Locating targets for therapy embedded in soft, deforming and moving tissues

Dave Hawkes,
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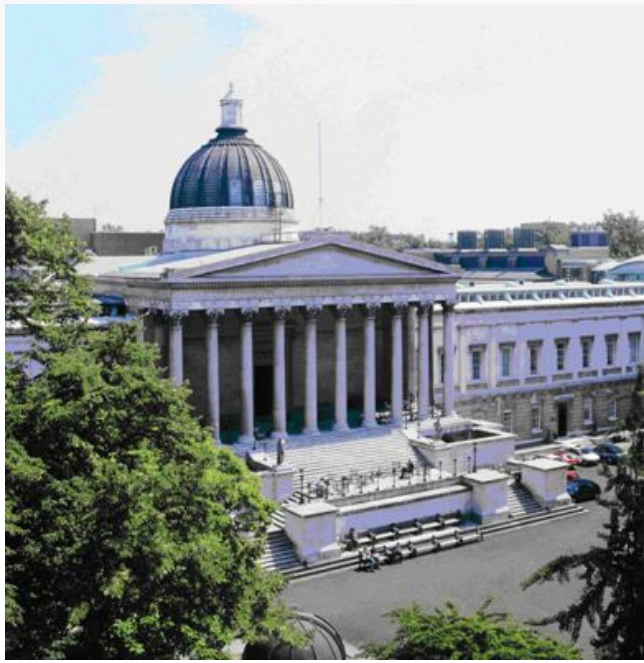
cmic
Centre for Medical Image Computing



Locating Squishy Bits that Move: SatNav for the Radiotherapist

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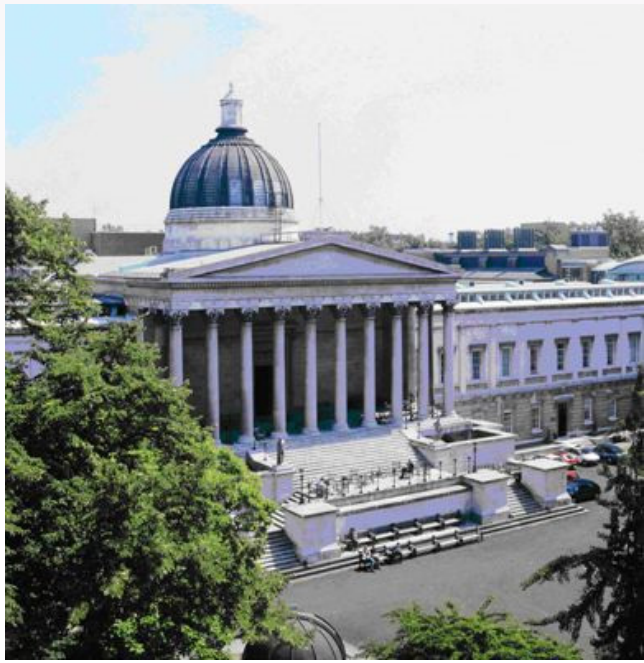
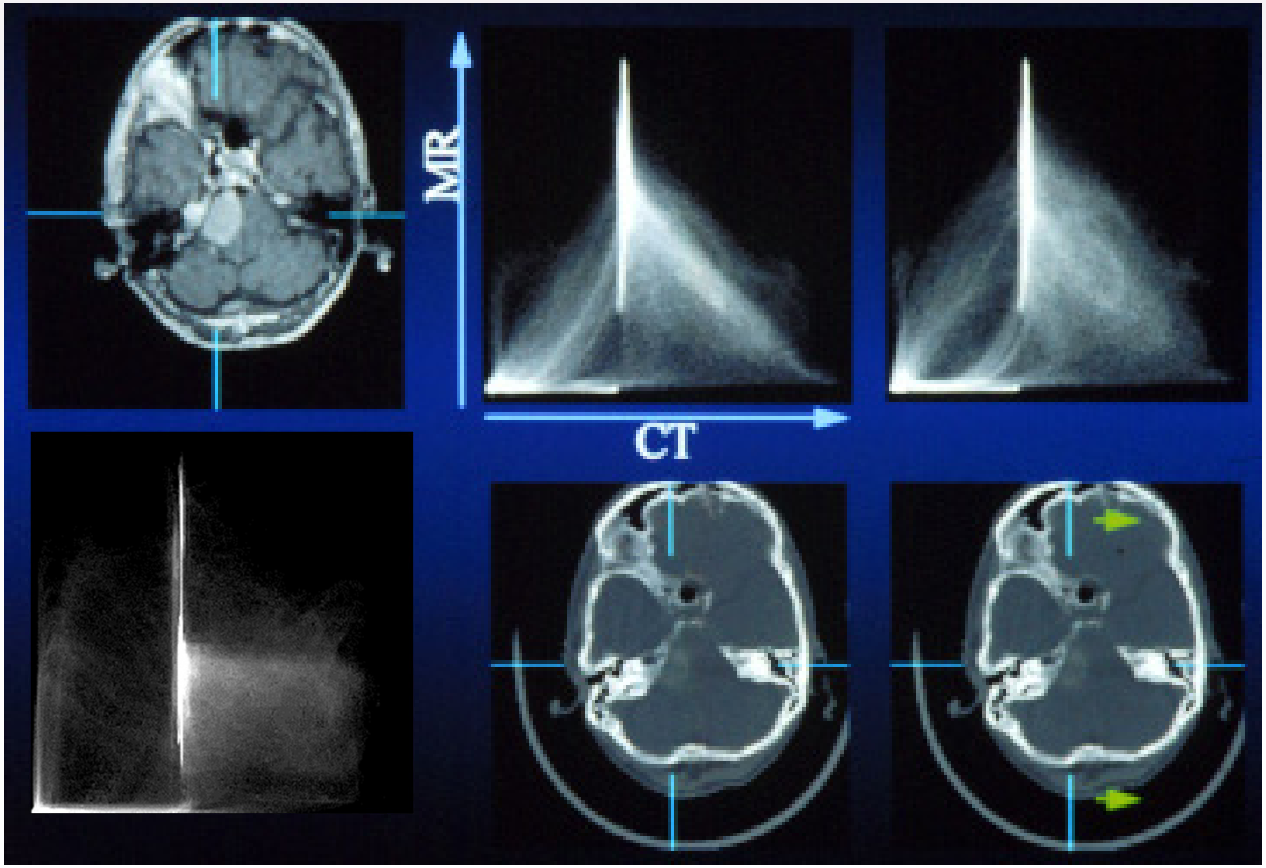


Professor Wilhelm Roentgen and the first X-ray image taken of his wife's hand in 1895

“First” Image Guided Surgery

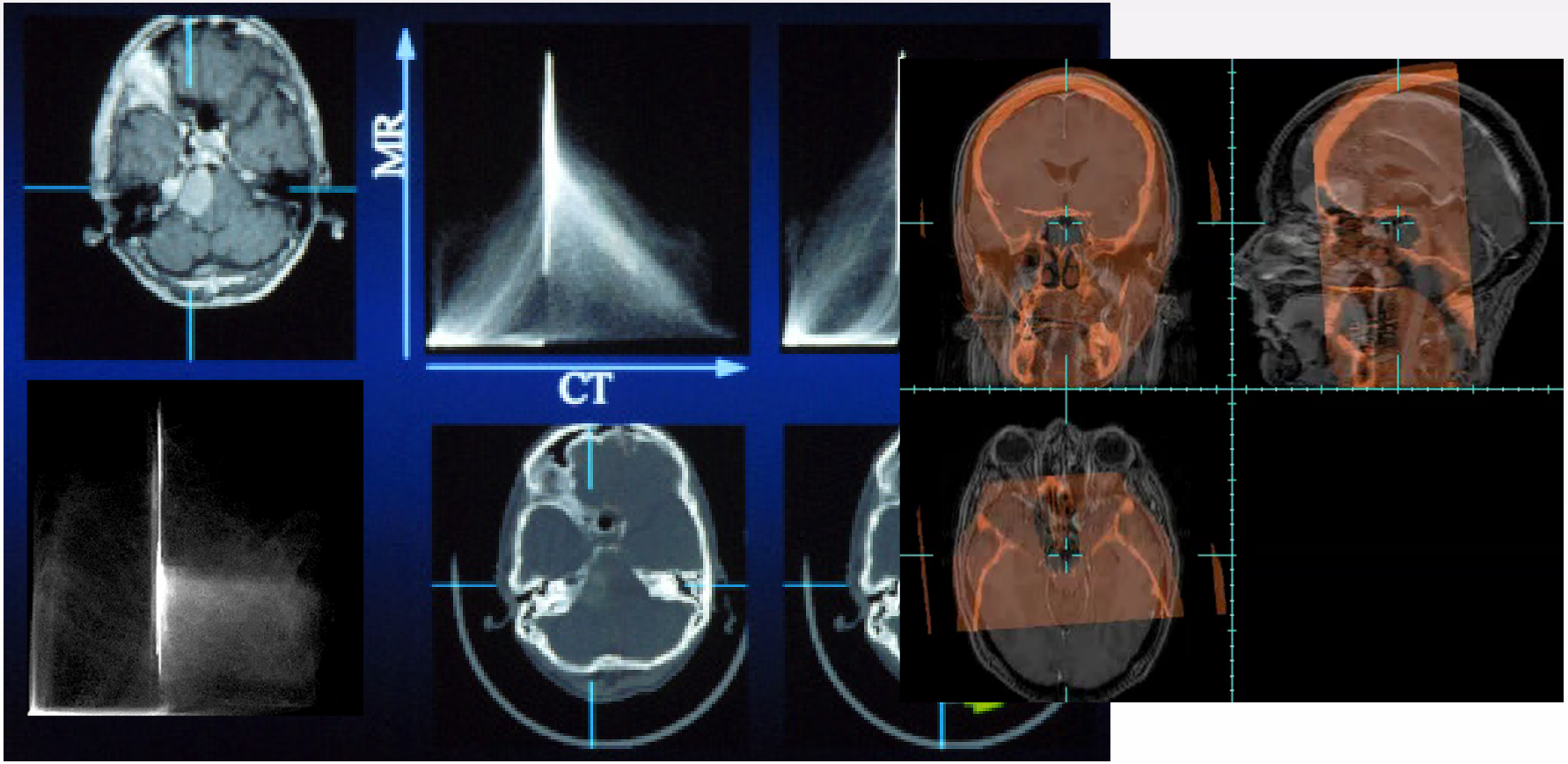
- 8th Nov 1895 X-rays discovered
- 28th Dec Paper submitted
- 5th Jan Paper published
- 13th Jan First X-ray with clinical intent (Birmingham)
- 14th Jan First image guided surgery (needle removed from hand)

Intensity Feature Space, Joint Histogram or Joint Probability Distribution



(Studholme et al, 1997 MedIA and 1999 Patt Recog Letters)

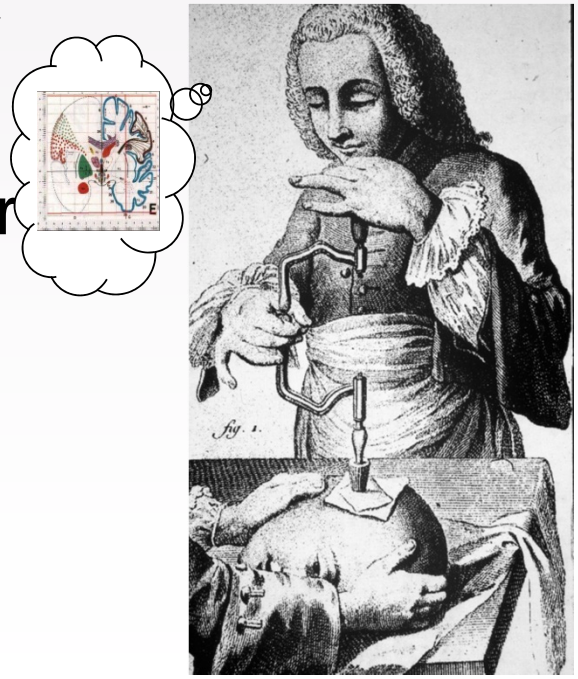
Intensity Feature Space, Joint Histogram or Joint Probability Distribution



(Studholme et al, 1997 MedIA and 1999 Patt Recog Letters)

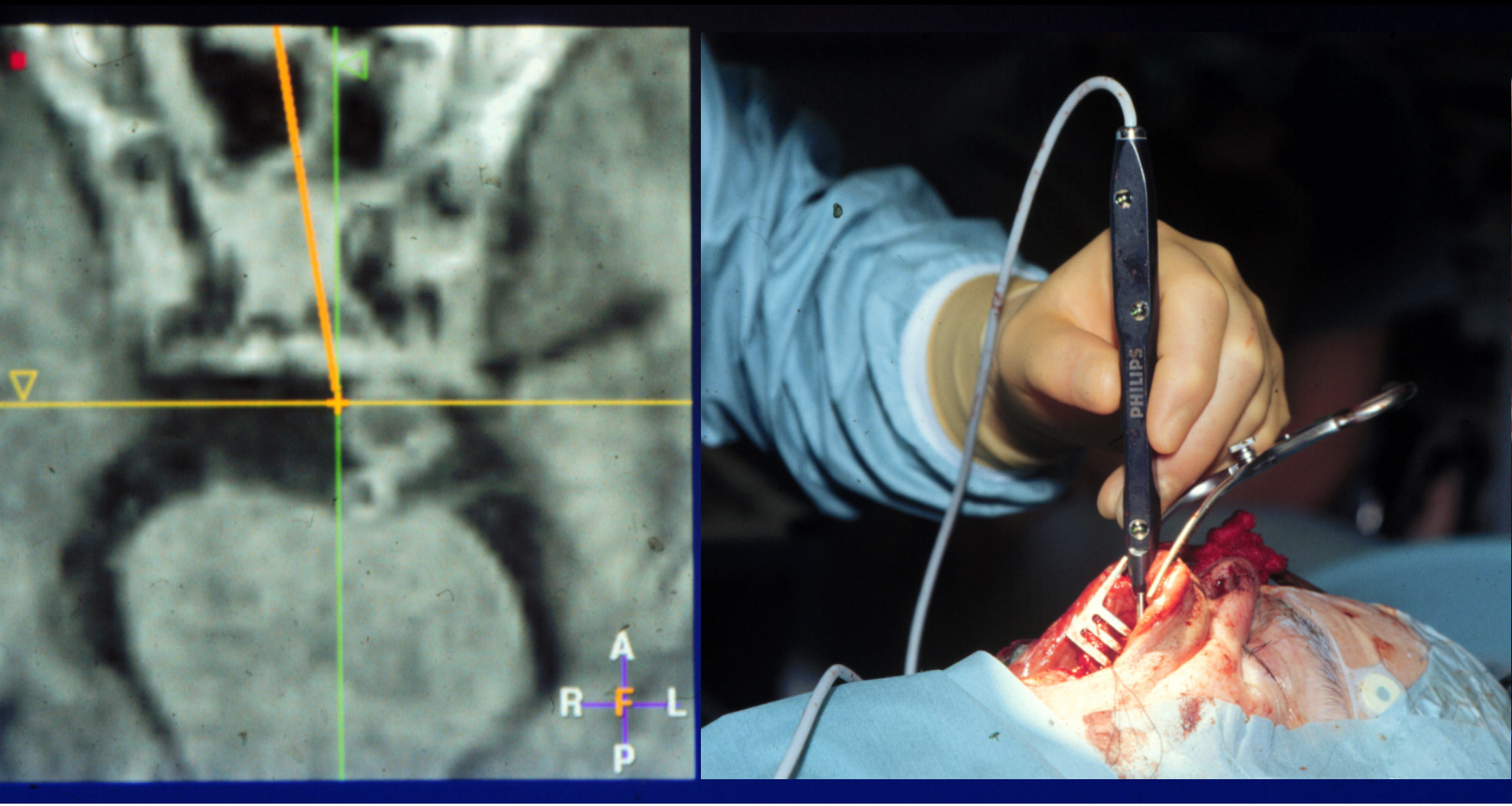
Spatial correspondence in image guided interventions

- Neurosurgery
- Prostate biopsy and Focal Therapy for Cancer
- High Intensity Focussed Ultrasound for Treating Liver Cancer
- Lung radiotherapy



Tracked localiser in use during maxillotomy

Alan Crockard, National Hospital, Queen Square



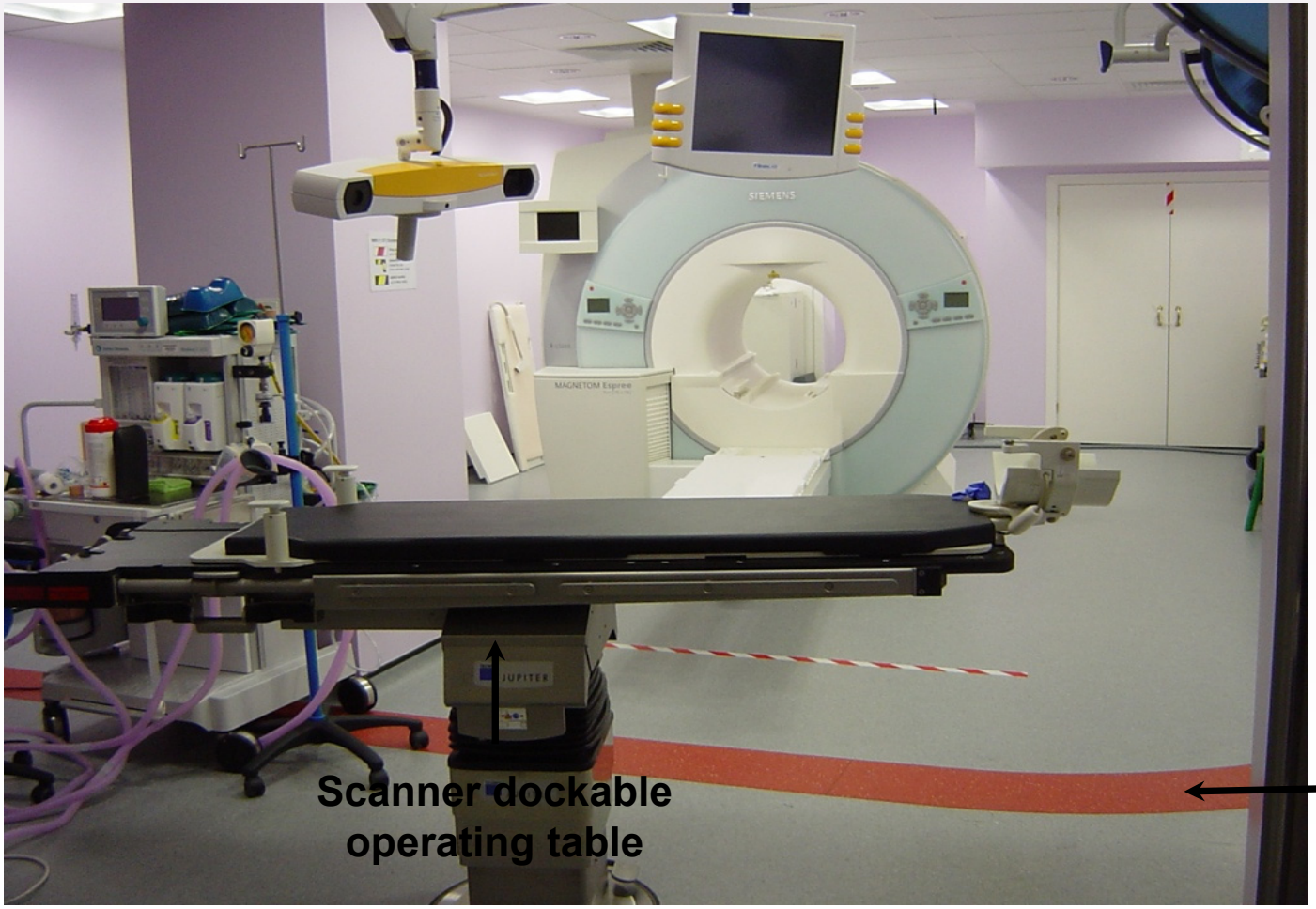
MAGI system in the Operating Room:

UCL

Overlay of 3D preoperative image data on stereo field of view of binocular operating microscope

(Edwards et al IEEE-Trans Med Imag 2000)

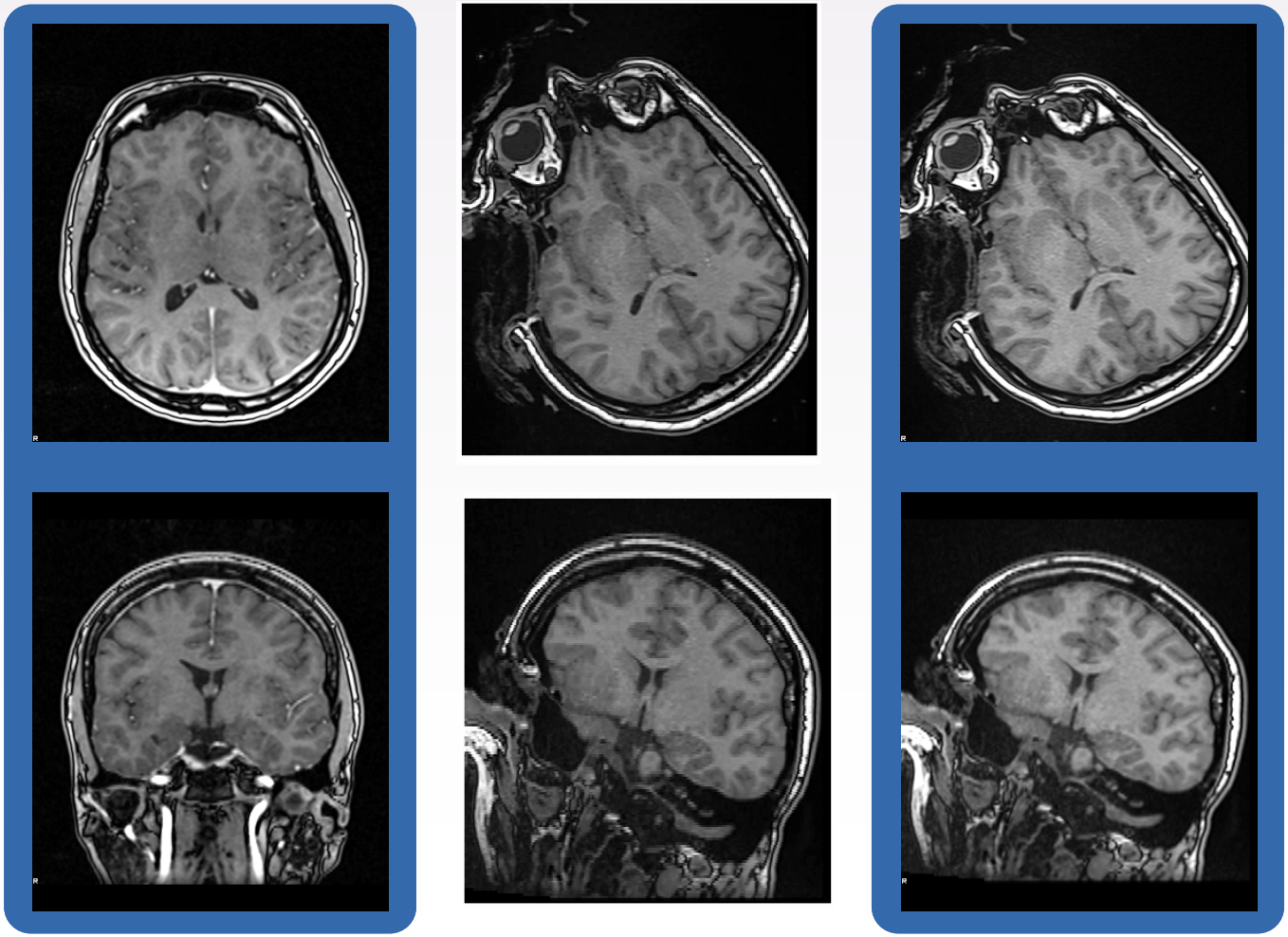
iMRI facility at NHNN



Registration example - brain shift illustration

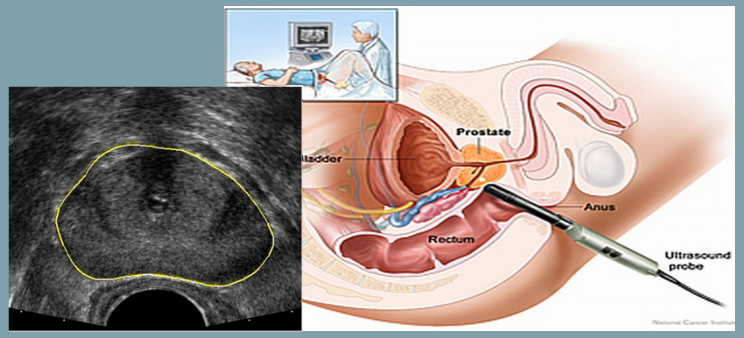
Daga et al 2011

Target image

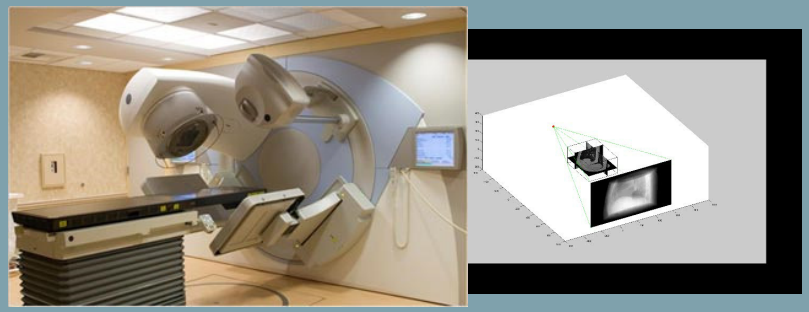


Source Image

Other interventions where moving and deforming tissue is a problem?



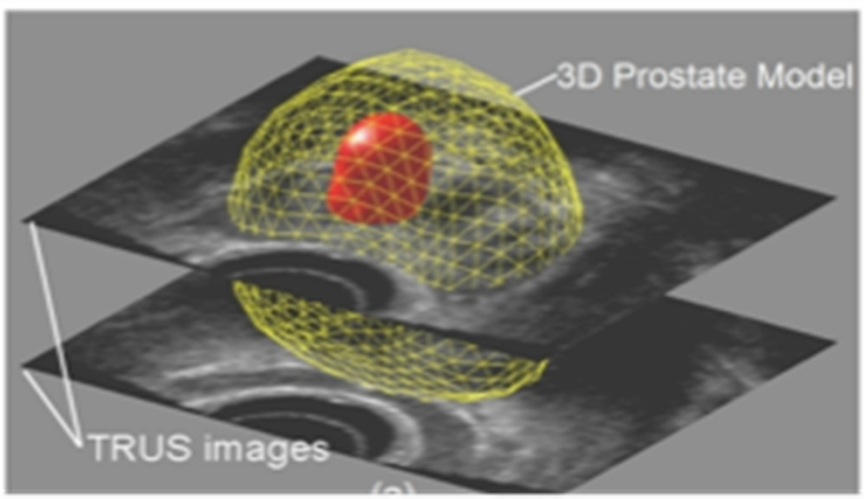
Needle placement for biopsy & therapy delivery

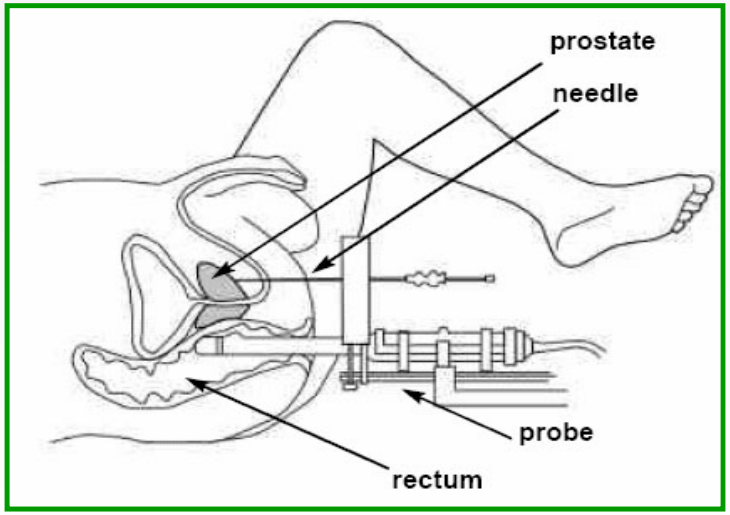


External beam therapy

Prostate Cancer:
Image guided biopsy and focal ablation

Mark Emberton, Hash Ahmed, Dean Barratt, Yipeng Hu

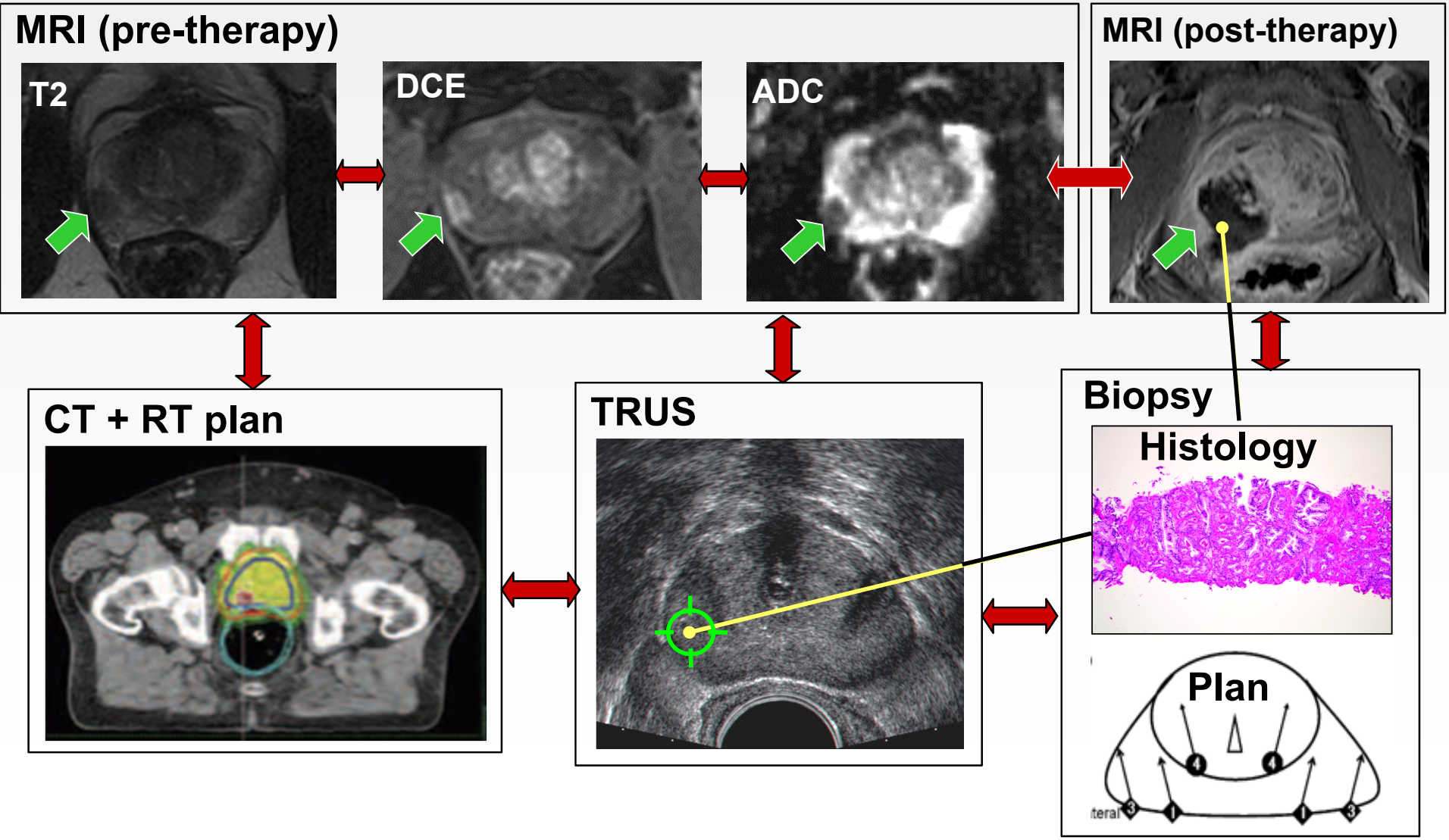




Ahmed et al Lancet Oncology 2012

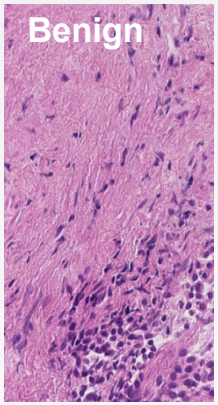
Centre for Medical Image Computing

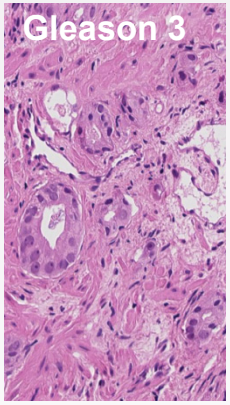
Prostate cancer: the need for image registration

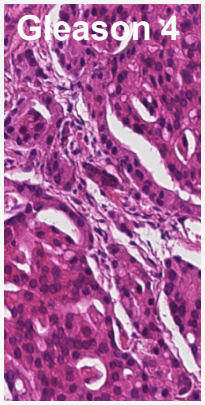


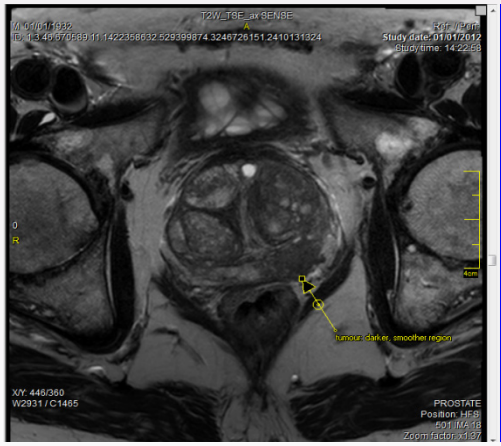
Microcompartment MRI-DW Imaging and modelling

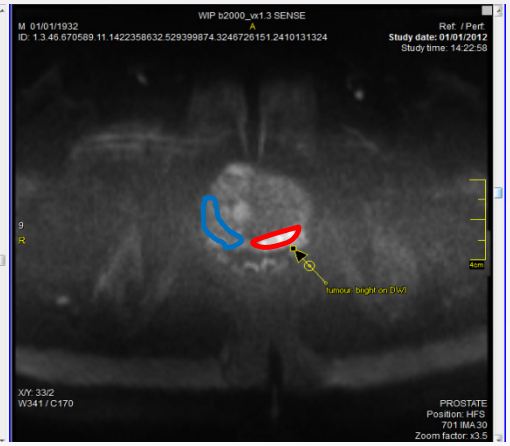
Non-invasive Gleason Grading of Prostate Cancer

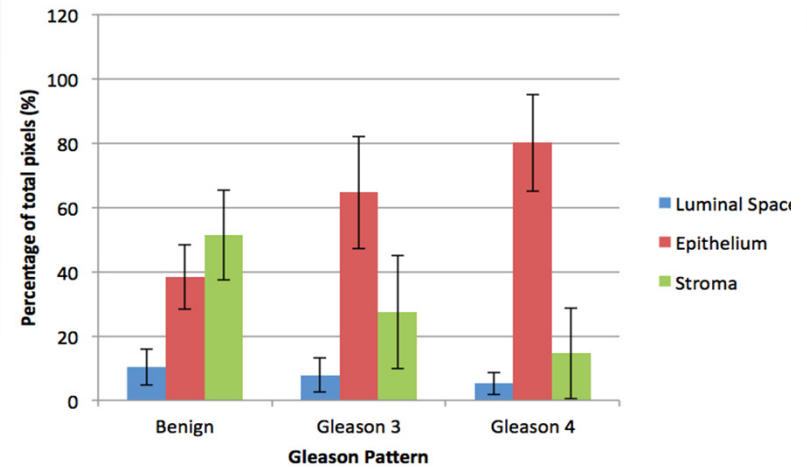


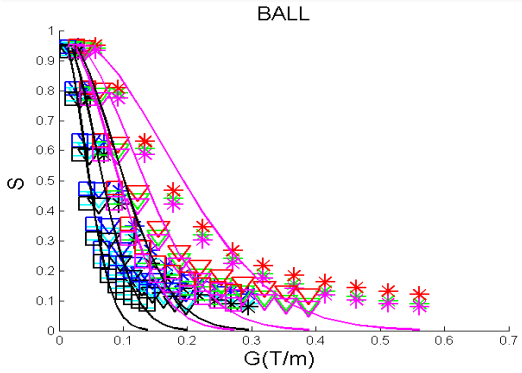




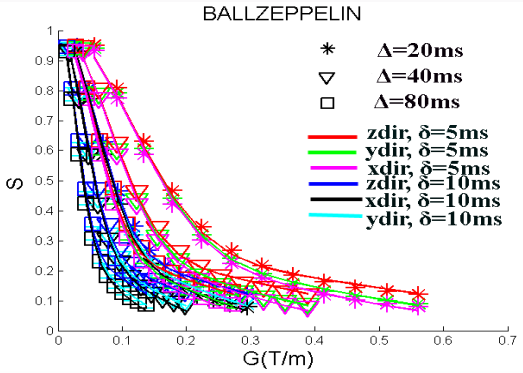








MSE fit= 1.36

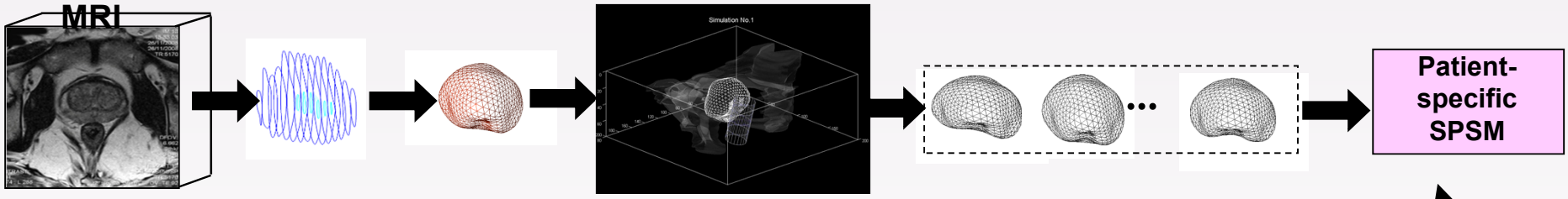


MSE= 0.0312

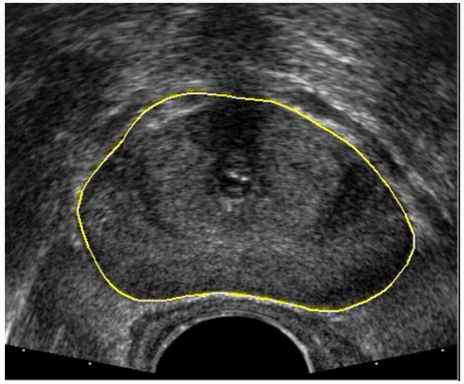
E. Panagiotaki, D. Alexander, D. Hawkes, ISMRM 2013 *EPSRC Programme Grant*

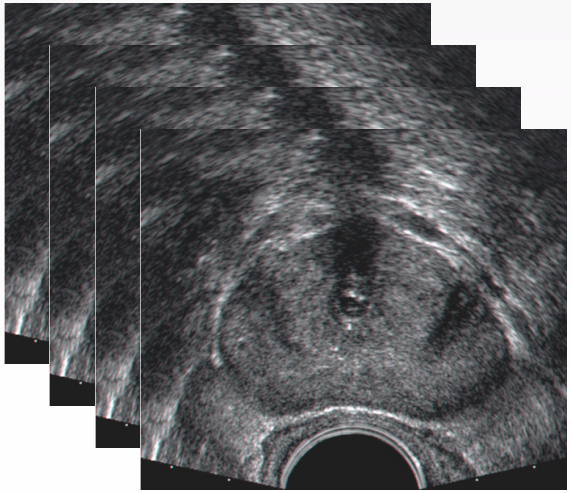
Real-time tracking of the prostate using US and MRI

PRE-PROCEDURE



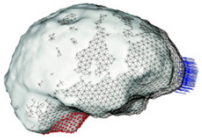
DURING PROCEDURE





Register

NiftySim



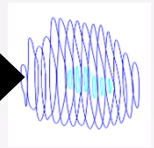
Real-time tracking of the prostate using US and MRI

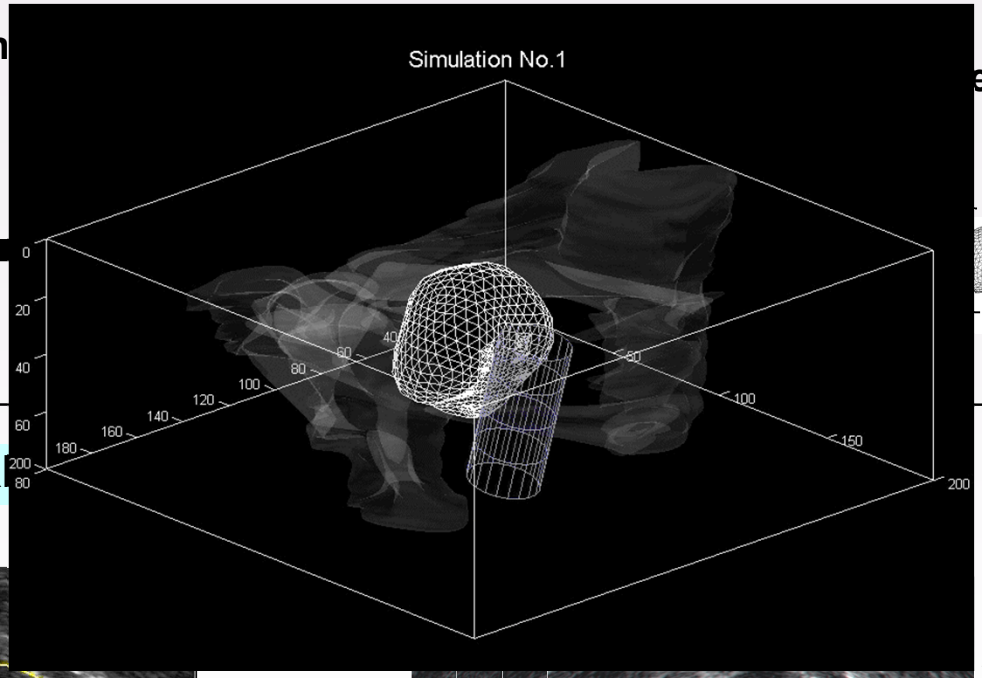
UCL

PRE-PROCEDURE

Referen

MRI





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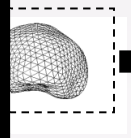
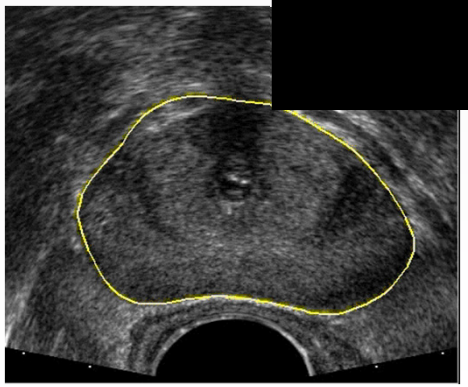
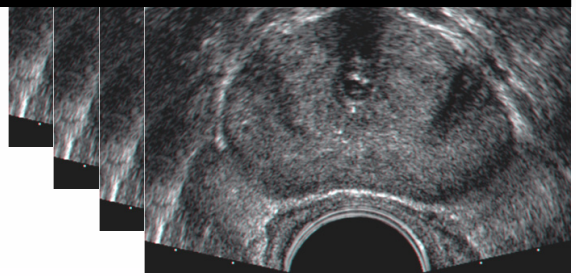


Patient-specific SPSM

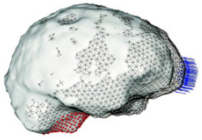
DURING PROCEDUR



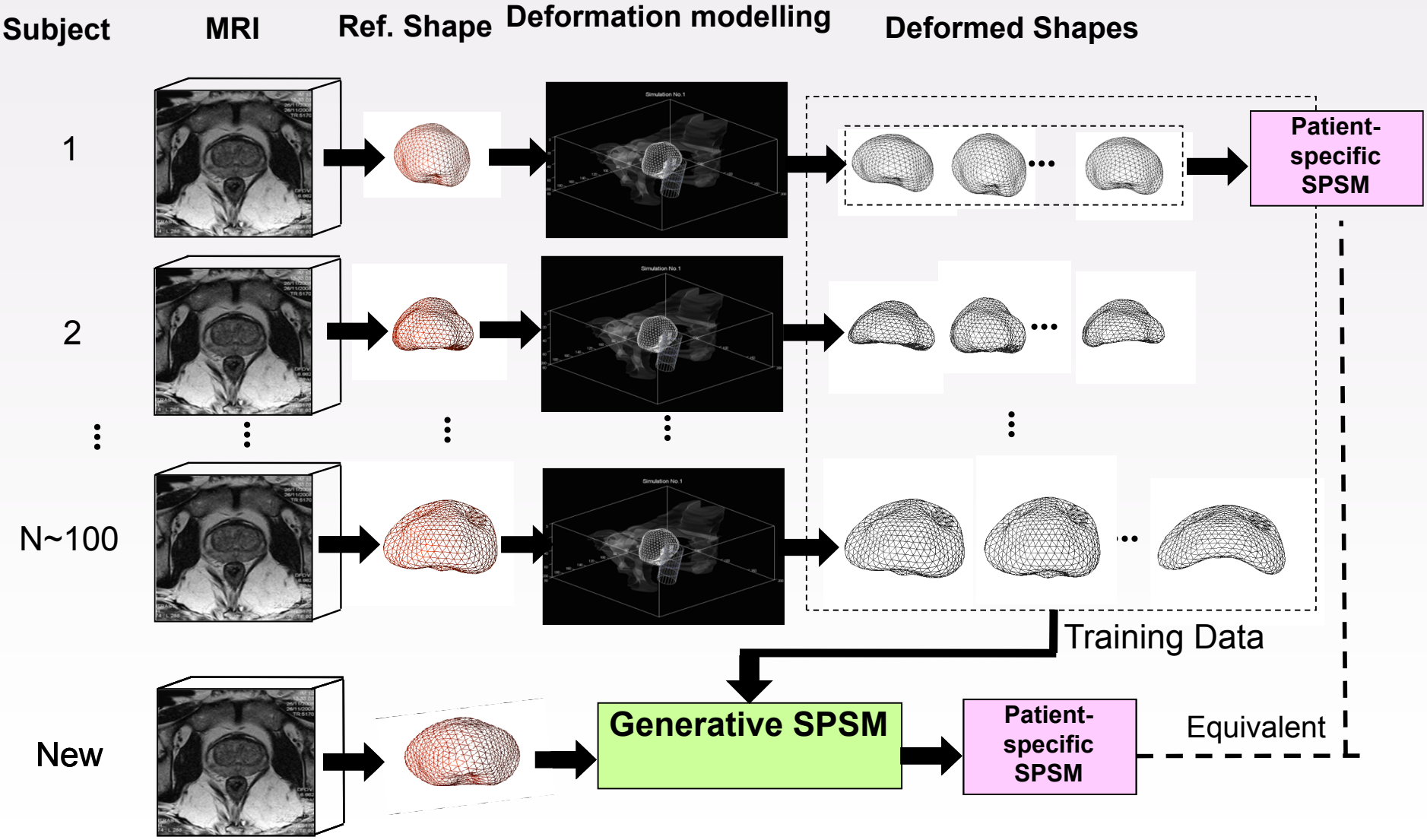


Register

NiftySim



Automatic generation of deformable organ models



Hu et al. Medical Image Analysis, 2012

Prostate Biopsy System Design

- Not reliant on expertise
- Automatic, deformable image registration
- < 3mm error
- Widely compatible
- Diagnosis and therapy
- Low-cost

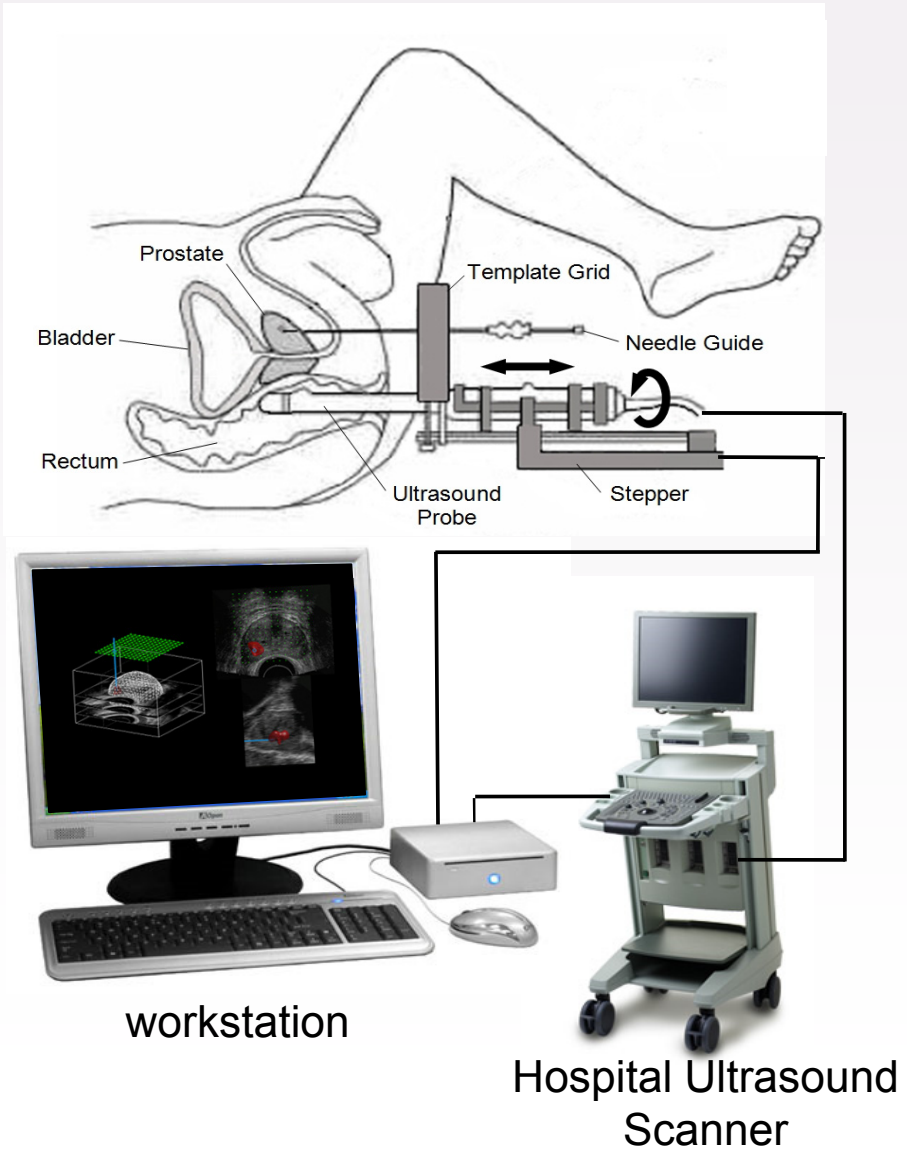
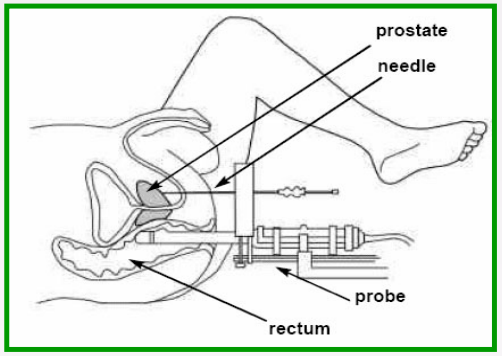
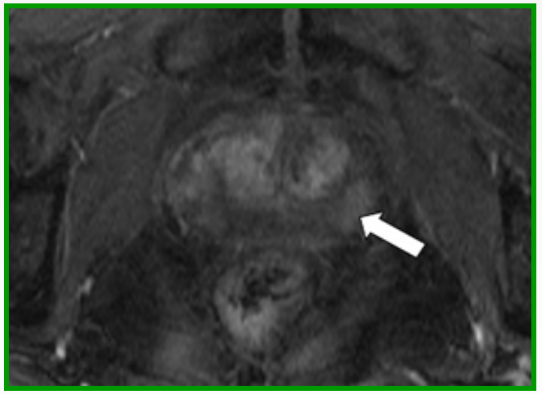
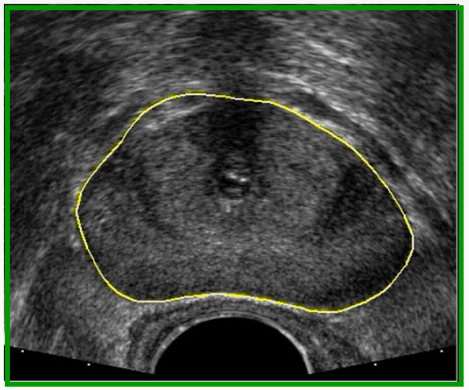


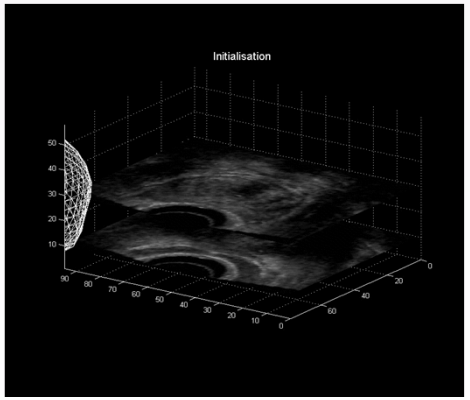
Image Directed Biopsy and Partial Prostate Ablation



- Multimodal MR, registration and tissue classification used to delineate focal, high grade cancer
- Cancer accurately targeted for biopsy and hence focal therapy (PDT or HIFU) delivered (via needle or transrectally) with transrectal ultrasound guidance
- Critical structures avoided.







Statistical motion model built from 100's of FEM examples

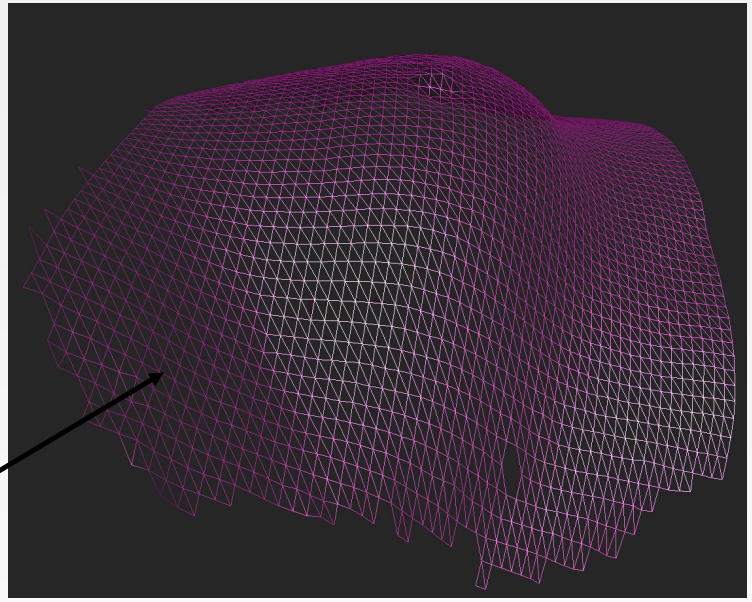
Capturing variation in pelvic anatomy, insufflation, mechanical properties

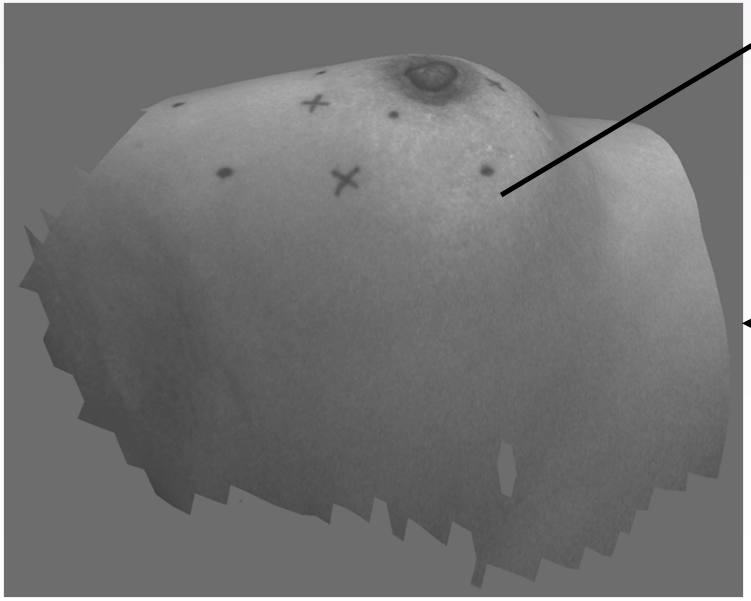
Hu Y, et al IEEE-tMI, 2011 + patent
Hu y et al MedIA 2012

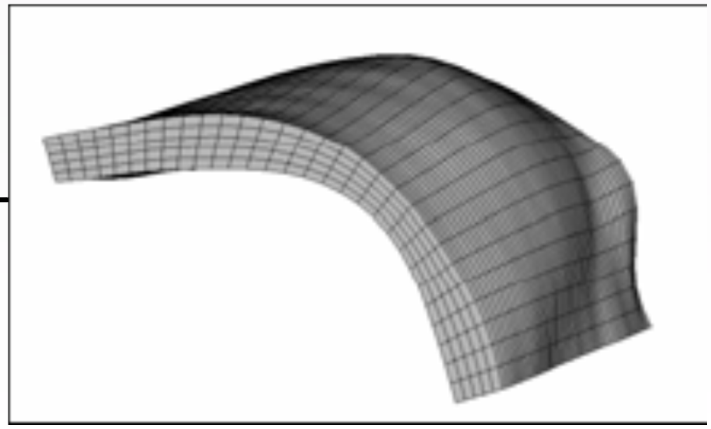
Model based non-rigid registration,
TRE 5 patients, 48 landmarks
1.8mm (RMS) +/- 0.7mm

EPSRC, NIHR i4i, Wellcome DoH HICF, clinical trial commenced, > 100 patients

Guidance for breast surgery

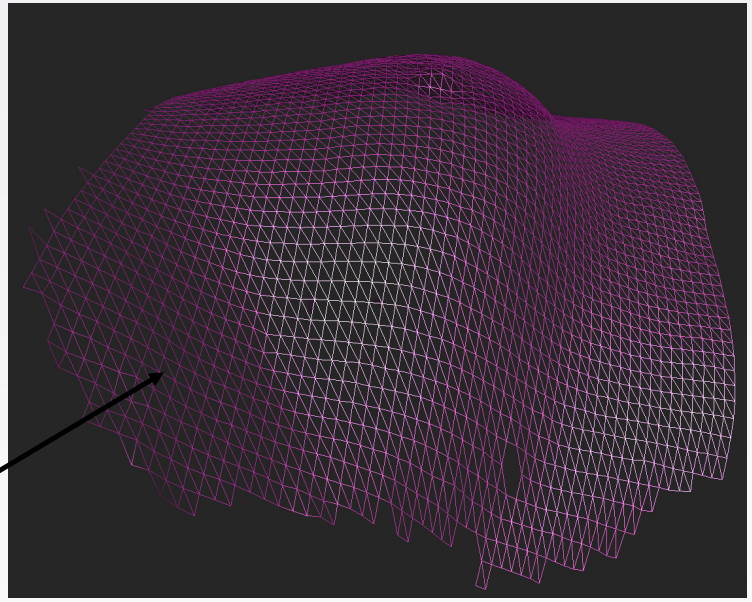


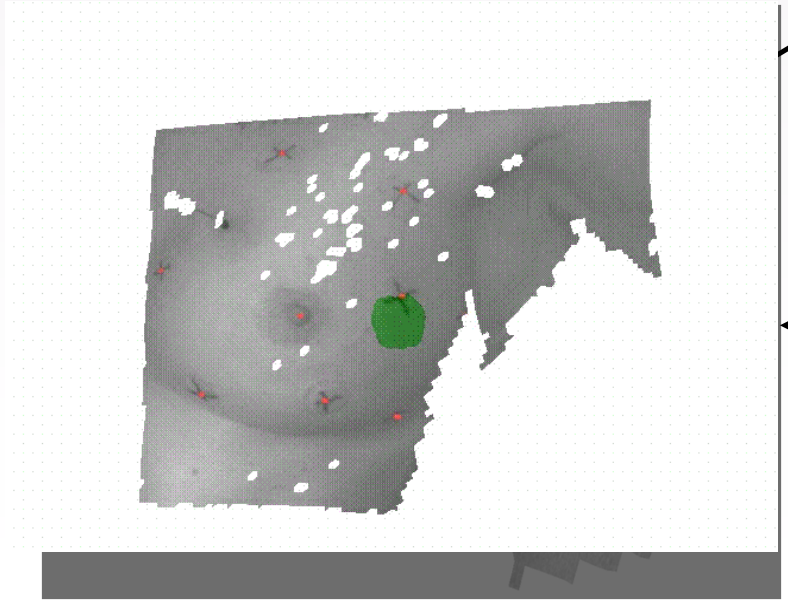


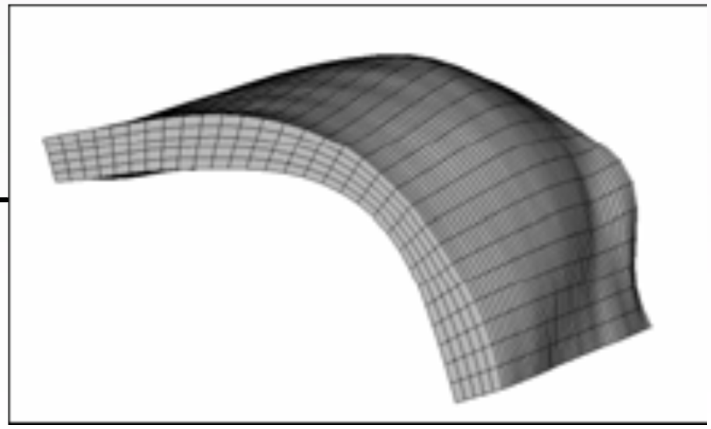


Tim Carter, Nick Beechy-Newman (Guy's Hospital) and Dave Hawkes

Guidance for breast surgery



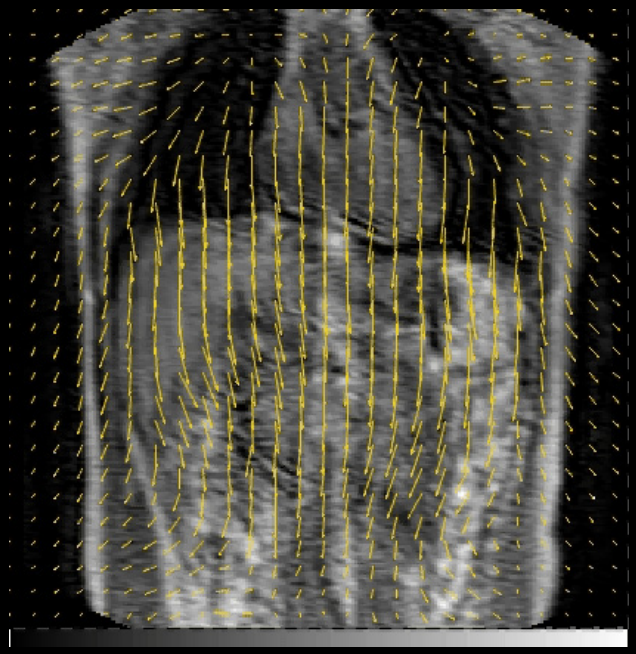


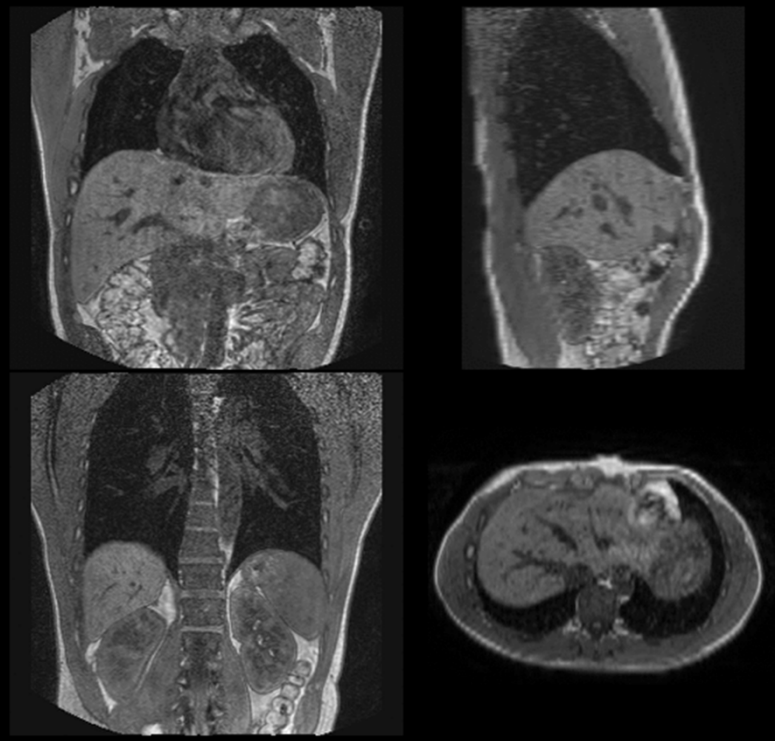


Tim Carter, Nick Beechy-Newman (Guy's Hospital) and Dave Hawkes

Transcostal High Intensity Focussed Ultrasound of Lesions of the Liver

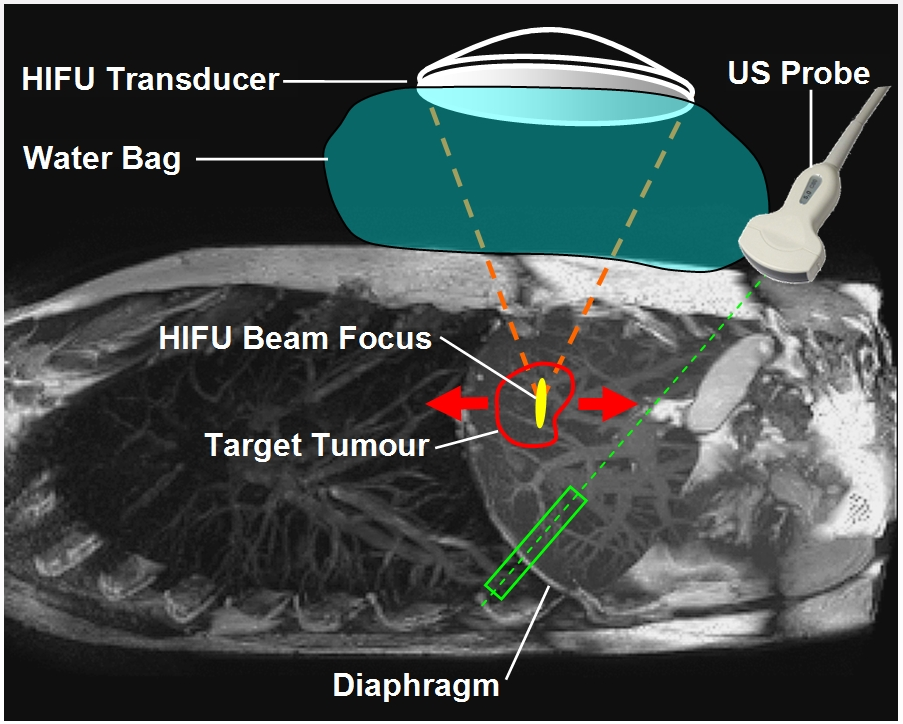
Breathing Patterns from Real-time MR THRIVE and motion modelling

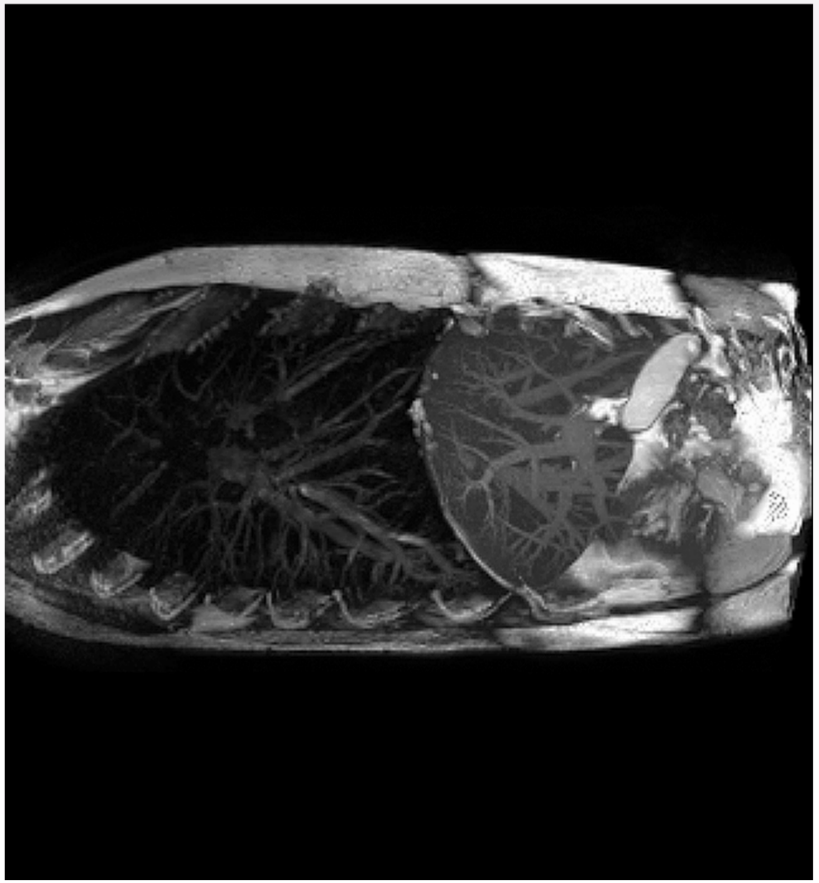




Erik Rijkhorst et al IPCAI 2010, MICCAI 2011

Transcostal High Intensity Focussed Ultrasound of Lesions of the Liver





Erik Rijkhorst et al IPCAI 2010, MICCAI 2011

HIFU heating of *moving* liver tissue

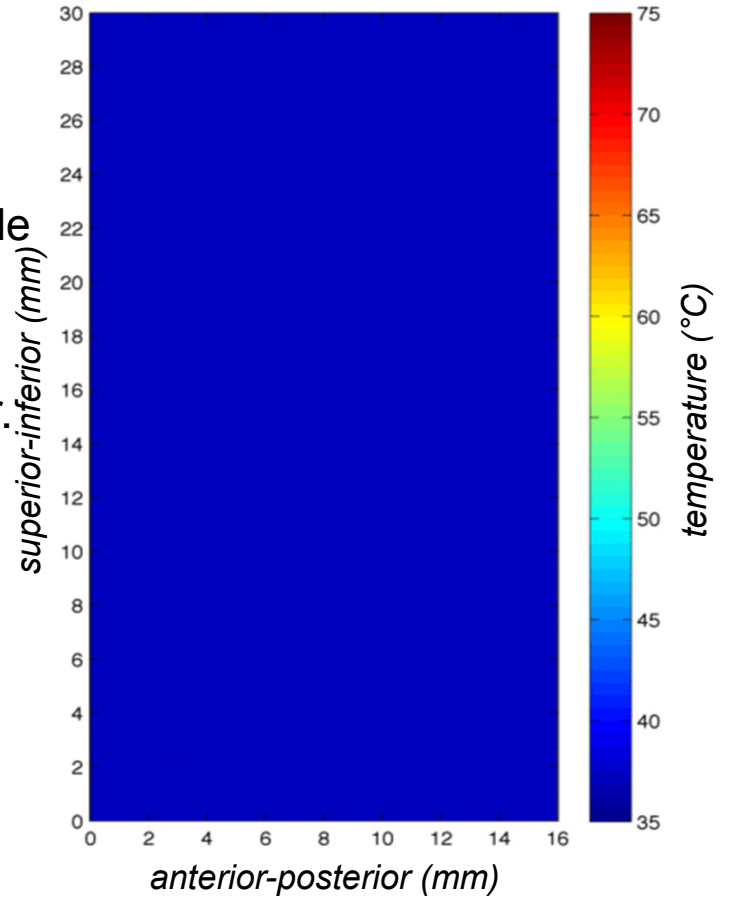
- Thermal model, bioheat equation: *(Pennes 1948)*

$$\rho C \frac{\partial T}{\partial t} = K \nabla^2 T - W_b C_b (T - T_b) + q(t)$$

thermal conductivity — blood perfusion — HIFU heating profile

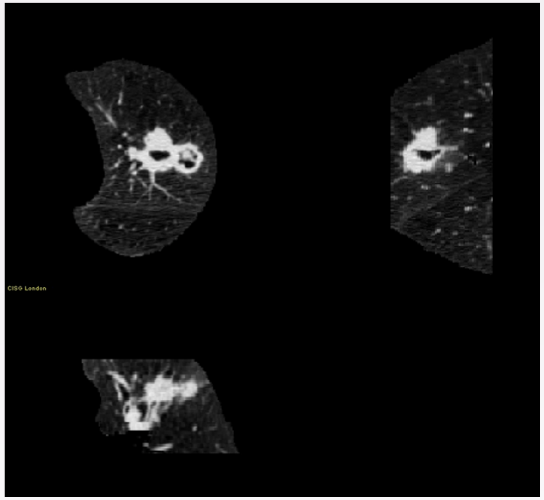
- HIFU energy density *q(t)*
  - Rayleigh integral for spherical bowl transducer. *(Meaney et al. 1998)*
  - Translation according to motion model.

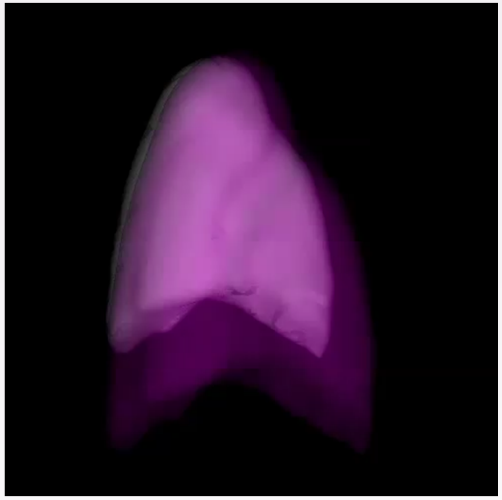
- Example of continuous heating for 8s, corresponding to 2 breathing cycles.



Rijkorst et al MICCAI 2011

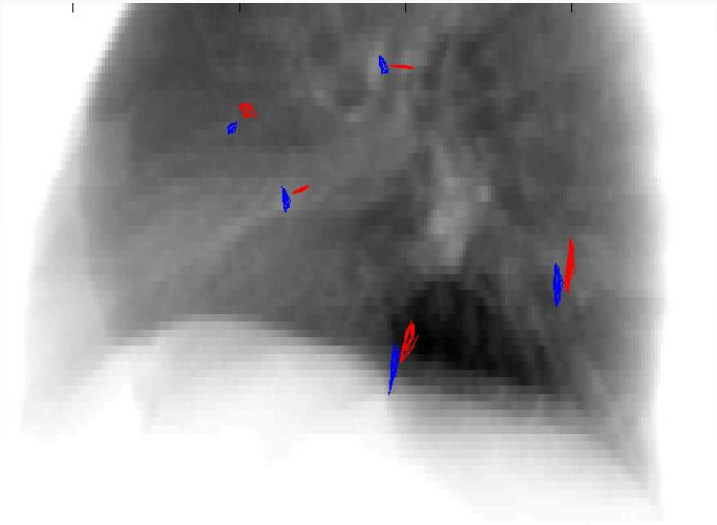
Motion compensation in lung radiotherapy





Model error 1.7mm (RMS), slice thickness 1.5mm

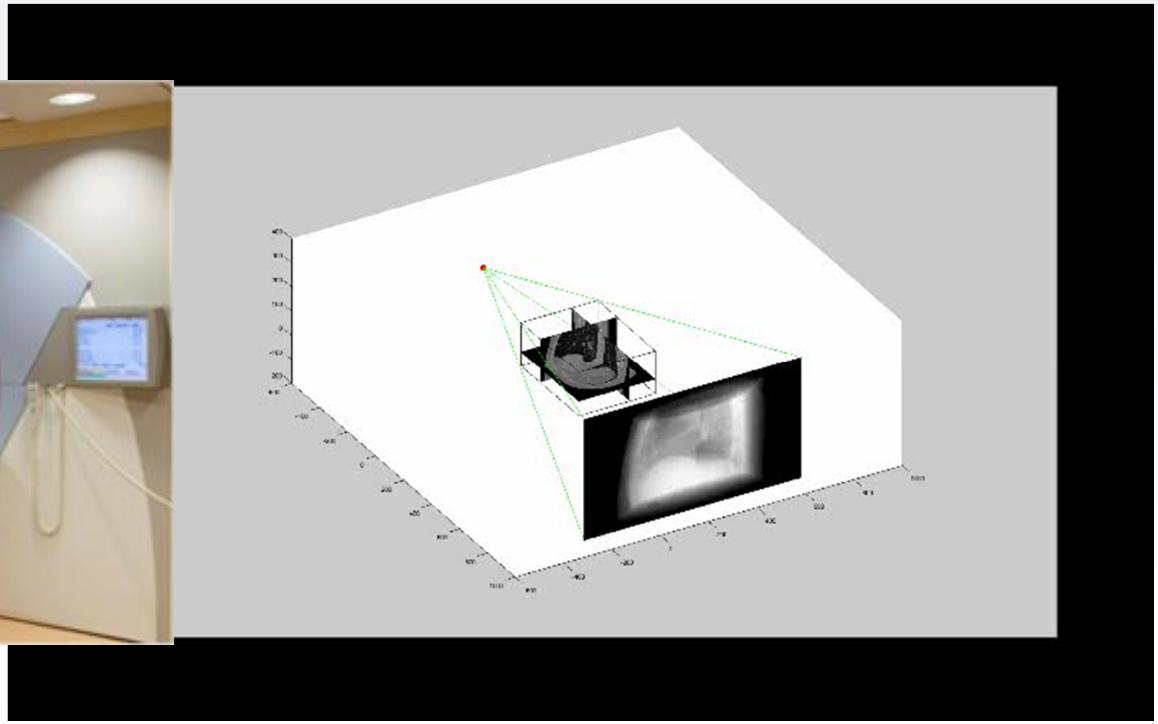
McClelland et al Medical Physics 2006



Problem: Significant interfractional variation in breathing patterns

McClelland et al Phys Med Biol 2011

In-room stereo video, KV and MV imaging with linac



Updated inter-fraction model from cone-beam CT

Combining Image Registration, Respiratory Motion Modelling, and Motion Compensated Image Reconstruction

- Deformation of high quality static reference driven by external surrogate
  - But cannot account for changes from one day to next

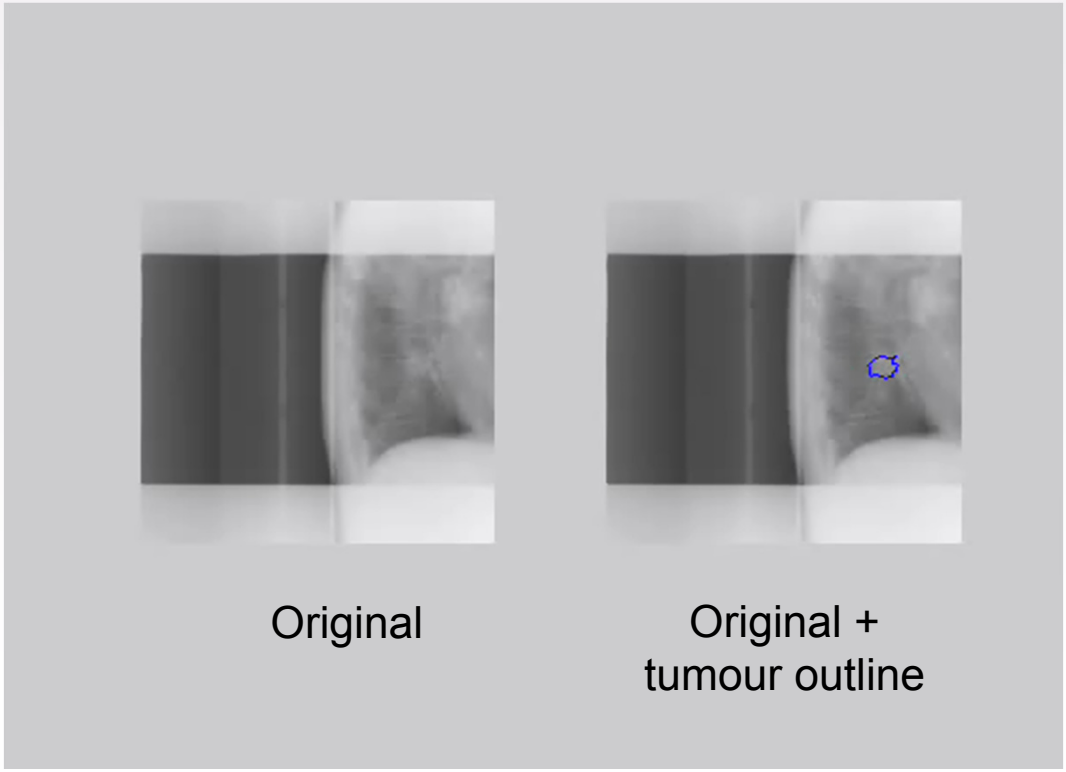
New paradigm

- Simultaneous reconstruction of motion model and static reference
- Synchronisation of motion model driven by real-time partial imaging data (projections, a few slices etc.)

McClelland et al WBIR 2014

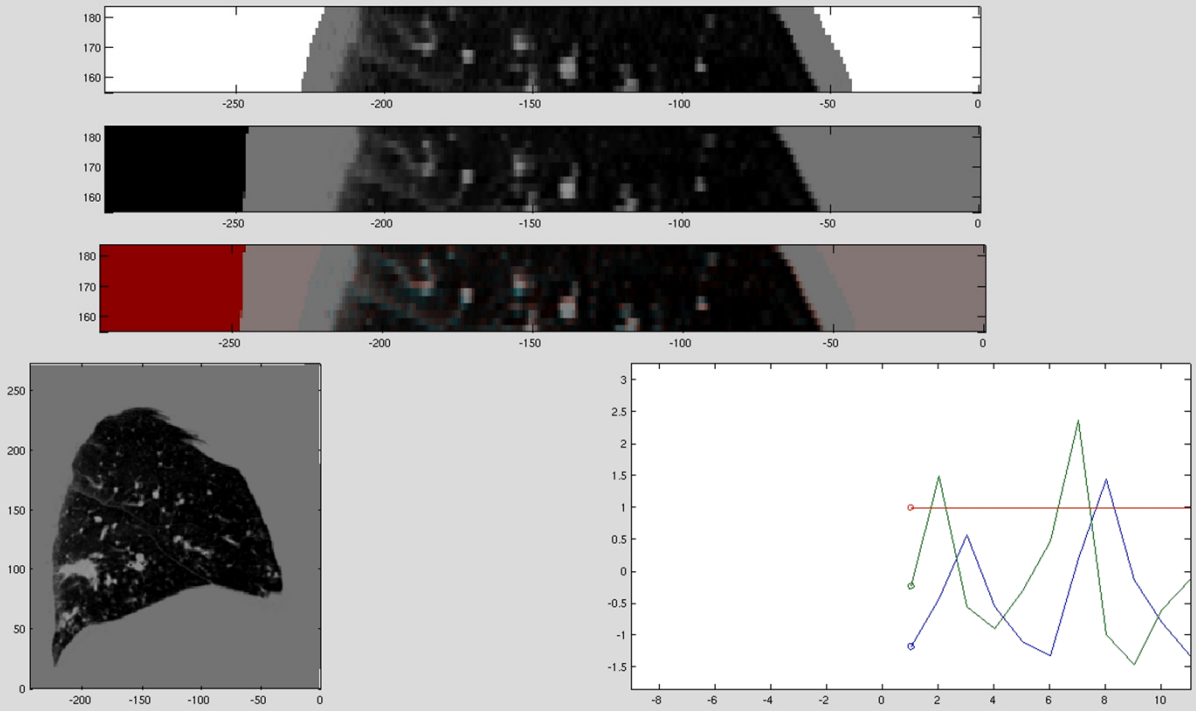
Simultaneous extraction of motion parameters and motion compensated cone-beam reconstruction

Martin et al Phys Med Biol 2013



Synchronised in real-time with intra-fraction 4D skin surfaces (VisionRT)

Preliminary results on real data
Cine CT data – BH as static reference



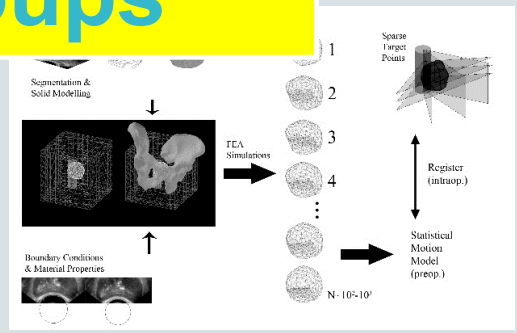
Healthcare Providers

UCL Partners

Medical Engineering Industry

Academic Imaging Groups

Compliance with regulatory environment
Enabling first-in-man and clinical trial



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