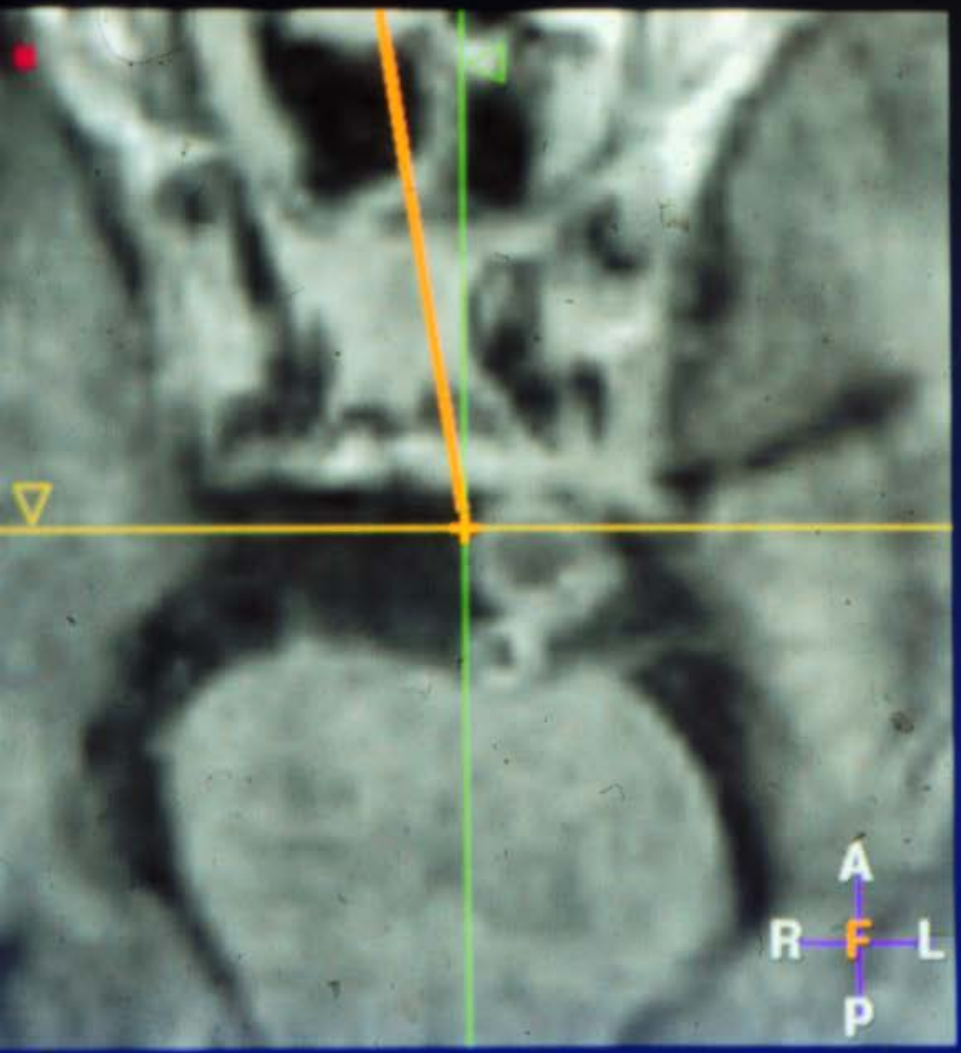
Multi-Scale Image-Guided Interventions

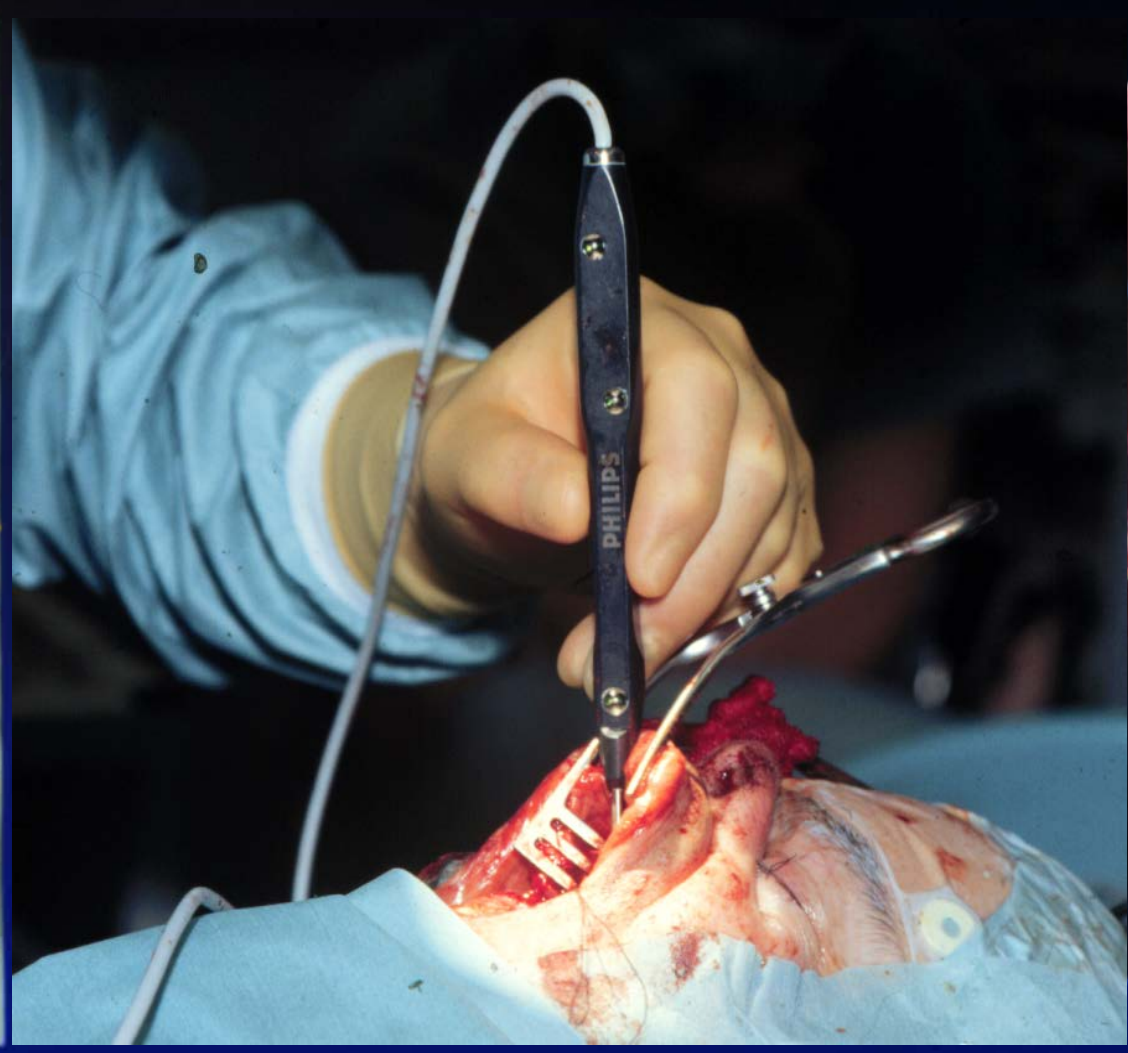
Dave Hawkes,
d.hawkes@ucl.ac.uk
www.ucl.ac.uk/cmic

cmic
Centre for Medical Image Computing

Tracked localiser in use during maxillotomy

Alan Crockard, National Hospital, Queen Square





MAGI system in the Operating Room:

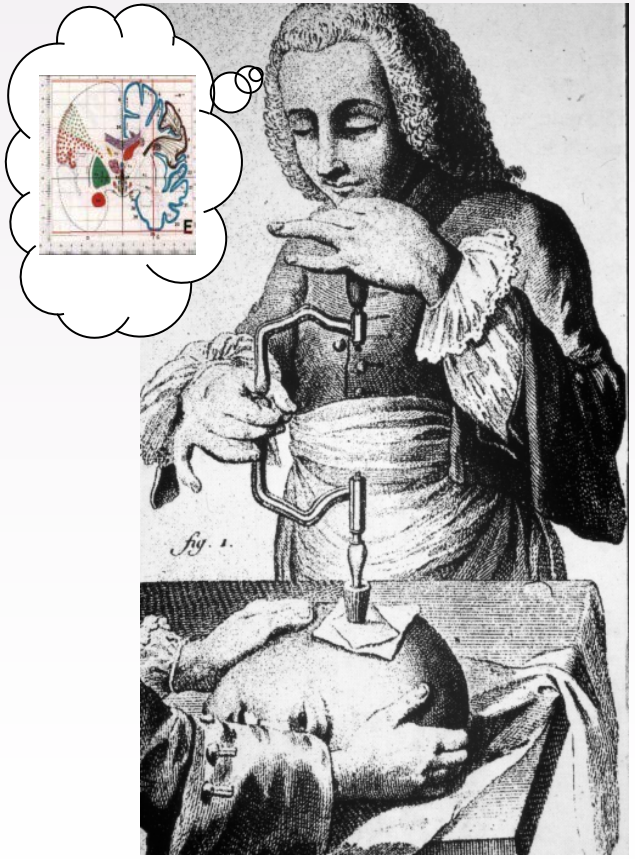
UCL

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

(Edwards et al IEEE-Trans Med Imag 2000)

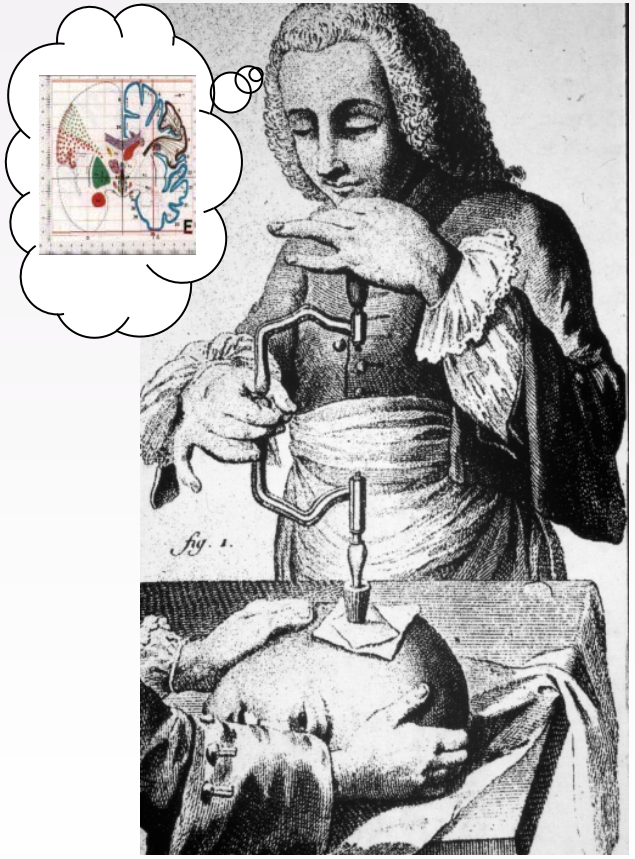
Multi-scale image guided interventions in cancer treatment

- Target identification
- Target location and verification
- Target destruction with minimal collateral damage



Spatial correspondence and tissue characterisation in image guided interventions

- Tissue microstructure, pre- and intra-operatively (In-vivo “histology”)
- Maintaining a target accuracy of ~1mm in presence of soft tissue deformation
  - Neurosurgery
  - Patient stratification and focal therapy in prostate and breast cancer
  - Compensation for tissue deformation in the prostate or breast and respiratory motion in the liver and lung.



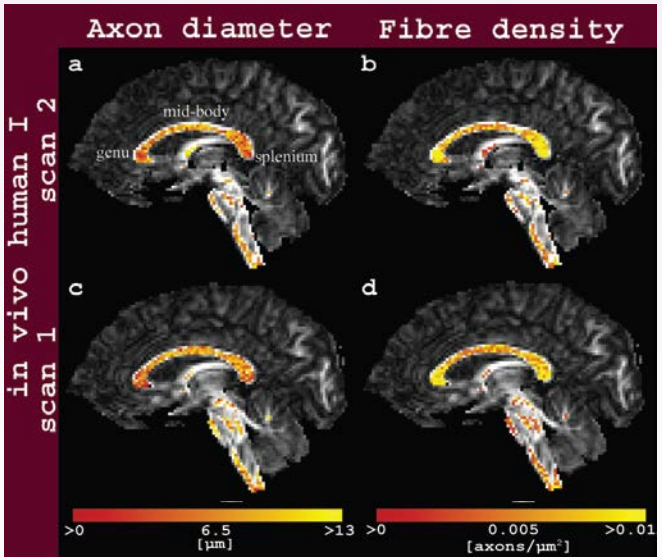
MR advances in tissue microstructure, physiology and metabolism in cancer

- Glucose CEST (Walker-Samuel et al, Nature Med 2013)
- C-13 Pyruvate etc with Hyperpolarised MR
- Tissue Microstructure with diffusion MRI – VERDICT (Panagiotaki et al Cancer Research 2013)
  - Exploring assessment of the tissue heterogeneity (the phenotype) related to the genetic heterogeneity

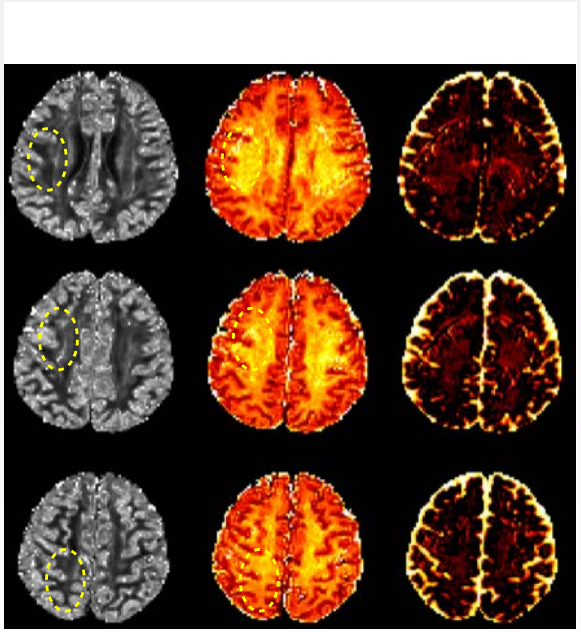
iMRI facility at NHNN

Brain Microstructure Imaging

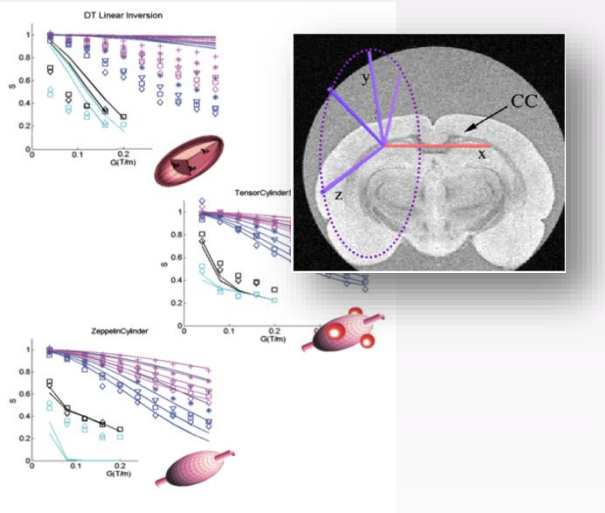
Alexander et al
NeuroImage 2010

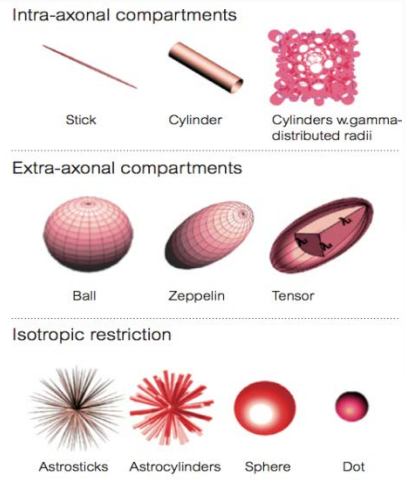


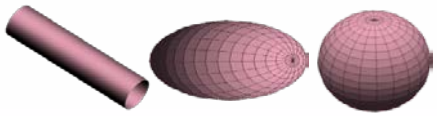
Zhang et al
NeuroImage 2012

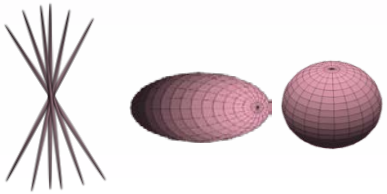


Panagiotaki et al
NeuroImage 2012



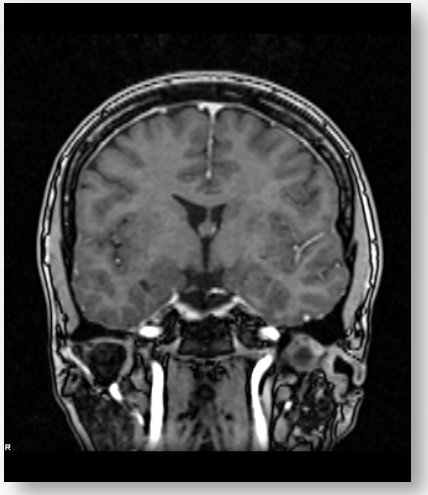


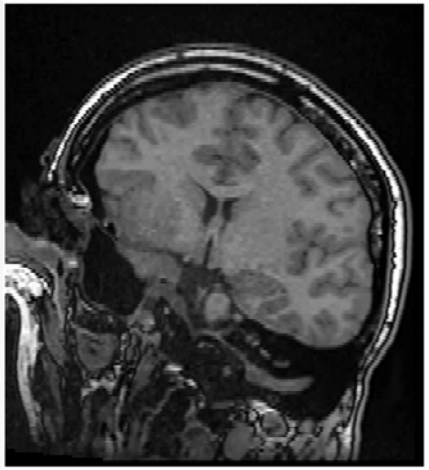


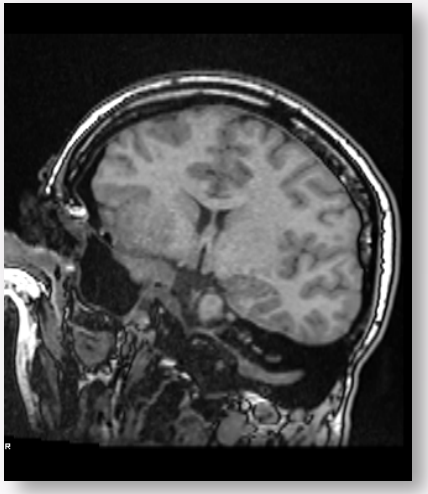


Planning and guiding avoidance of optic radiation

Daga, Duncan, Ourselin et al IEEE TMI 2012



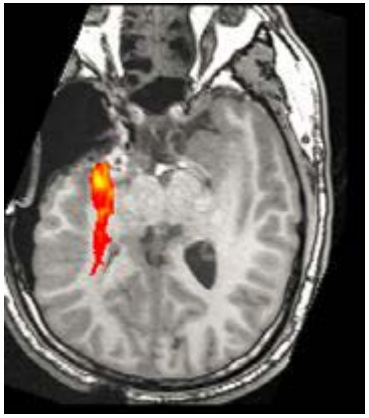




Pre-operative image and plan

Intra-operative image

Optic radiation

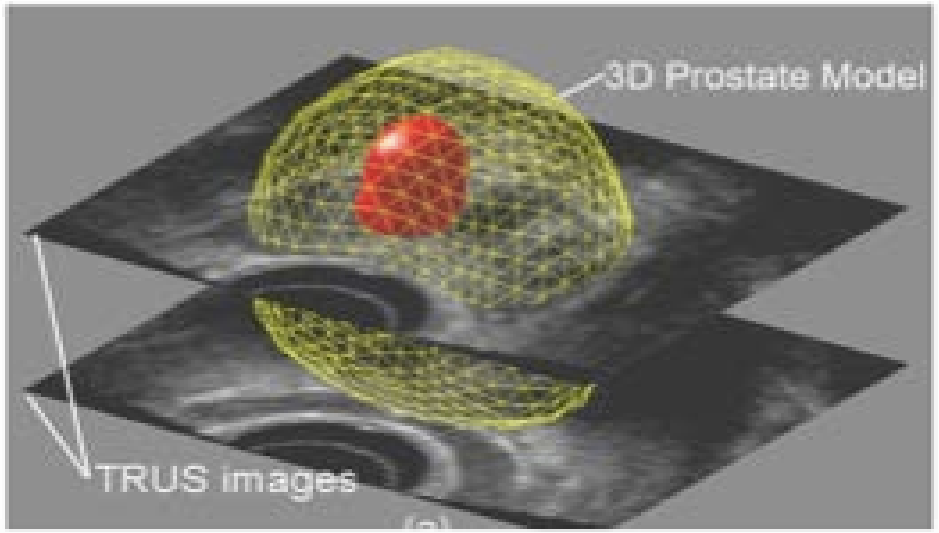


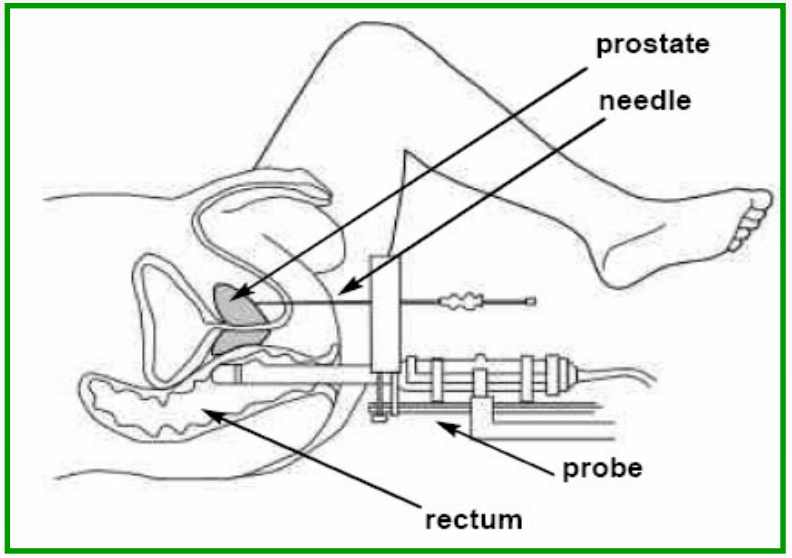
27% visual field loss

No visual field loss

Prostate Cancer:
Image guided biopsy and focal ablation

Mark Emberton, Hash Ahmed, Dean Barratt, Yipeng Hu

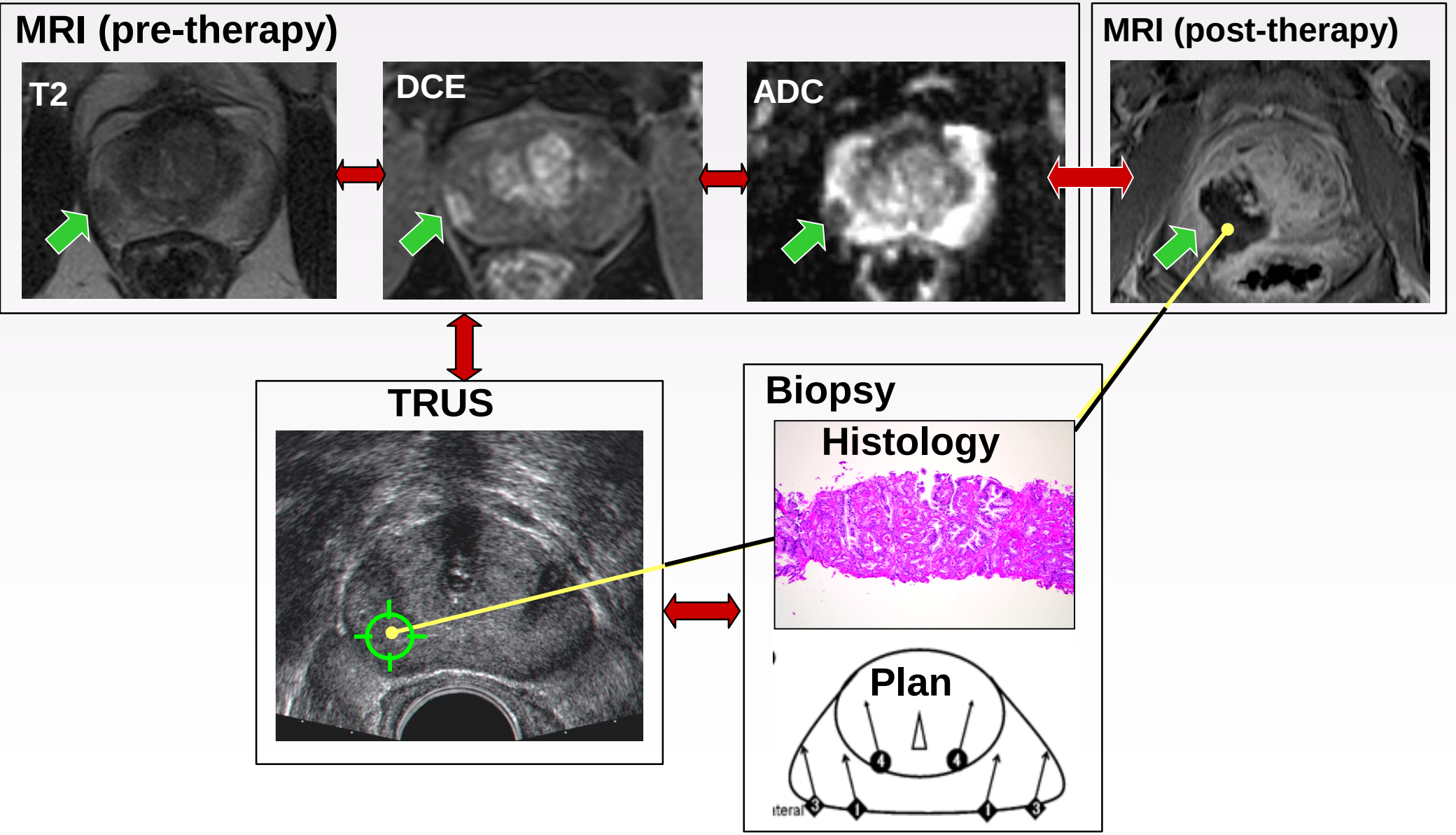




Ahmed et al Lancet Oncology 2012

Centre for Medical Image Computing

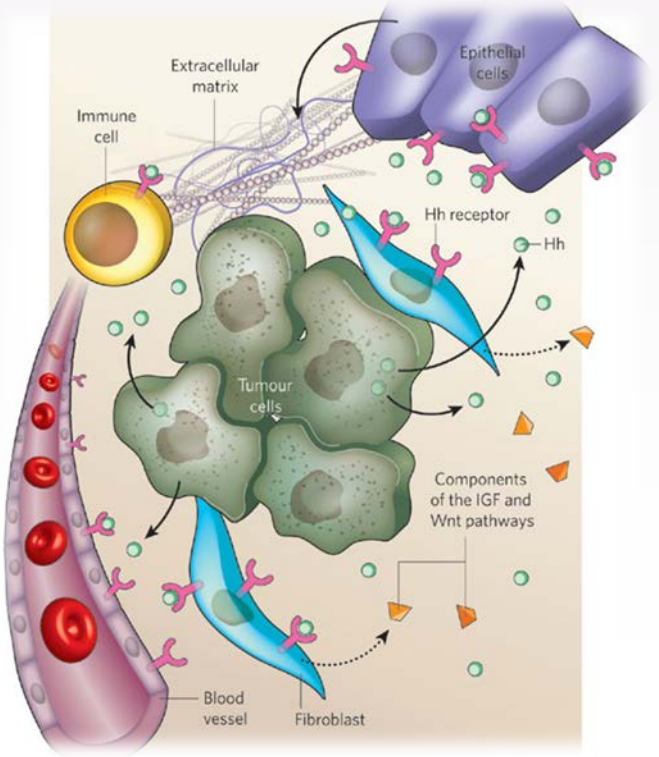
Prostate cancer: the need for image registration



The VERDICT Model

- Signal comes from
  - intracellular water trapped inside cells.
  - extracellular, non-vascular water adjacent to, but outside cells and blood vessels.
  - water in blood undergoing microcirculation in the capillary network.

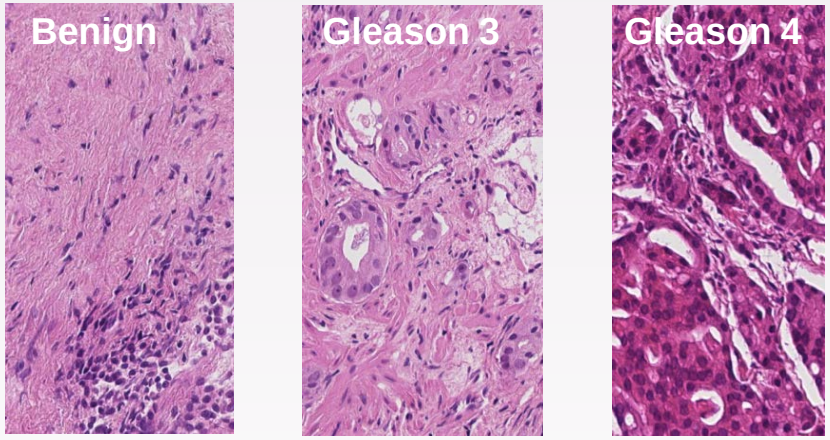
$$S = \sum_{i=1}^{3} f_i S_i \qquad i\ , 0 \leq f_i \leq 1\ , \sum_{i=1}^{3} f_i = 1.$$

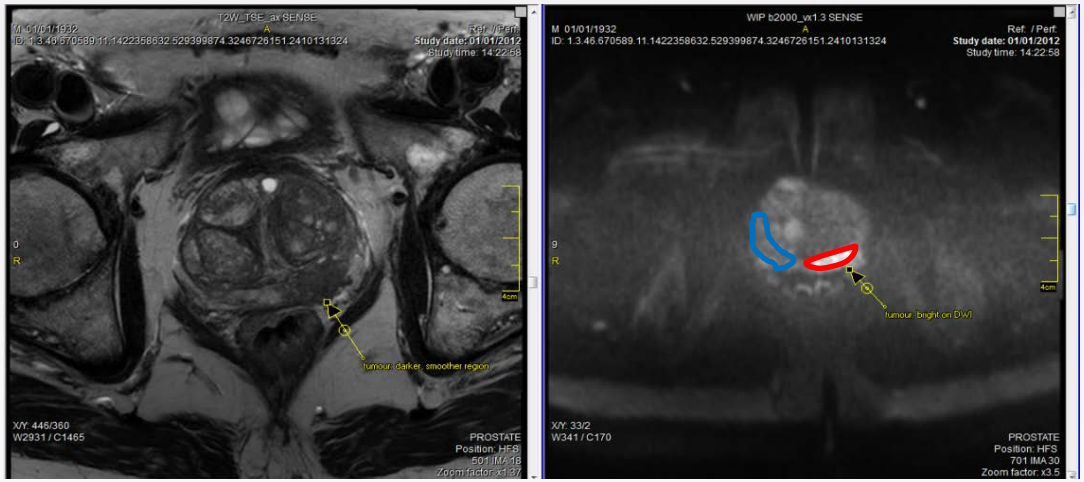


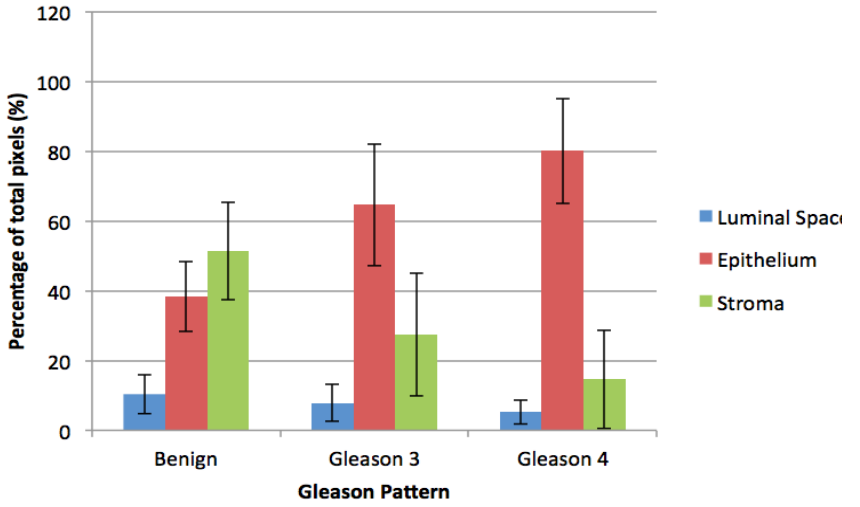
Panagiotaki et al Cancer Research 2013

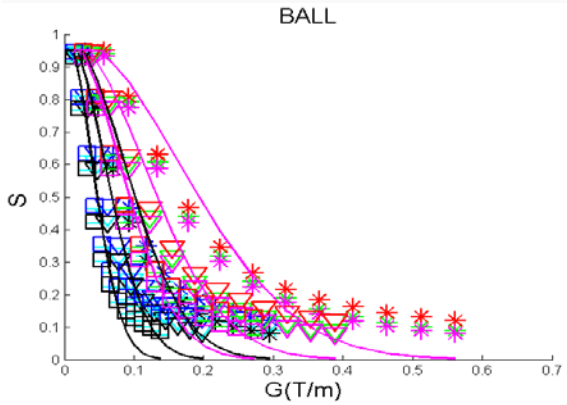
Microcompartment MRI-DW Imaging and modelling

Non-invasive Gleason Grading of Prostate Cancer

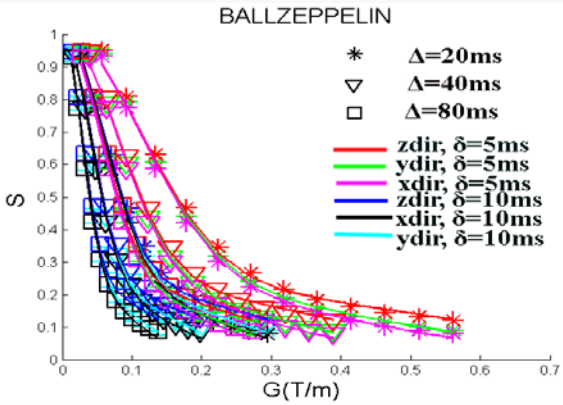








MSE fit= 1.36



MSE= 0.0312

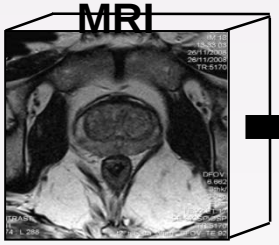
E. Panagiotaki, D. Alexander, D. Hawkes, ISMRM 2013, 2014 *EPSRC Programme Grant*

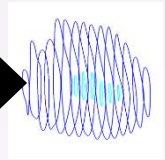
Real-time tracking of the prostate using US and MRI

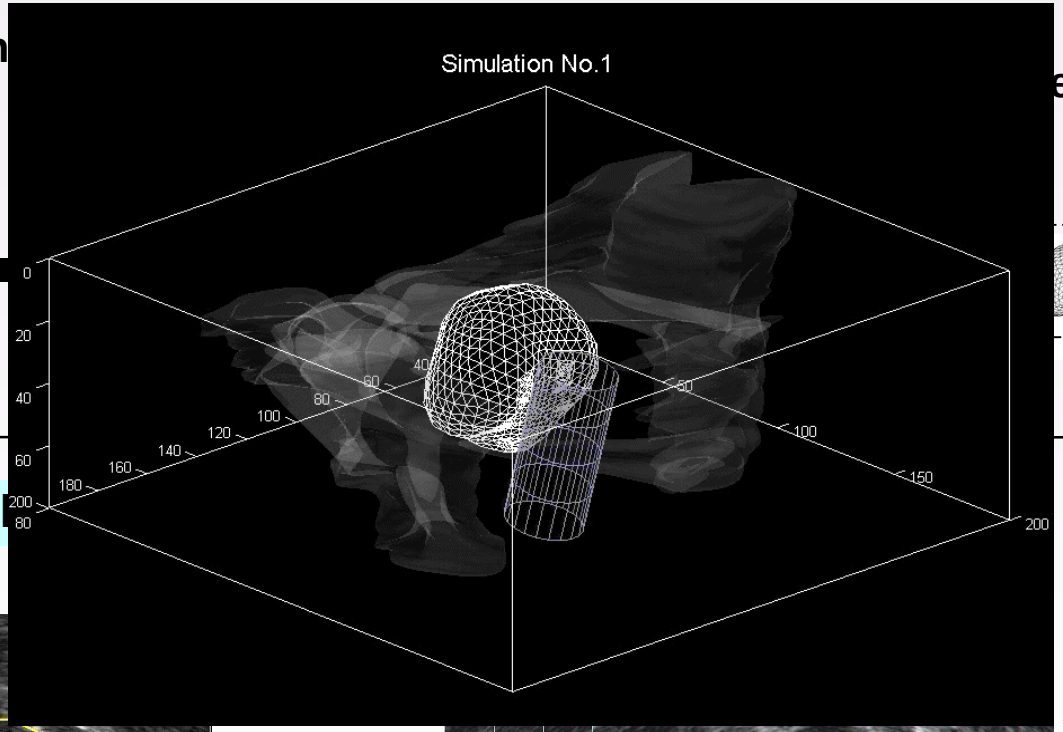
PRE-PROCEDURE

Referen

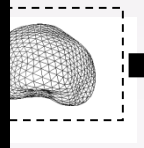
MRI





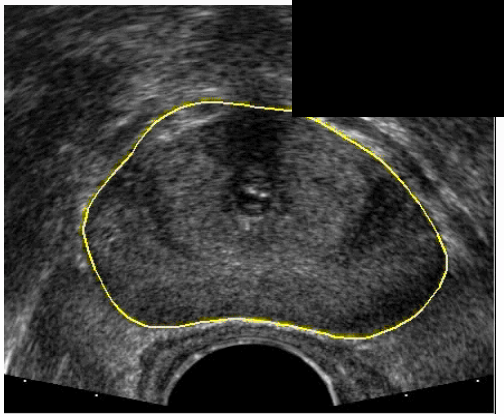


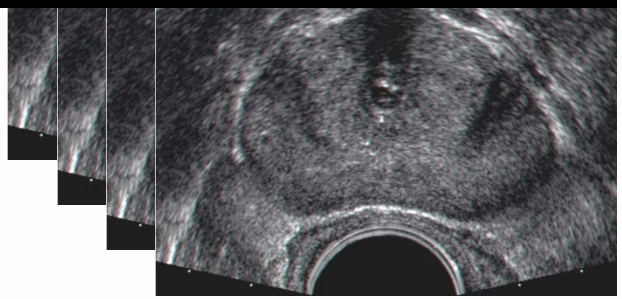
es



Patient-specific SPSM

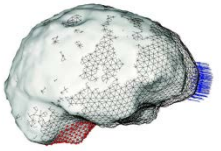
DURING PROCEDURE



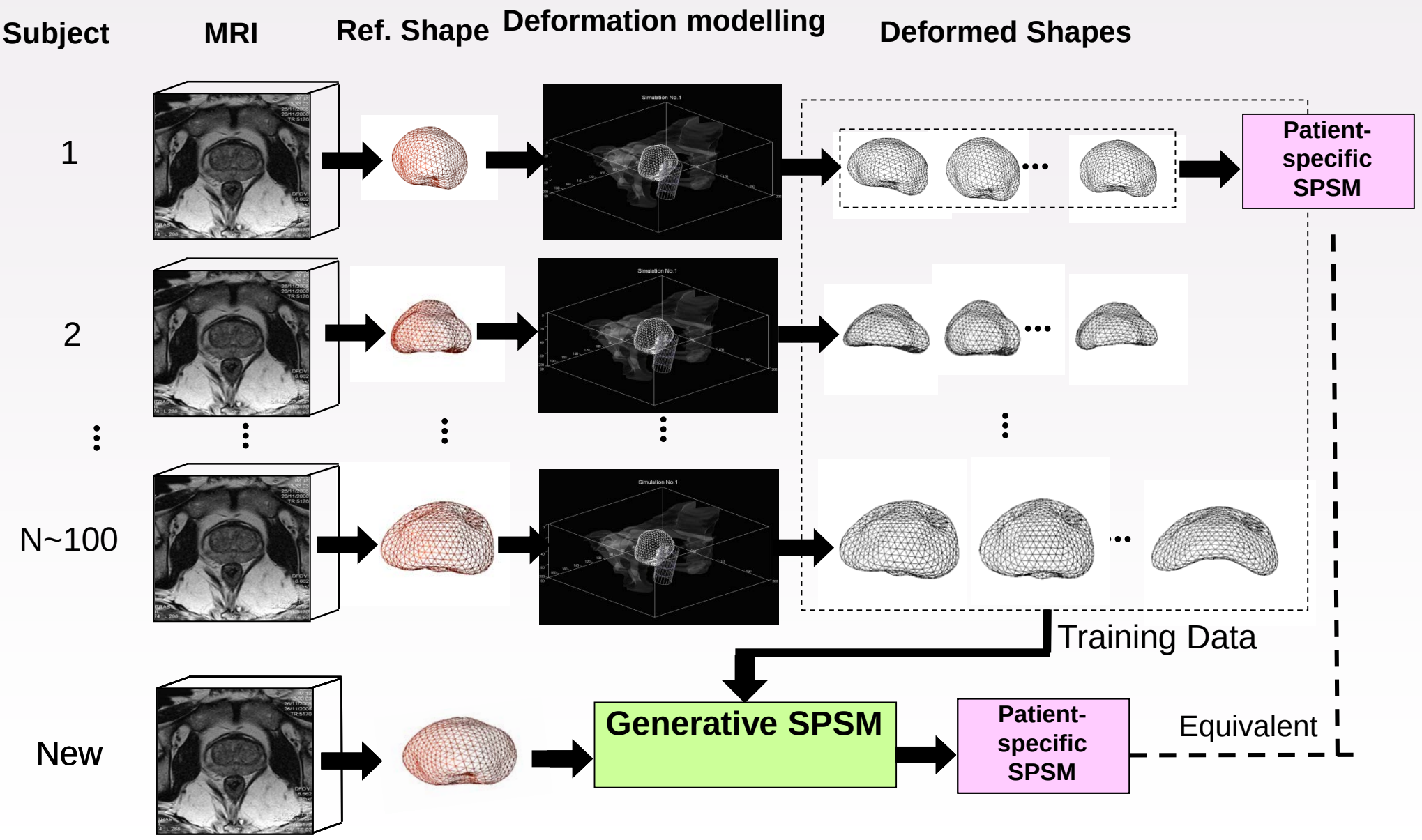


Register

NiftySim

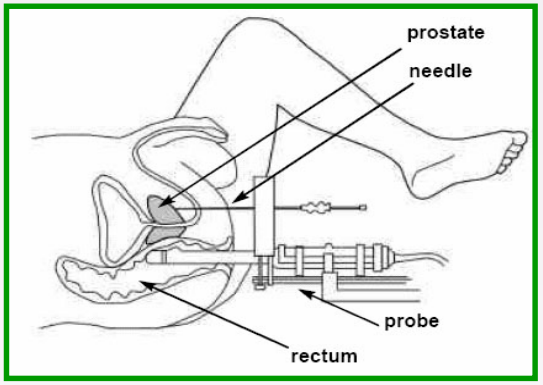


Automatic generation of deformable organ models

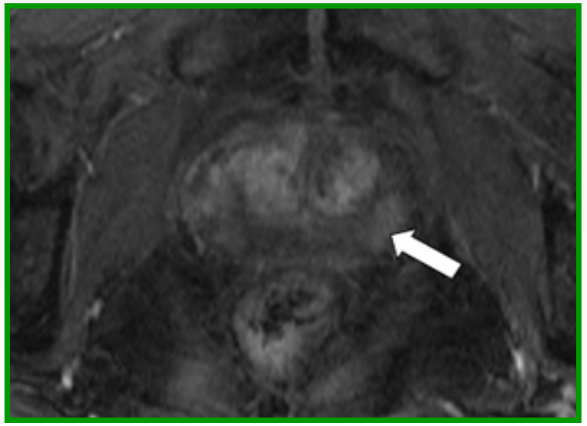


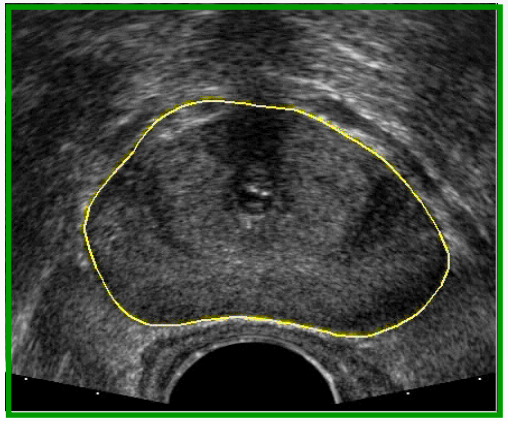
Hu et al. Medical Image Analysis, 2012

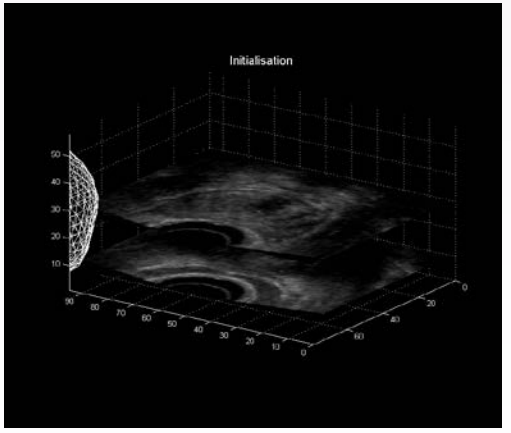
Image Directed Biopsy and Partial Prostate Ablation



- 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

Screening, diagnosis and treatment of breast cancer

X-ray mammography screening

Diagnostic MRI

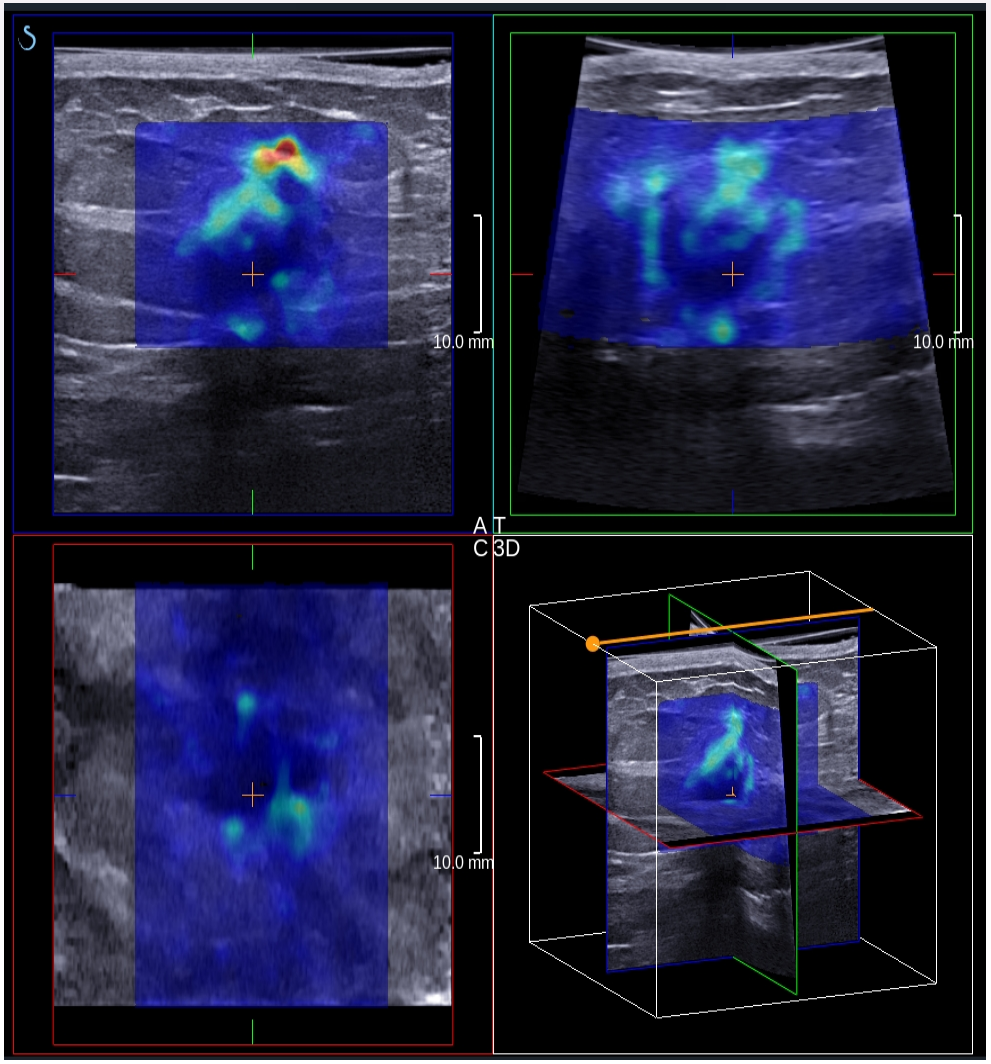
Image guided lumpectomy

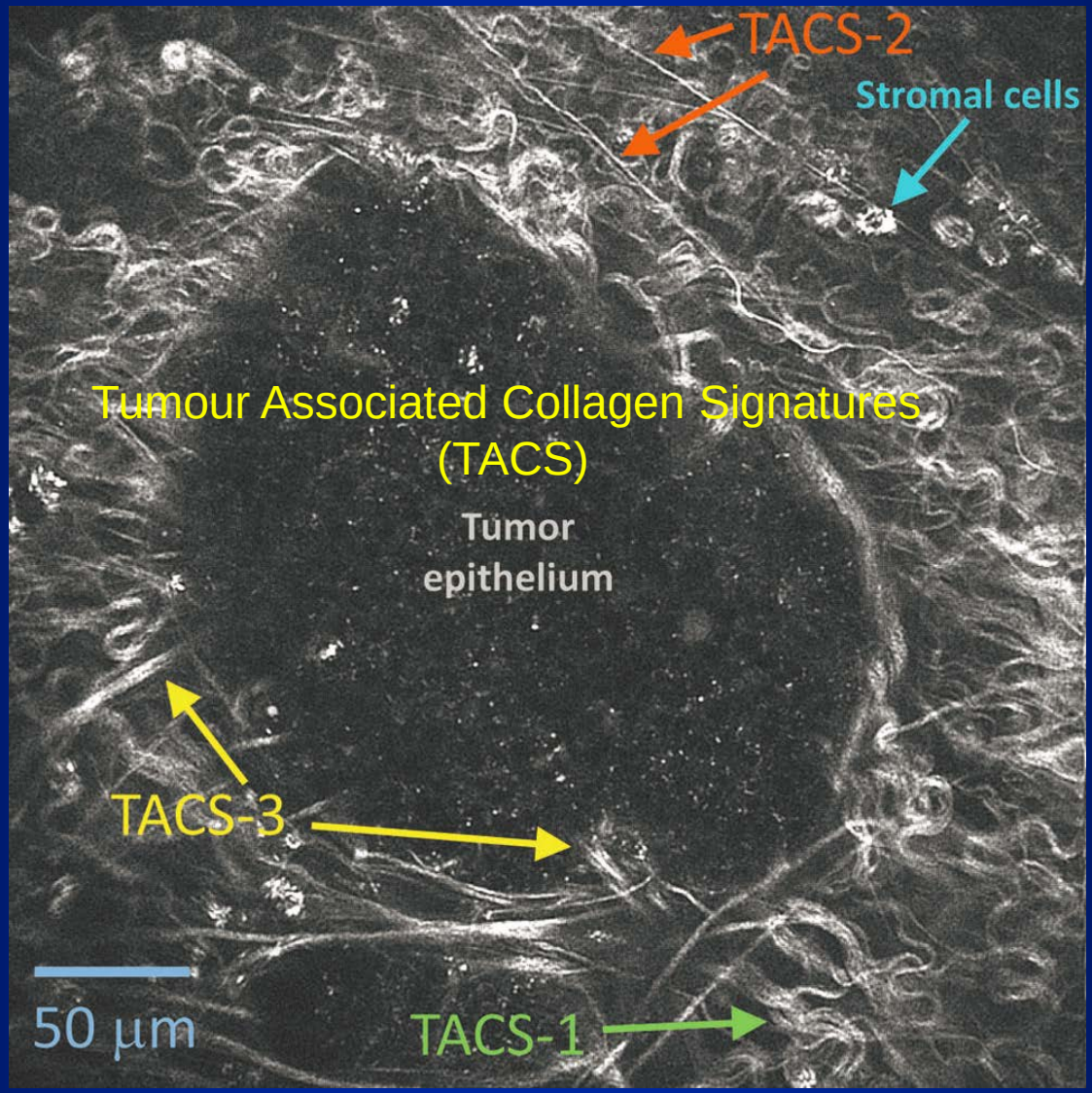
Over diagnosis of breast cancer

- Wolfe suggests dense breast has 37x greater risk than least dense grade [1976]
- 2 – 6 fold increase in breast cancer risk with breast density (Boyd et al, JNCI, 1995)
- Mammographic density increase associated with increase in cellularity but primarily increase in collagen
- Evidence that in symptomatic patients peri-tumoral stromal tissue is stiffer (Evans et al 2012)

3D ultrasound shearwave

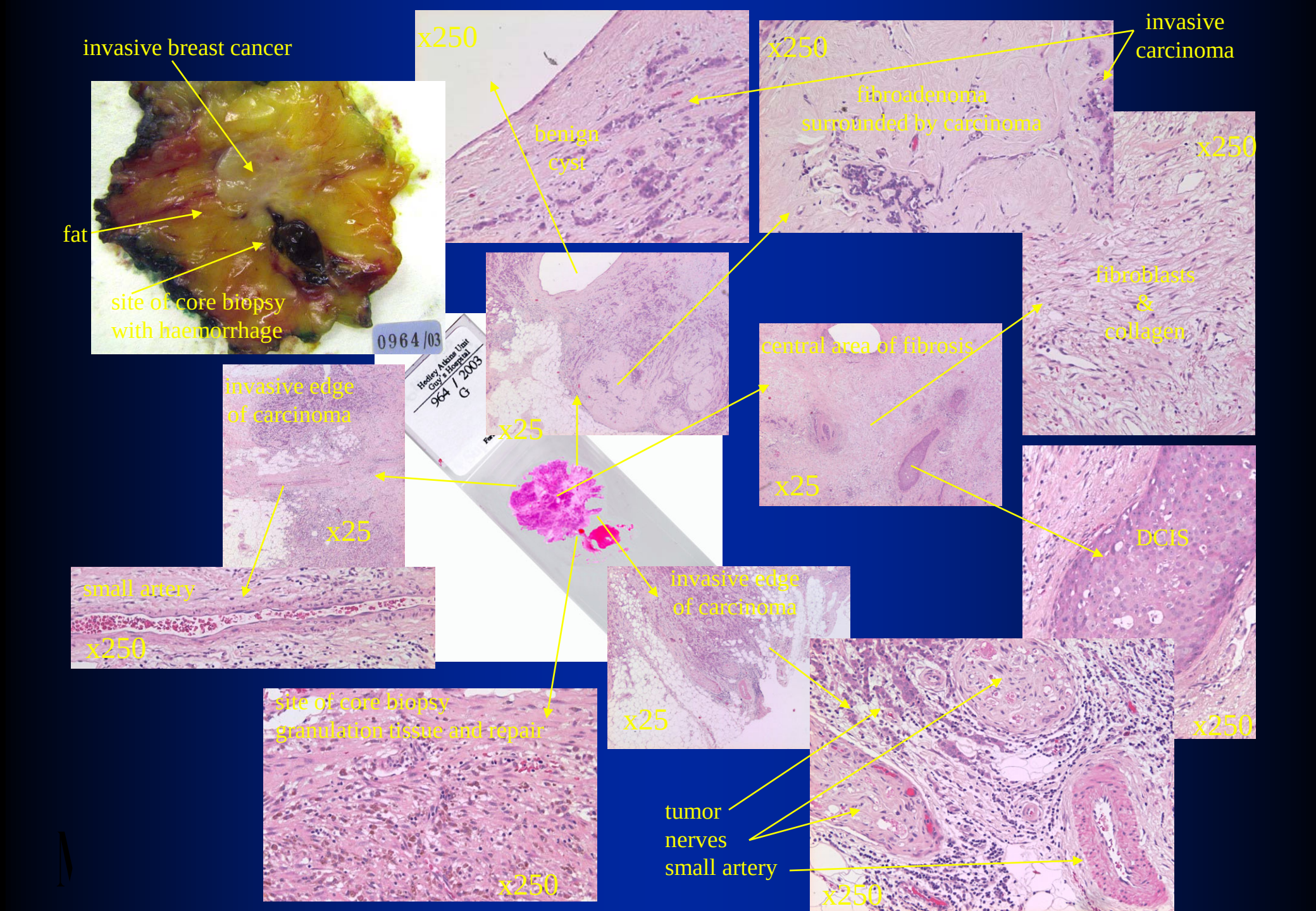
(Courtesy of Prof Andy Evans, Dundee)



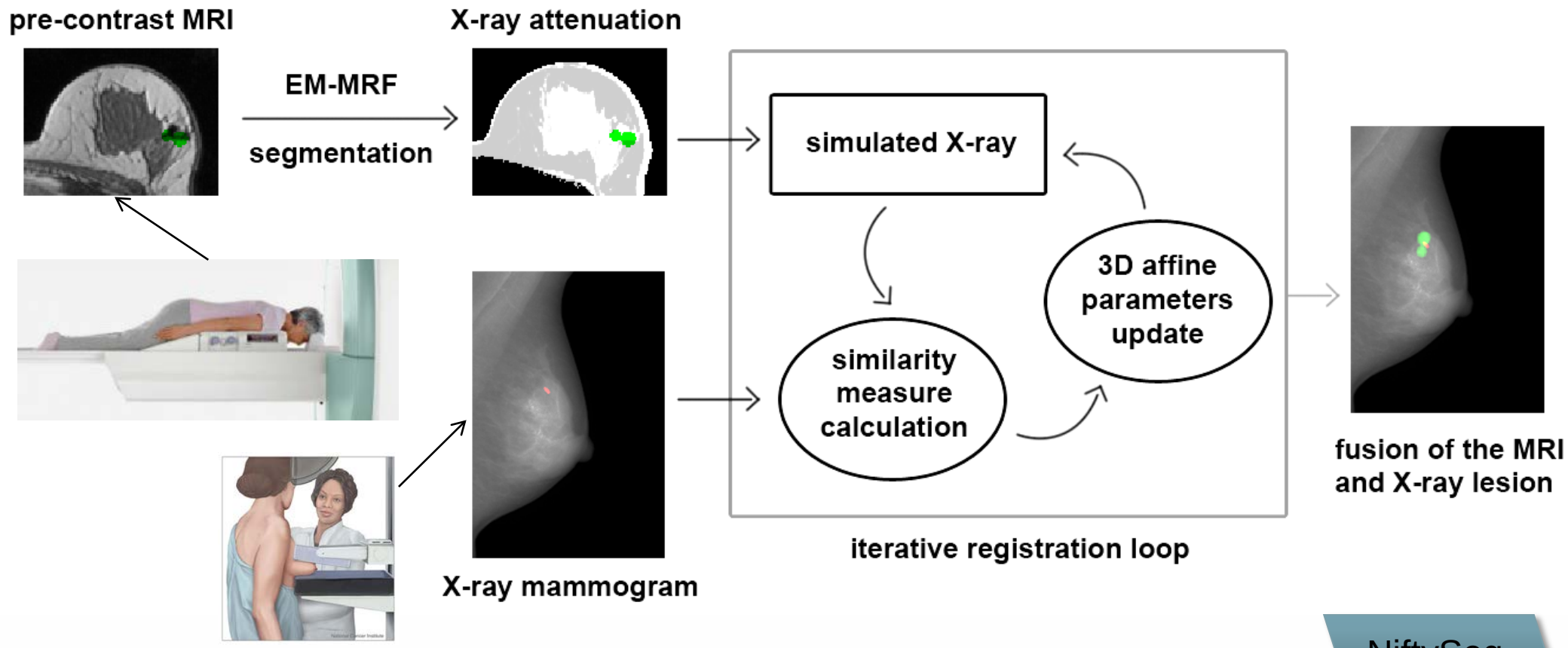


- "Potential for application during surgery and biopsy … can be performed on fresh, unstained tissue"
- "Changes in tensional forces and extracellular matrix stiffness could be used to define disease progression"

Conklin and Keeley, Cell Adhesion and Migration(2012), 6:3, 249-260


invasive breast cancer
fat
site of core biopsy
with haemorrhage
0964/03
Hedley Atkins Unit
Guy's Hospital
964 / 2003
G
For
x250
benign
cyst
x250
invasive
carcinoma
fibroadenoma
surrounded by carcinoma
x250
fibroblasts
&
collagen
x25
central area of fibrosis
x25
invasive edge
of carcinoma
x25
DCIS
x250
small artery
x250
invasive edge
of carcinoma
x25
site of core biopsy
granulation tissue and repair
x250
tumor
nerves
small artery
x250

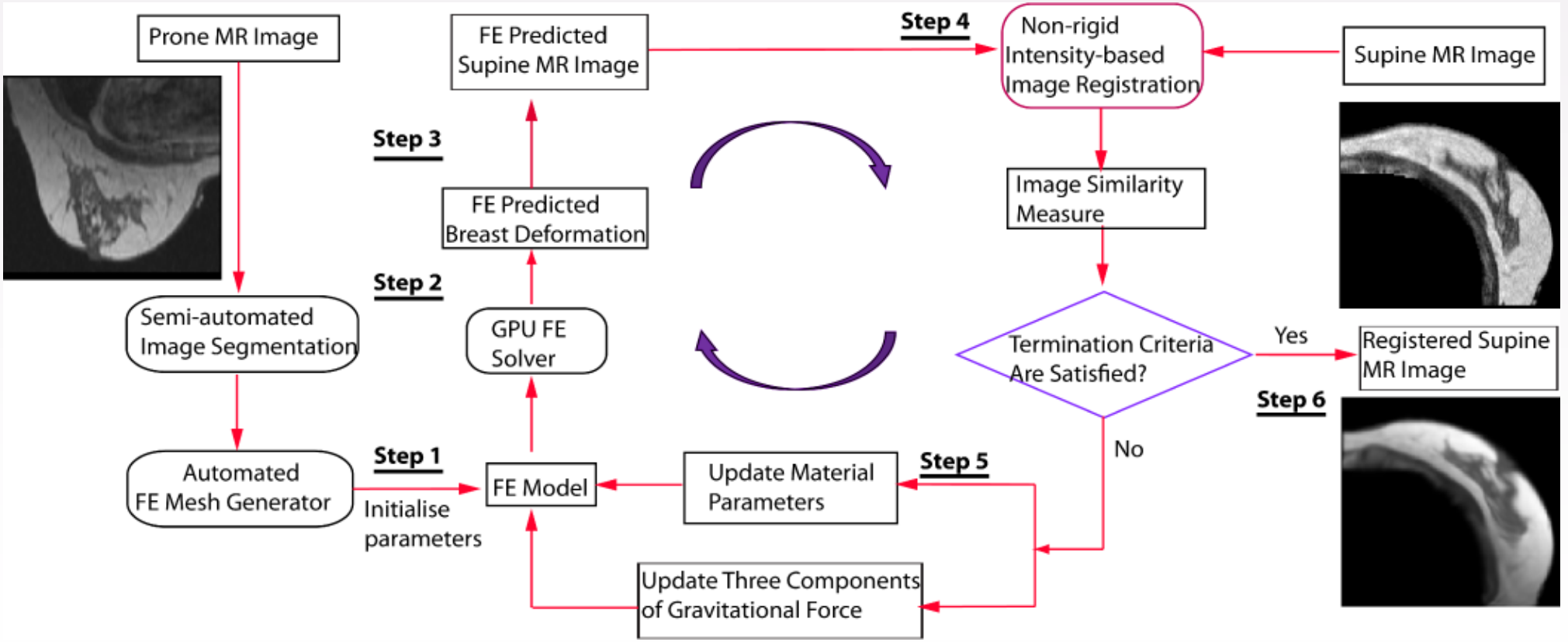
MRI to X-ray mammography registration and visualisation



T. Mertzanidou et al IWDM 2010, Medical Image Analysis 2012, 2014

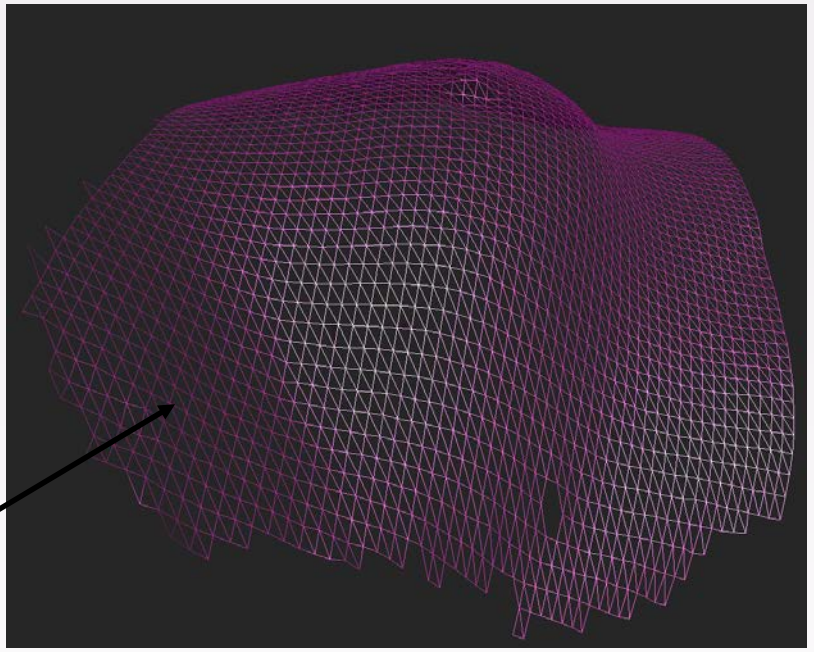
NiftySeg

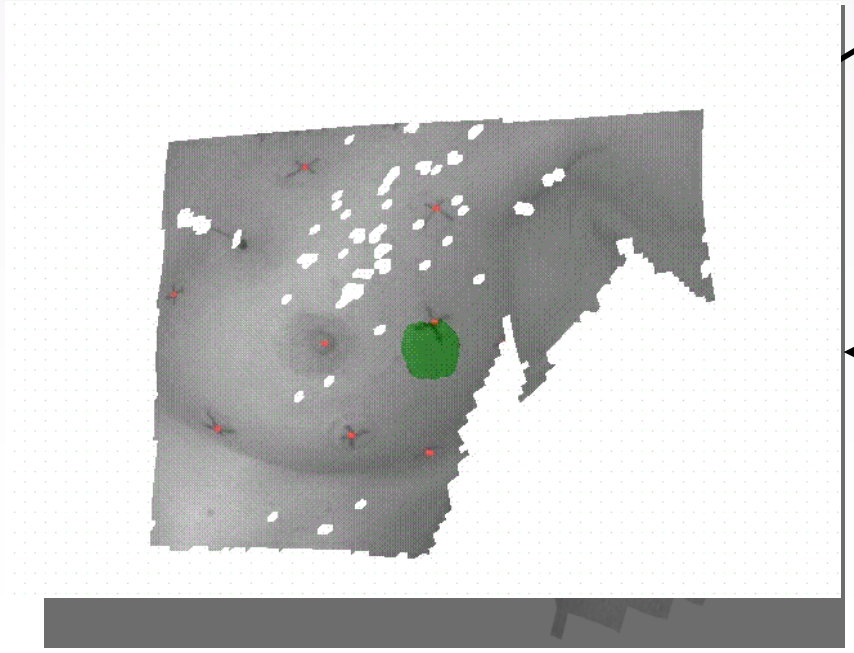
Correspondence between prone and supine MR images of the breast

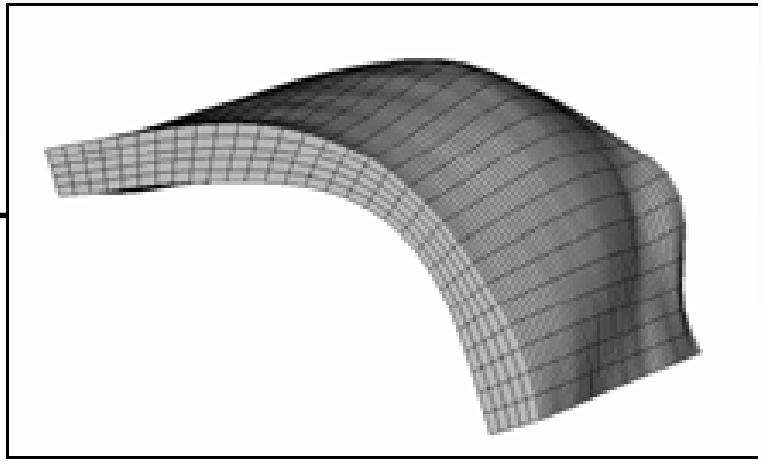


Han et IEEE-tMI 2014

Guidance for breast surgery

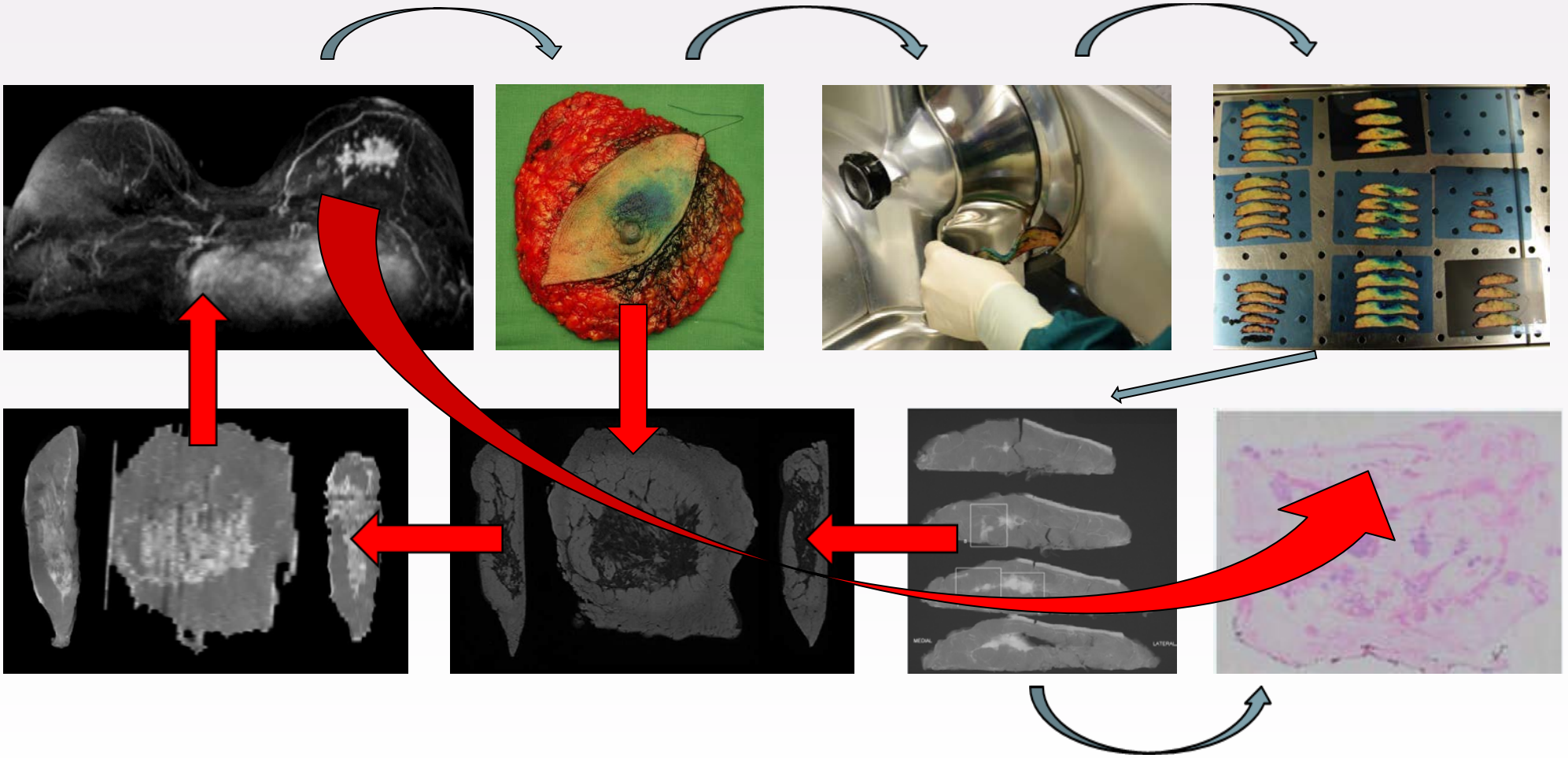






Tim Carter, Nick Beechy-Newman (Guy's Hospital) and Dave Hawkes

Spatial correlation from radiological image to histology



Mertzanidou, Hipwell, Dalmis, Platel, van der Laak, Mann, Karssemeijer, Bult, Hawkes
RUMC Nijmegen and UCL, IWDM 2014

Motion models to improve tissue correspondence in structures moving with the respiratory cycle

e.g. Lung and Liver

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

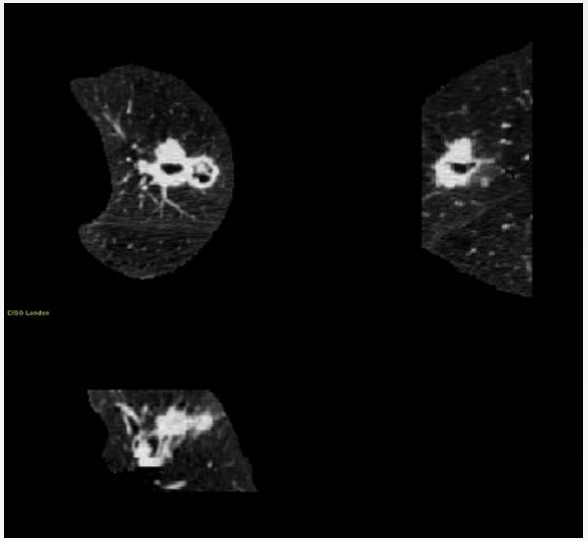
- Deformation of high quality static reference driven by external surrogate
  - But cannot account for changes from one day to next

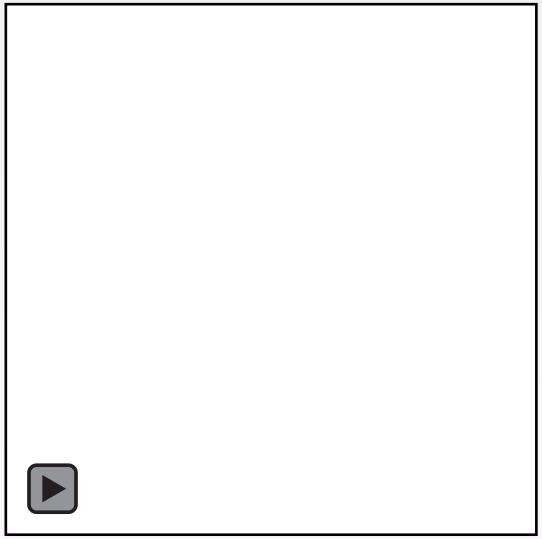
New paradigm

- 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

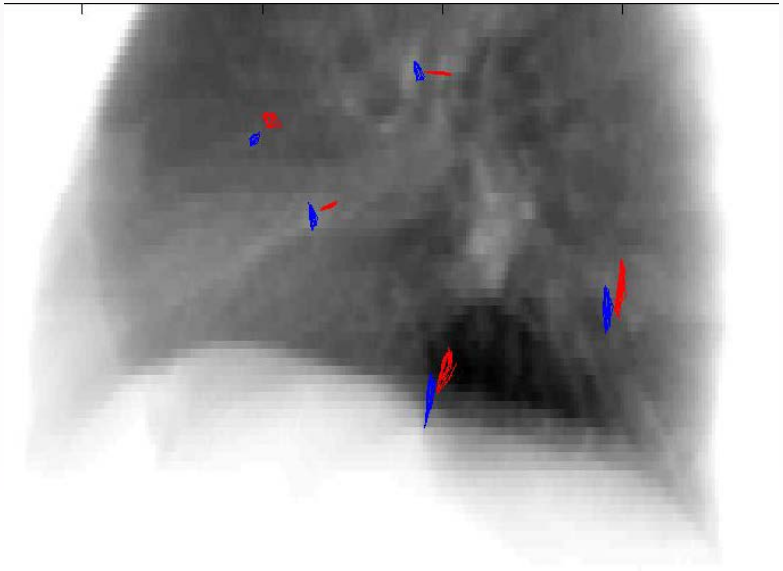
Motion compensation in lung radiotherapy





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

McClelland et al Medical Physics 2006

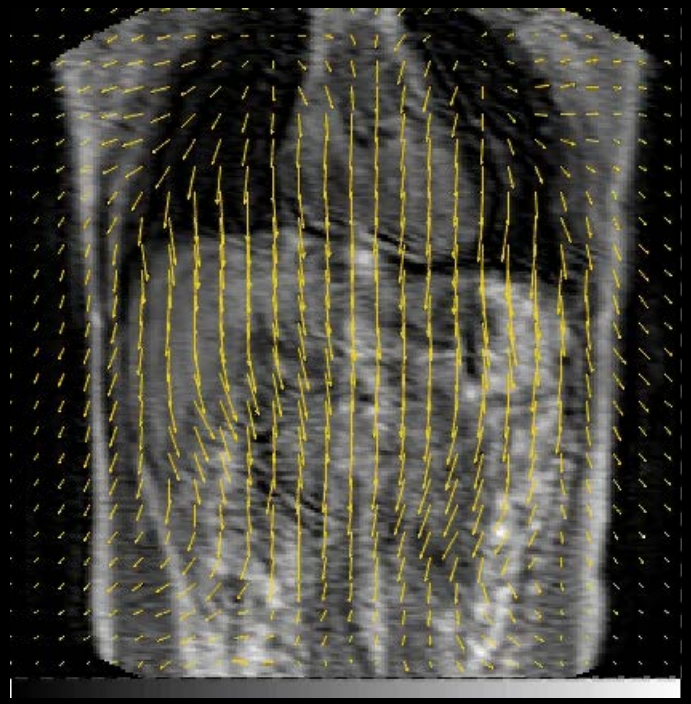


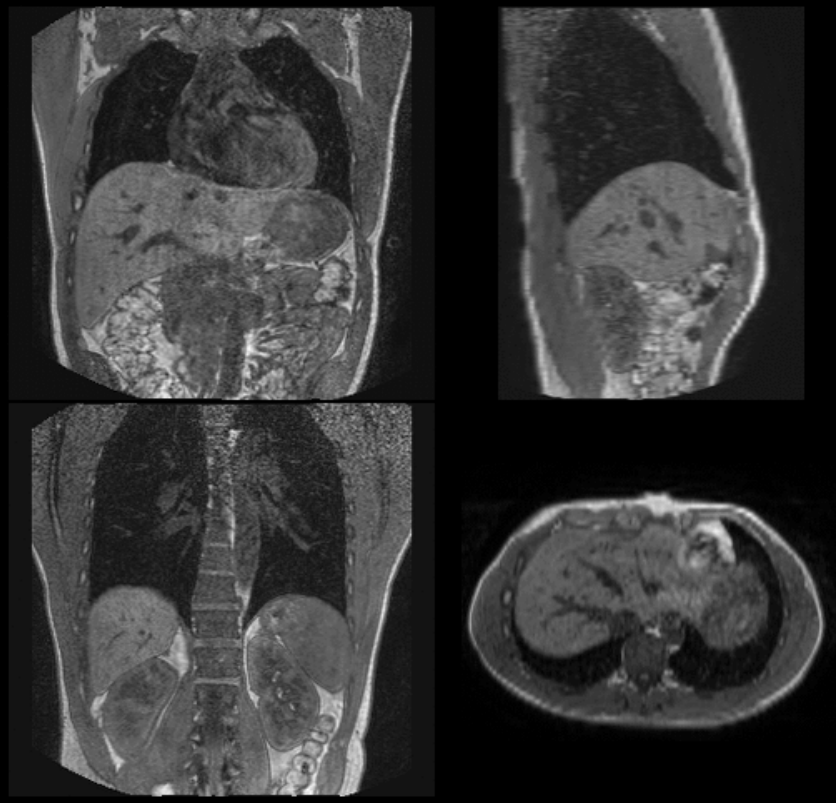
Problem: Significant interfractional variation in breathing patterns

McClelland et al Phys Med Biol 2011

Transcostal High Intensity Focussed Ultrasound of Lesions of the Liver

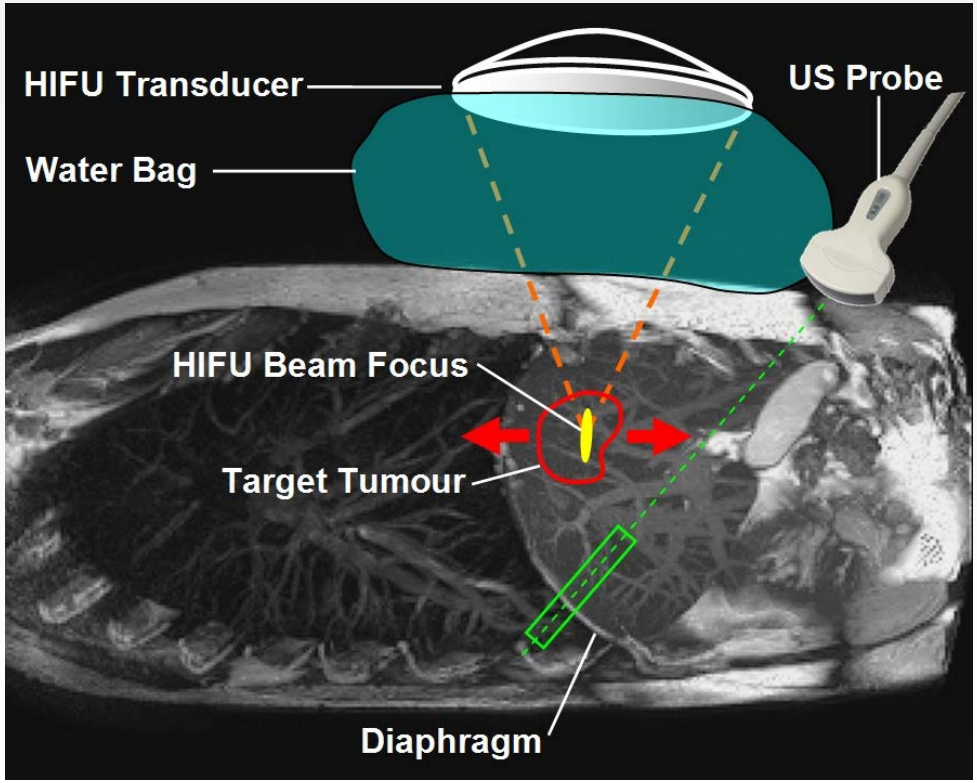
Breathing Patterns from Real-time MR THRIVE and motion modelling

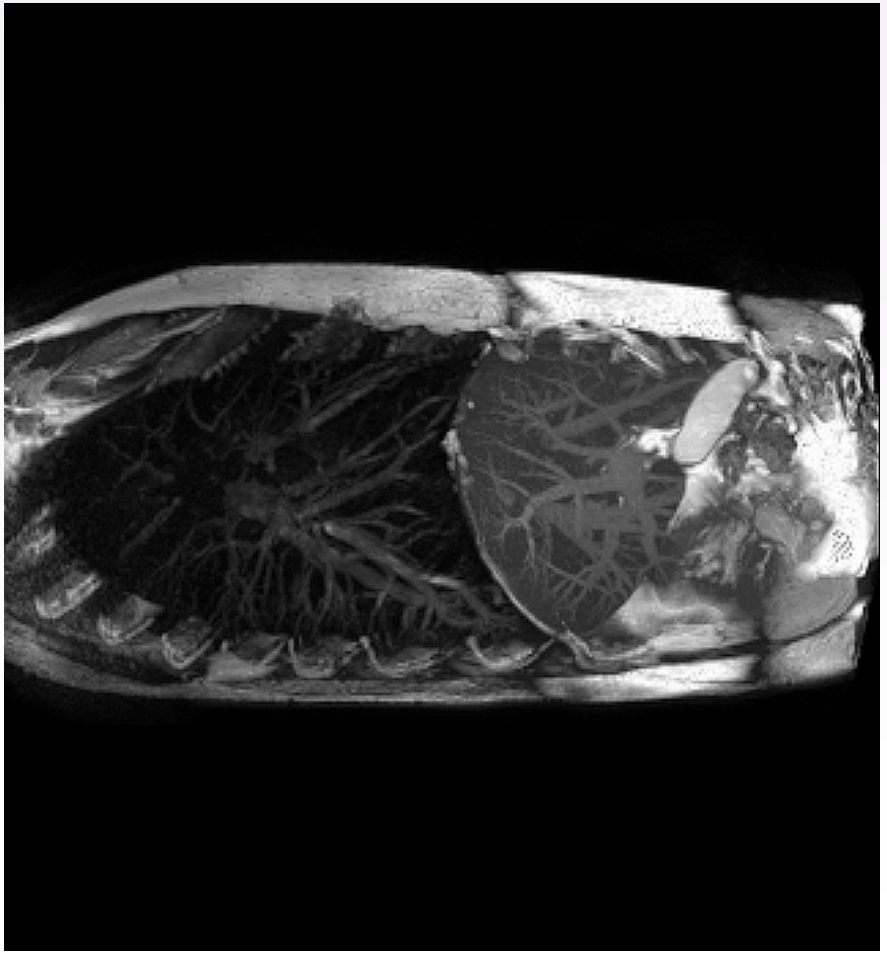




Erik Rijkhorst et al IPCAI 2010, MICCAI 2011

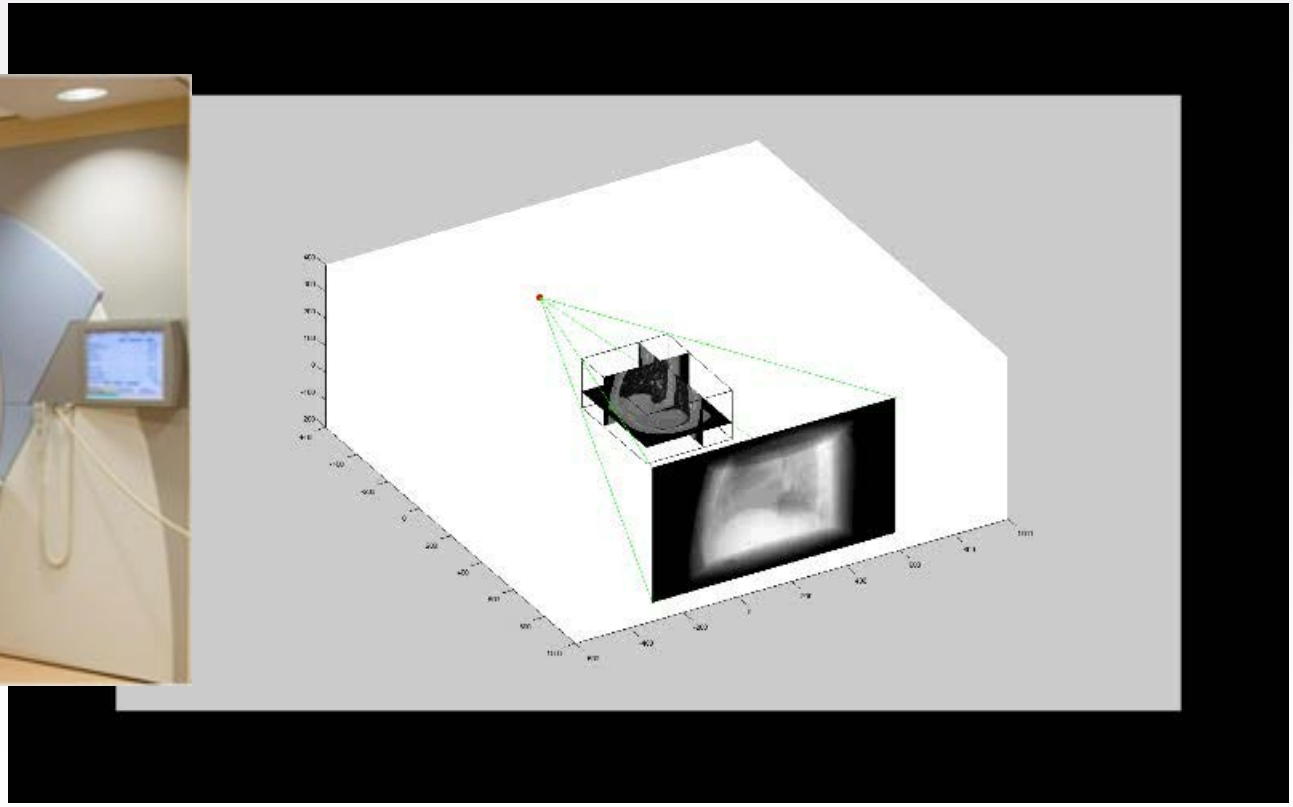
Transcostal High Intensity Focussed Ultrasound of Lesions of the Liver





Erik Rijkhorst et al IPCAI 2010, MICCAI 2011

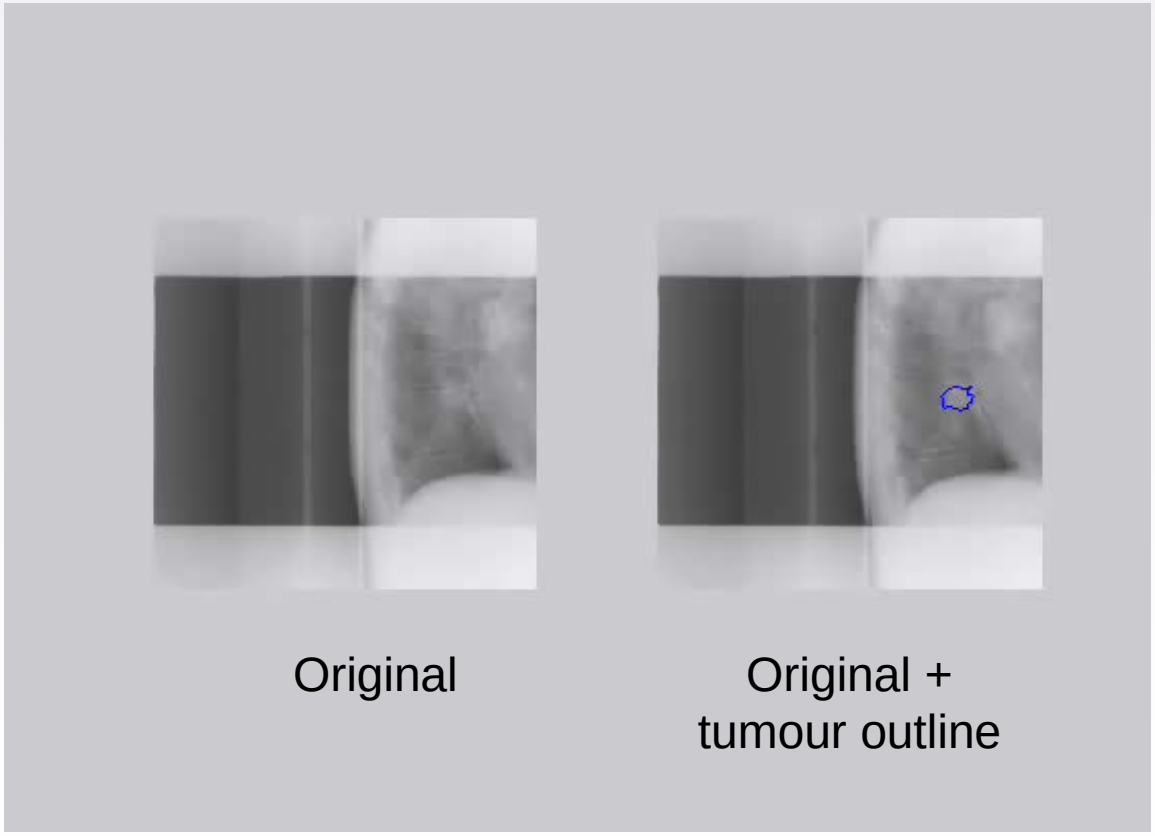
In-room stereo video, KV and MV imaging with linac



Updated inter-fraction model from cone-beam CT

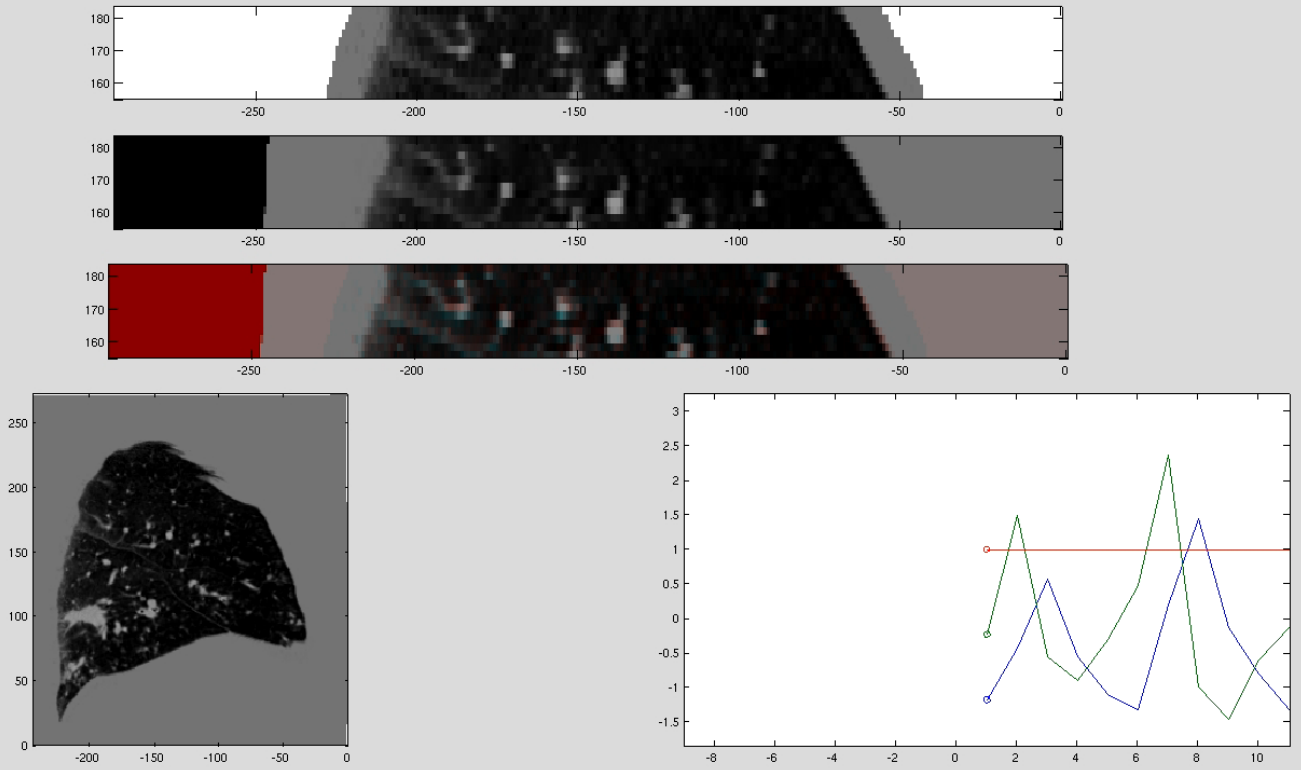
Simultaneous extraction of motion parameters and motion compensated cone-beam reconstruction

Martin et al Phys Med Biol 2013

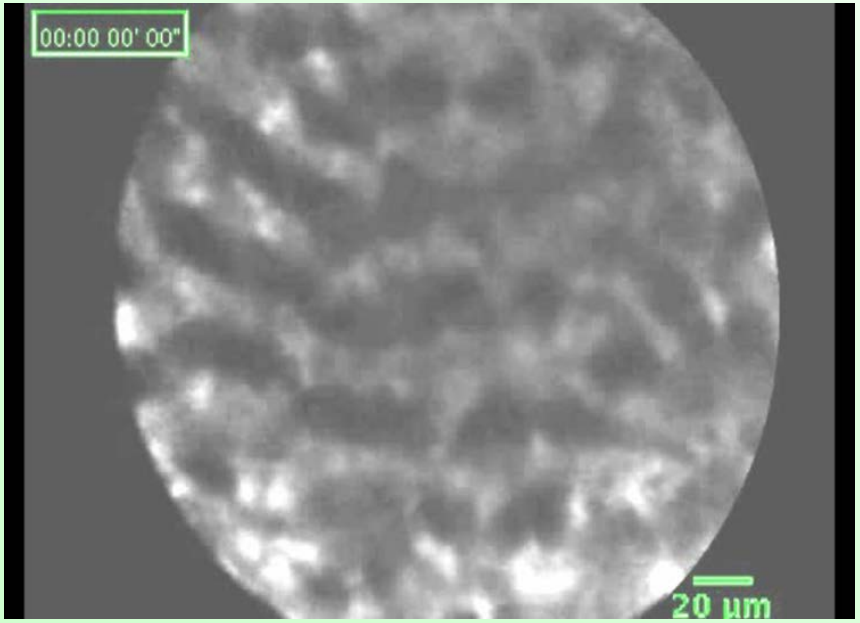


Synchronised in real-time with intra-fraction 4D skin surfaces (VisionRT)

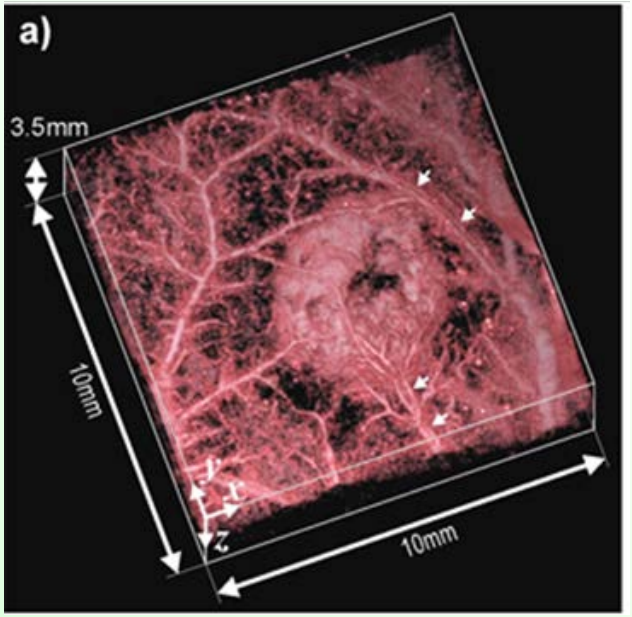
Preliminary results on real data
Cine CT data – BH as static reference



Integration with novel optical tissue interrogation methods:



Fibred microendoscopy
(Mauna Kea Technologies)



3D photacoustics
(Beard, Desjardins et al UCL)

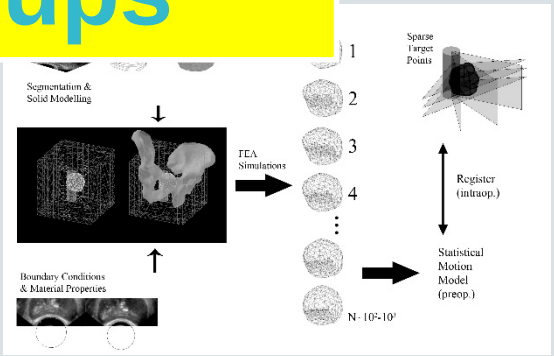
Healthcare Providers

UCL Partners

Med Tech

Academic Imaging Groups

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



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Dave Hawkes

d.hawkes@ucl.ac.uk
www.ucl.ac.uk/cmic