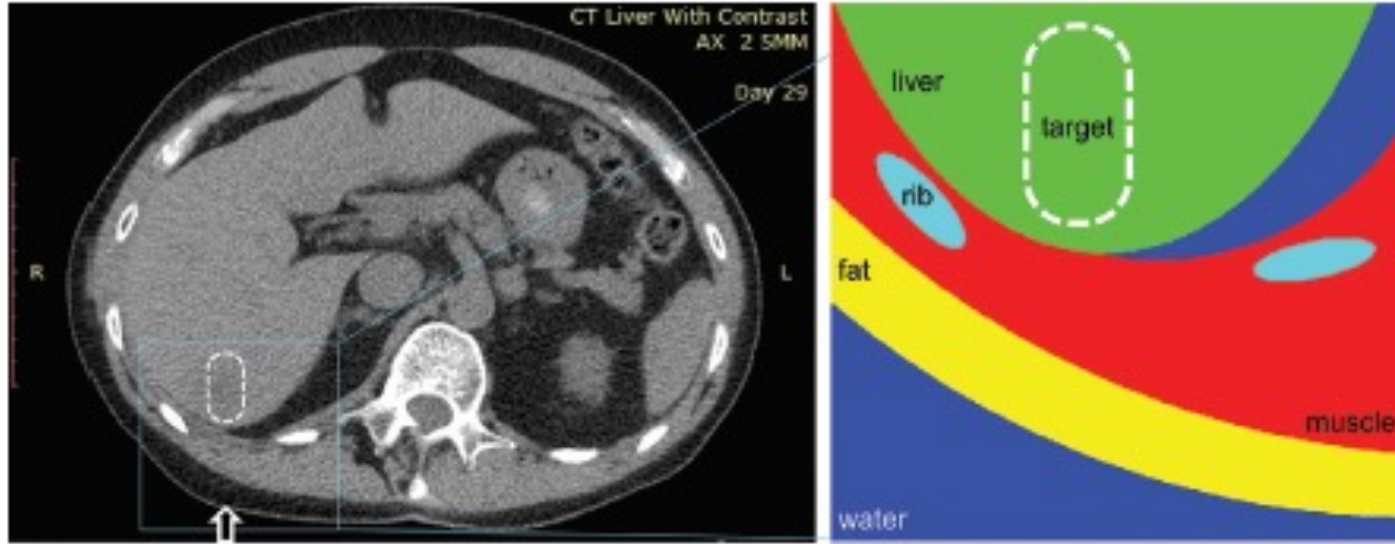


From: Salgaonkar *et al*, *Med Phys*, 41(3), 2014

Focused ultrasound hyperthermia

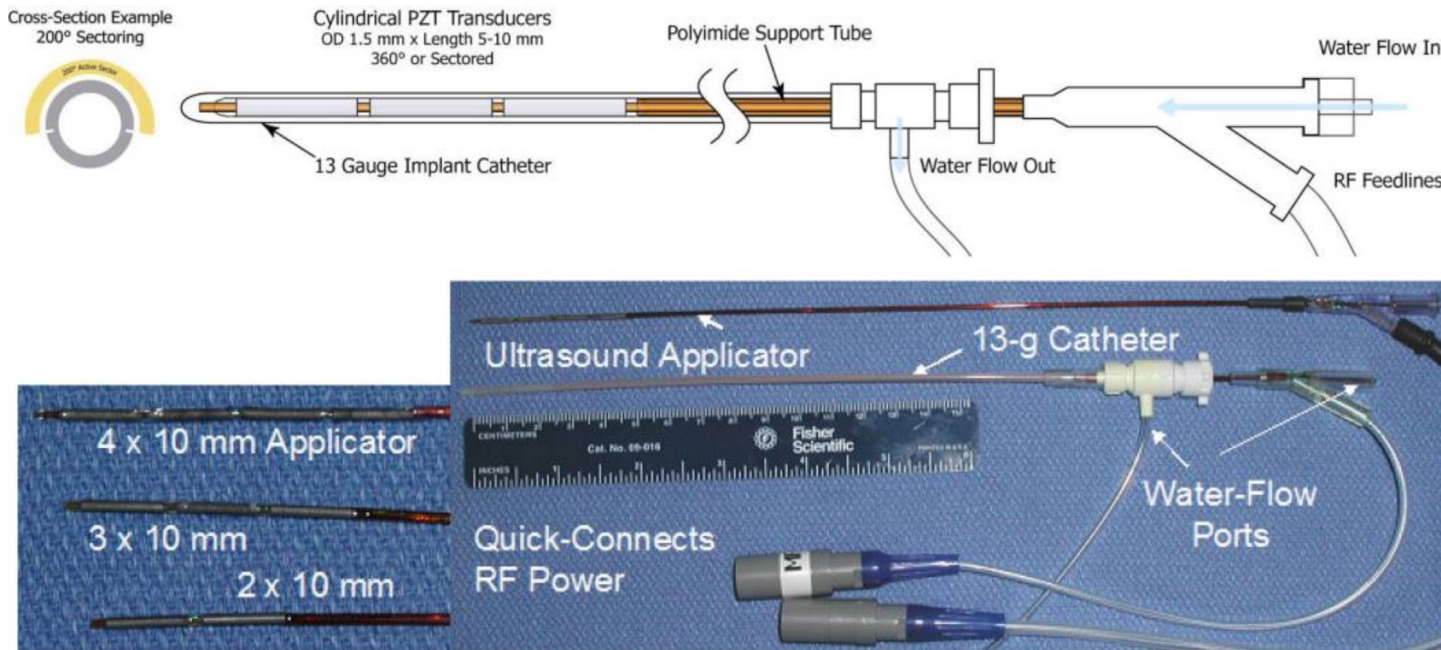


Focused ultrasound hyperthermia

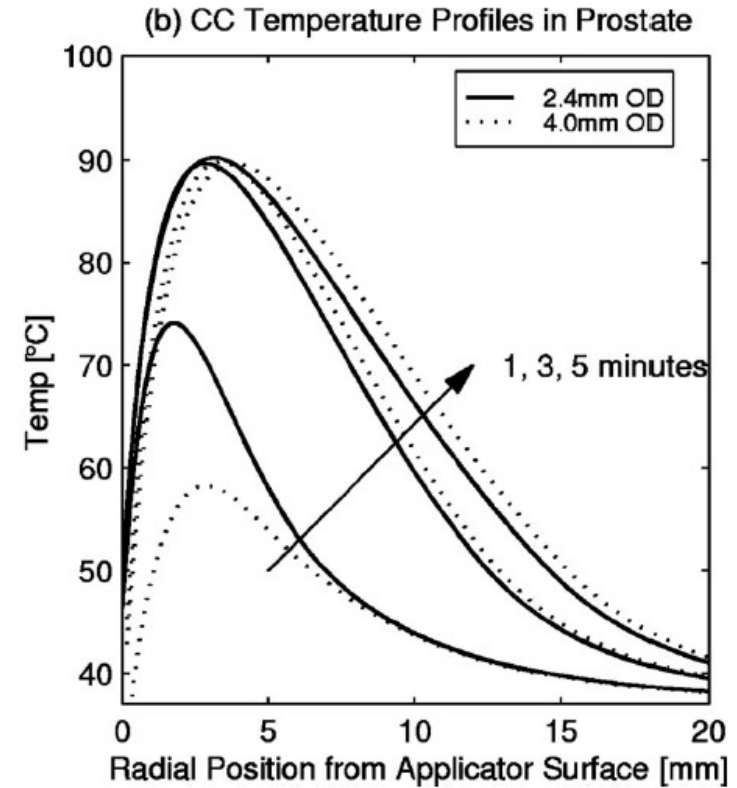


From: Gray *et al*, *Radiology*, 291, 2019

Interstitial ultrasound thermal therapy devices



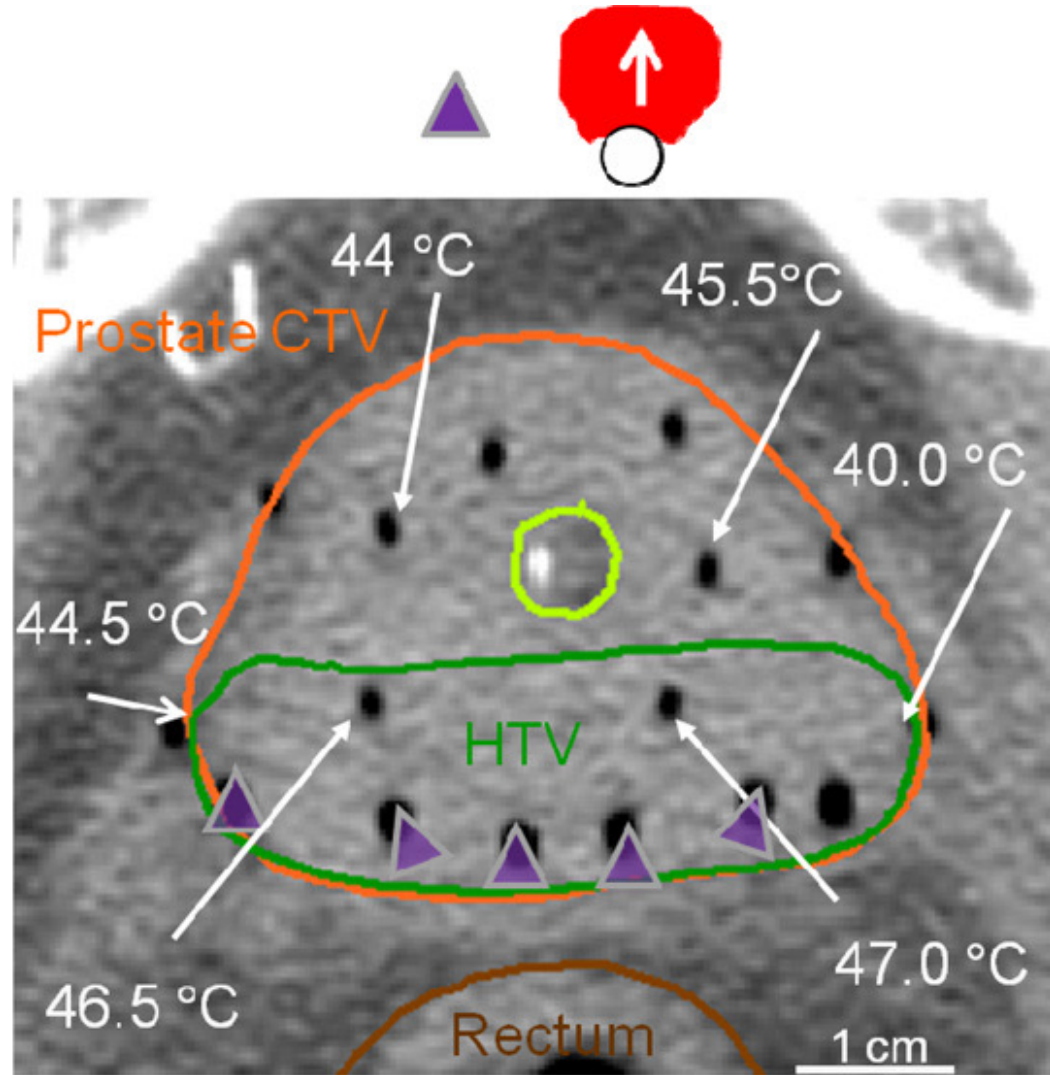
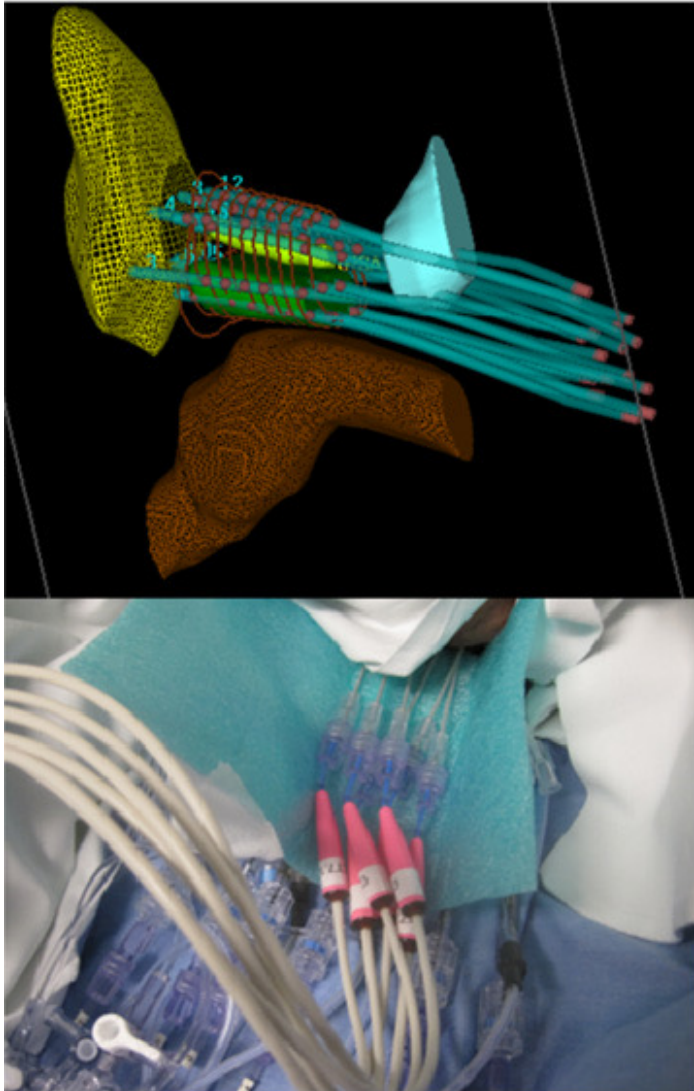
From: Diederich et al, Proc SPIE, 7901: 790100, 2011



From: Tyreus et al, *Med Phys*, 30(7), 2003

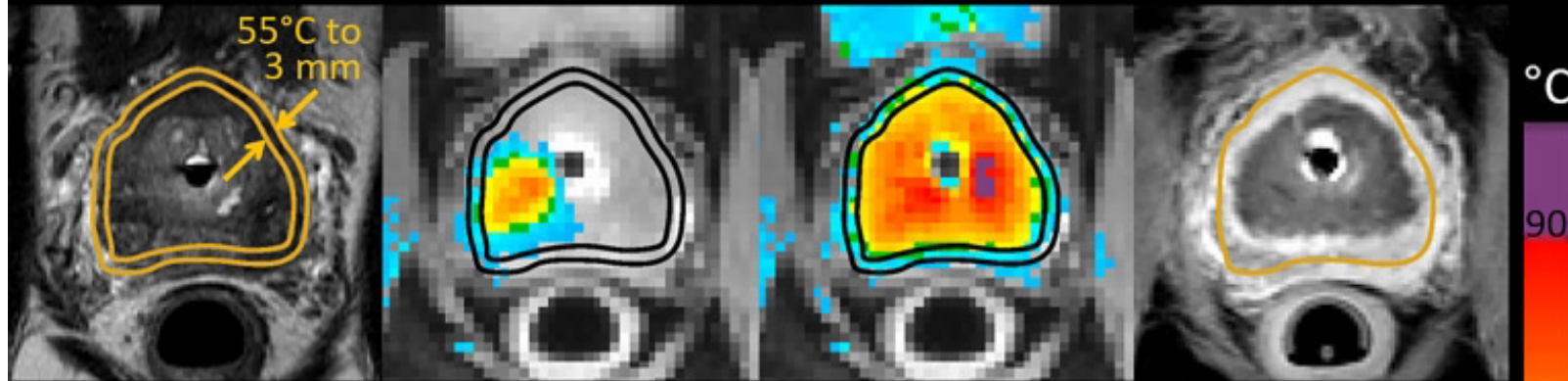
- Linear arrays of independently powered ultrasound transducers
 - Typical operating frequencies: ~6 – 9 MHz
 - Angular control of power absorption feasible with sectored transducers

Interstitial ultrasound thermal therapy: prostate

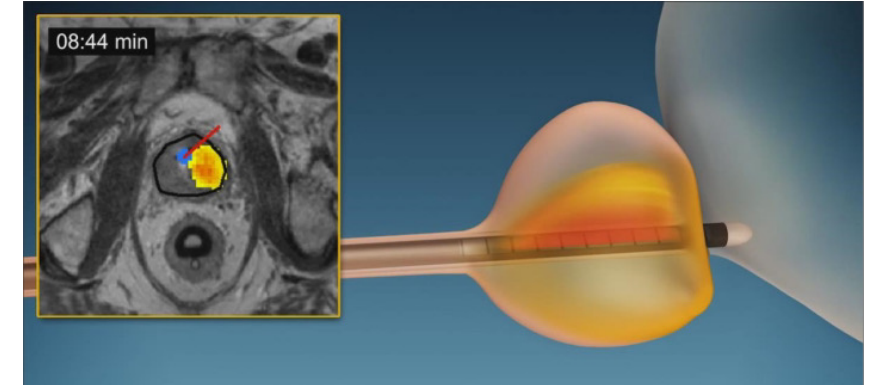
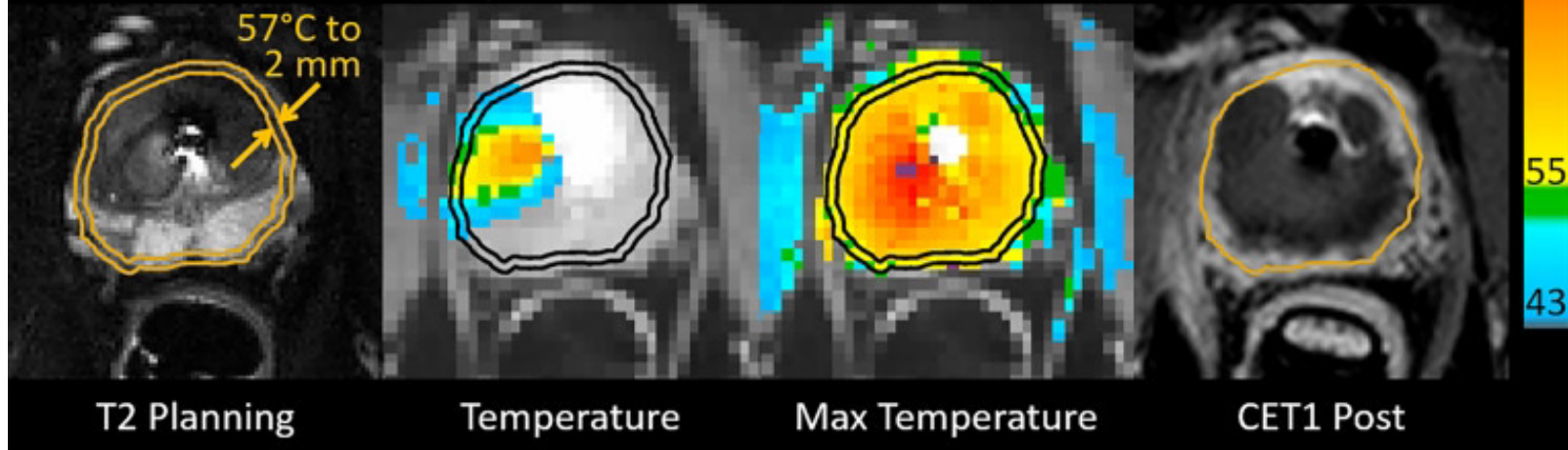


Transurethral ultrasound prostate ablation

Phase I Study: 55°C at 3 mm inside capsule, 90% ablation



TACT Pivotal Study: 57°C at 2 mm inside capsule, 99% ablation



- Multi-element linear array of planar transducers with rotary control

Summary

- Ultrasound offers deep penetration and short wavelengths for conformal thermal therapy of targets in diverse anatomic sites
- Ultrasound thermal therapy systems have been integrated with magnetic resonance and ultrasound imaging for thermometry and guidance of clinical delivery
- Non-invasive and catheter-based ultrasound systems are in clinical use for thermal treatment of uterine fibroids, painful bone metastases, prostate disease, and other conditions

Q&A – discussion

Thank you!

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<http://ece.ksu.edu/bcdl>