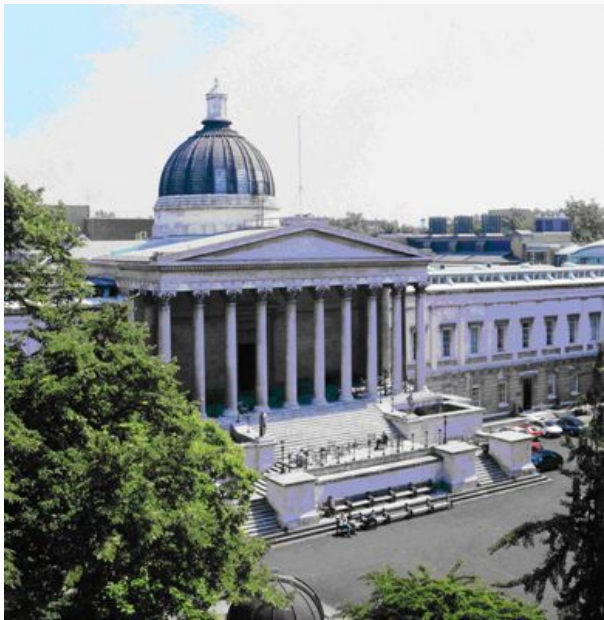
Image guided interventions: rigid and deformable image registration, fusion, visualization, and augmented reality

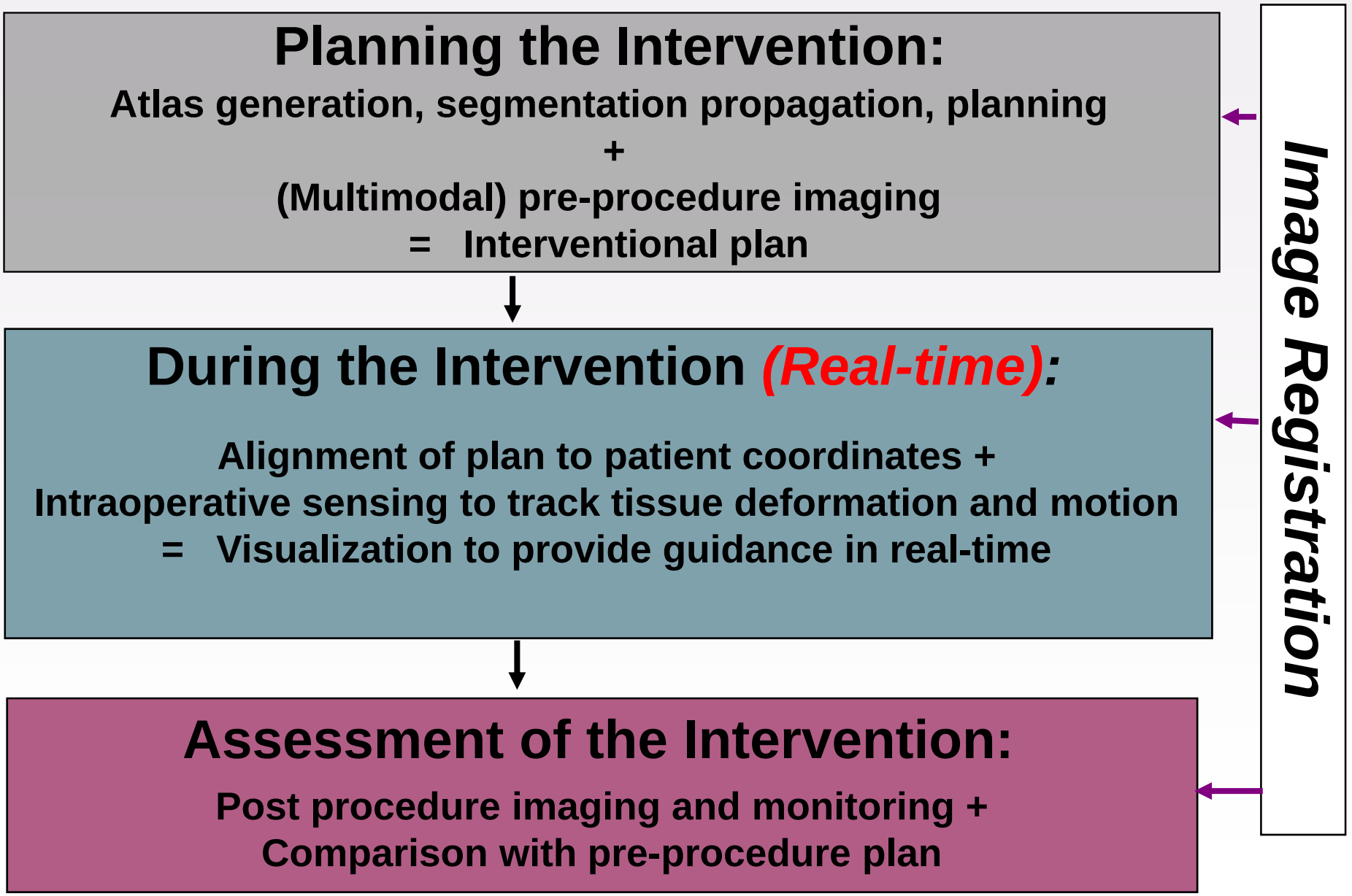
Dave Hawkes
University College London

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



Outline of Talk

- Role of Image Registration in IGI
- Dealing with Deforming and Moving Tissues
  - Development of non-rigid registration algorithms
    - Fast free form deformation
    - Biomechanical models
    - A combination of the two
  - Dimension Reduction
    - Local Rigid Body Approximation
    - Motion Modelling
    - Shape Modelling
    - A combination of the two


Planning the Intervention:
Atlas generation, segmentation propagation, planning
+
(Multimodal) pre-procedure imaging
= Interventional plan
During the Intervention (Real-time):
Alignment of plan to patient coordinates +
Intraoperative sensing to track tissue deformation and motion
= Visualization to provide guidance in real-time
Assessment of the Intervention:
Post procedure imaging and monitoring +
Comparison with pre-procedure plan
Image Registration

MAGI system in the Operating Room:

UCL

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

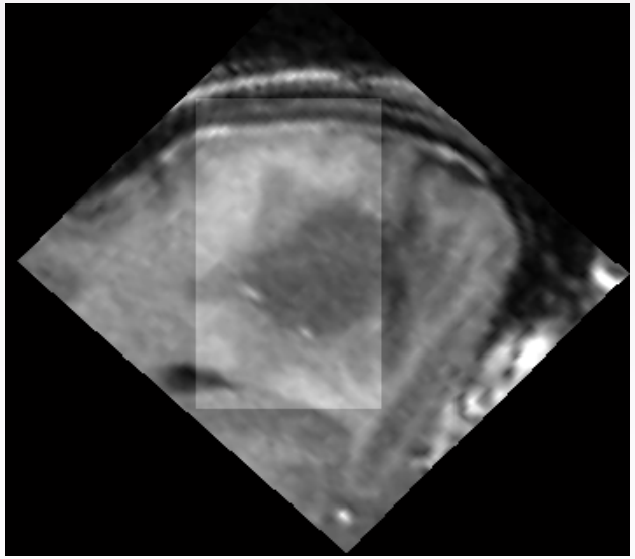
(Edwards et al IEEE-Trans Med Imag 2000)

Compensation for Deformation During Surgery

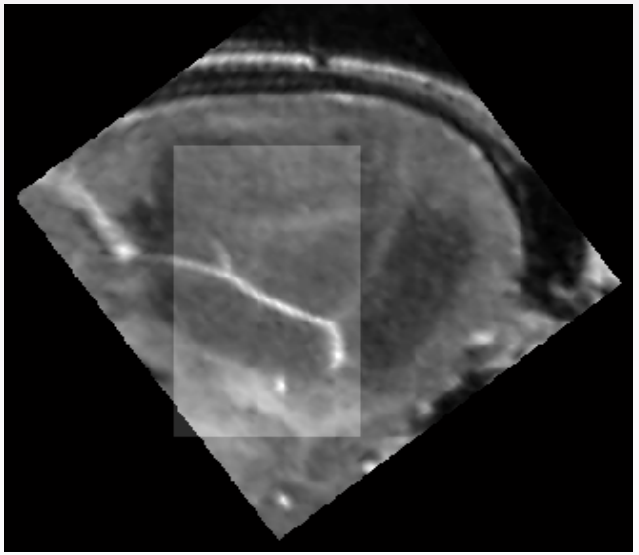
- Local Rigid Body Approximation

Registration of 3D Plan with 2D Intraoperative Imaging

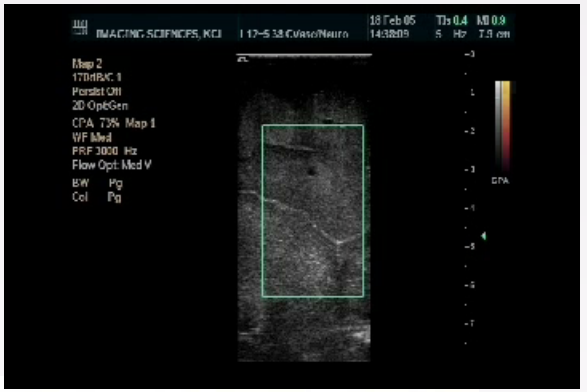
Intraoperative 3D Power Doppler US



1. Marker-based Registration



2. Updated US-based Registration

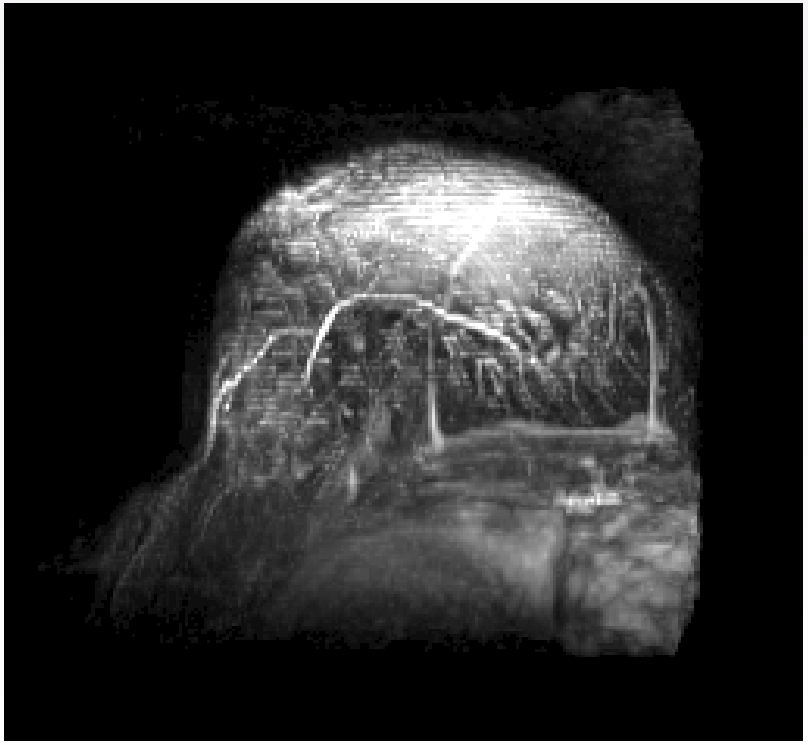


Dean Barratt, Neil Kitchen and Dave Hawkes, UCL and Queen Square, London

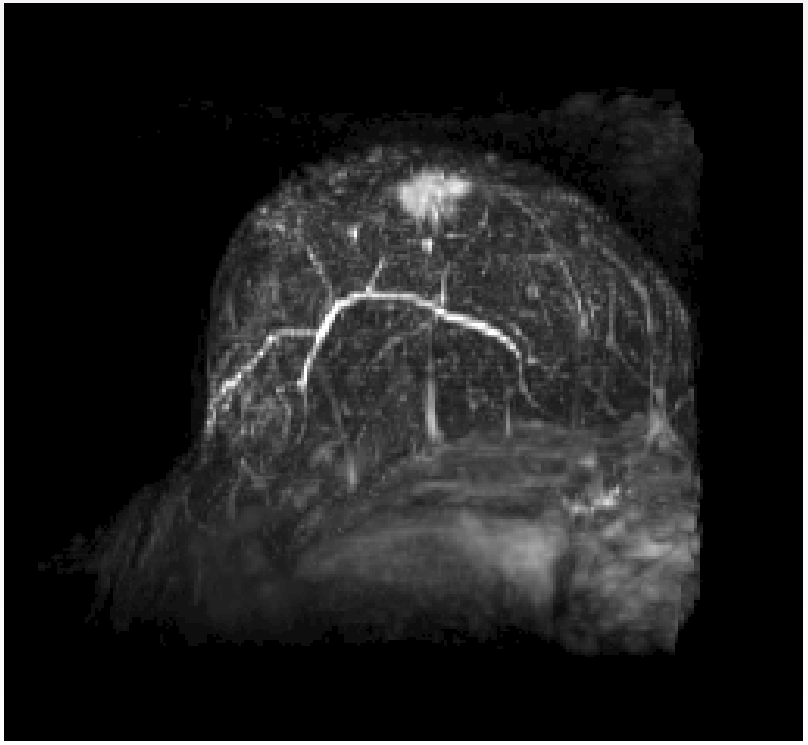
Fully automated non-rigid registration based on FFDs defined by cubic B-splines:

DCE-MR Mammography

Rueckert et al IEEE-Trans Med Imag, 1999



Difference of original images

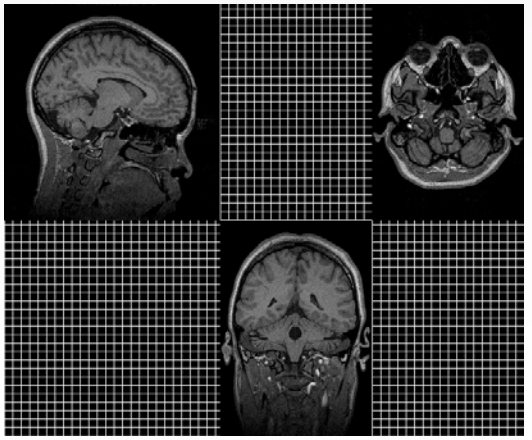


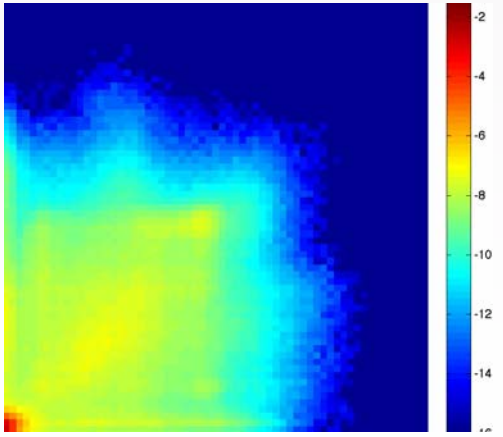
Difference of aligned images

From Free-Form Deformation (FFD) to Fast Free-Form Deformation (F^3D)

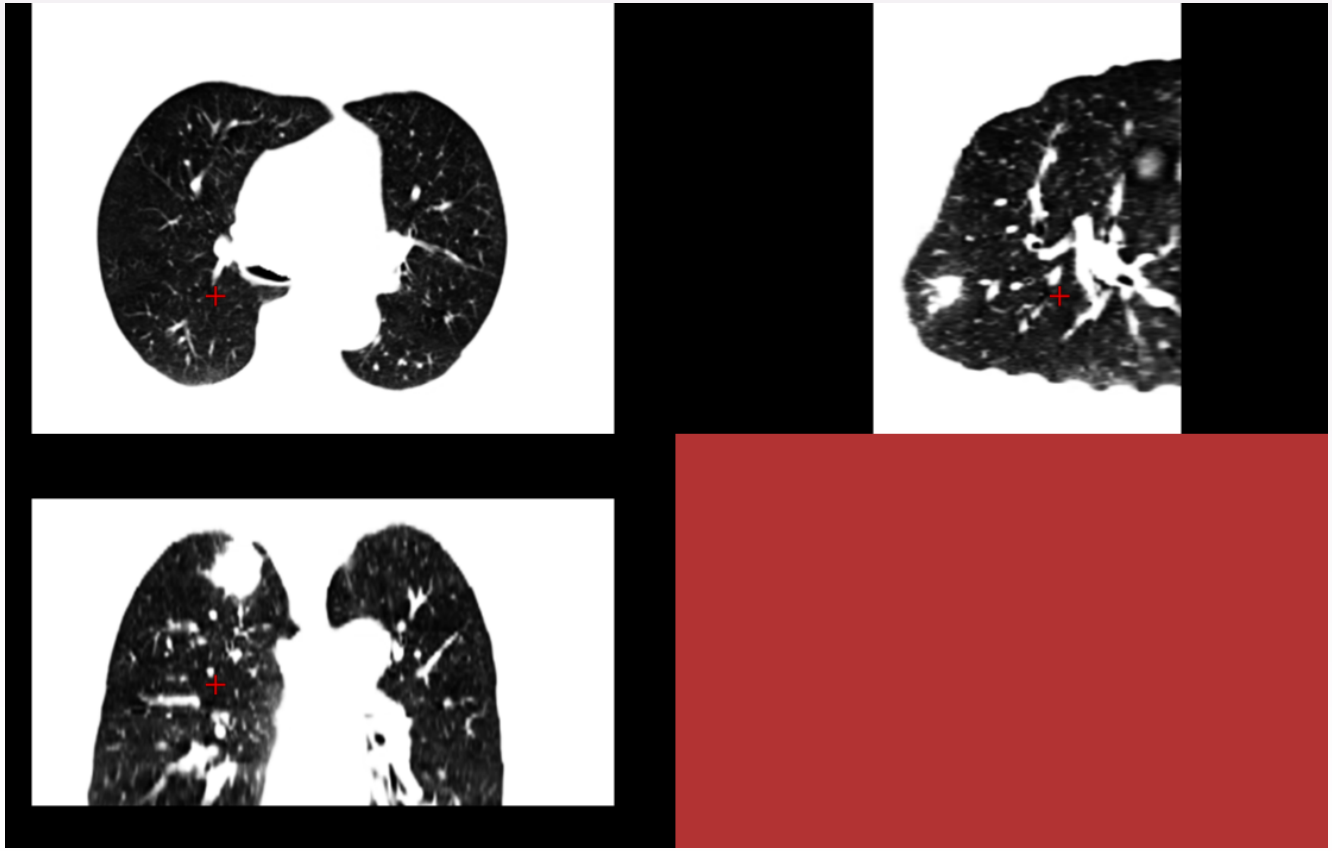
Marc Modat, …, Seb Ourselin,
Computer Methods and Programs in Biomedicine, 2009 (in press)

- Update all control points for each resampling
- Parzen Window estimation of Joint Histogram
- Convolution of gradient field of the cost function (NMI)
- Conjugate Gradient Optimisation
- 10 fold speed up from CPU to GPU implementation





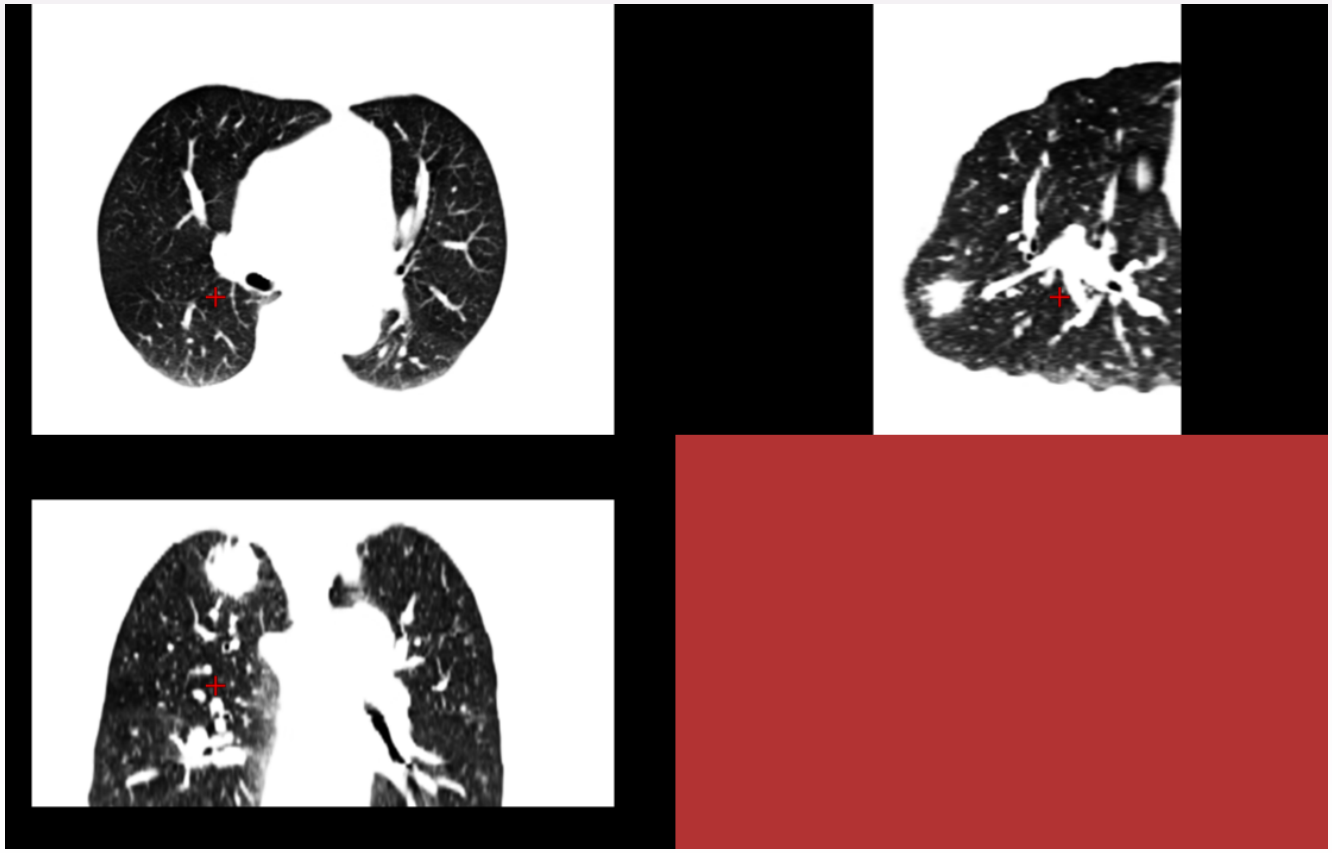
Lung
Target – 4DCT end-inhale phase



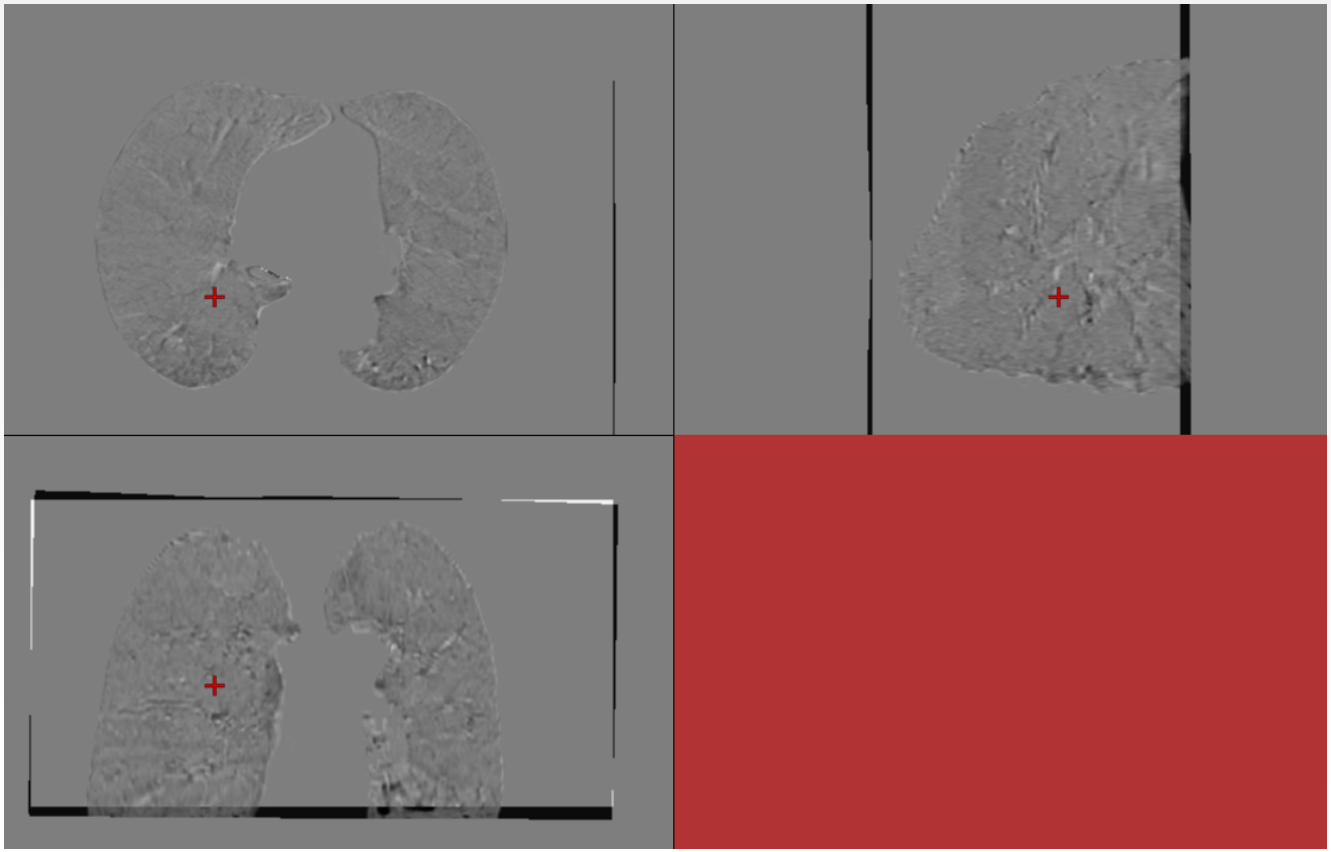
(lungs segmented, images windowed to highlight internal lung structures)

Jamie McClelland and Marc Modat

Lung
Source – 4DCT end-exhale phase



Lung
Target – FFD registration result



Compensation for Deformation in Image Guided Surgery Using Biomechanical Modelling

Finite Element Modelling

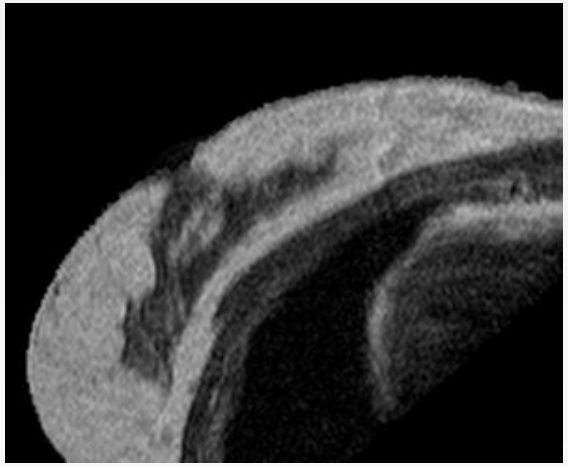
- Hexahedral mesh
- Finite strain formulation (large displacements)
- Neo-Hookean constitutive relationship
- At chest wall only allow tangential displacements
- Ansys software

(Carter et al MIAR, 2006, MICCAI 2008)

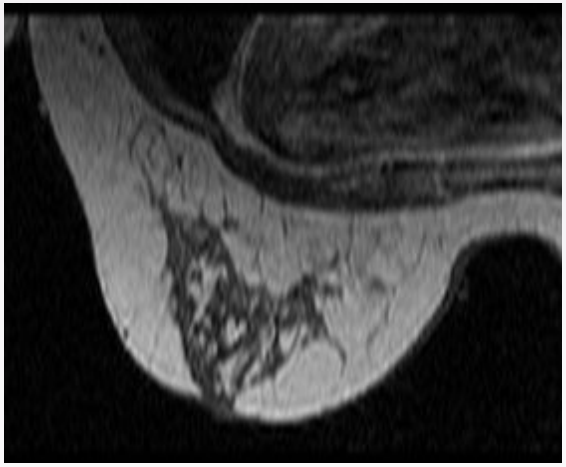
Guidance for breast surgery

Registration of Prone Pre-op to Supine MR Image:

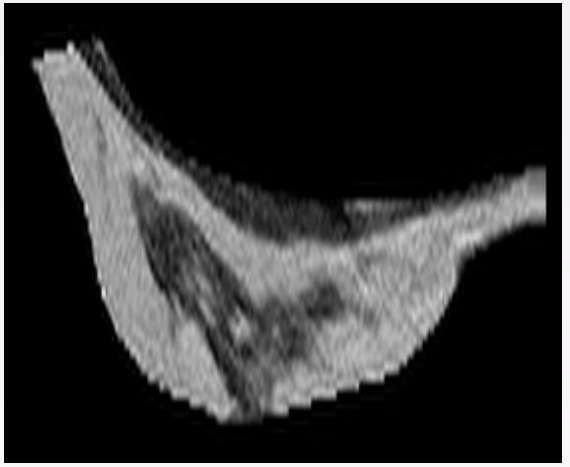
(Carter et al MICCAI, 2008)



Supine source

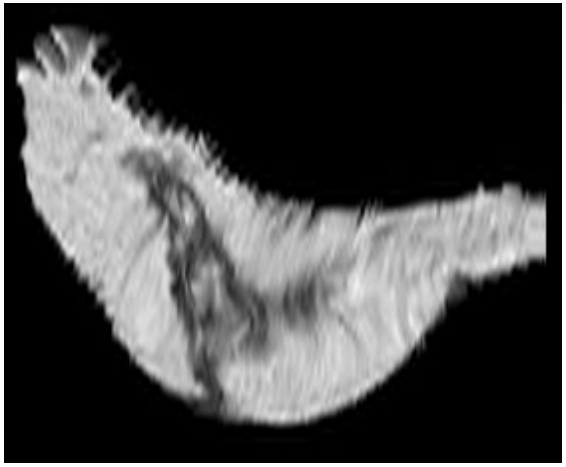


Prone target

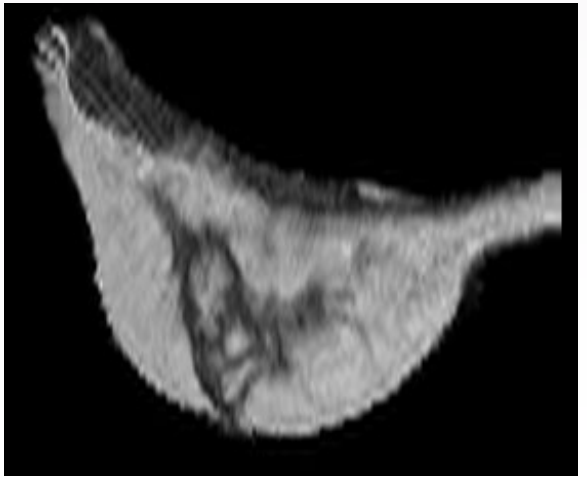


Rigid + FEM

Rigid only:
20mm (TRE RMS)
Rigid + FEM + Fluid TRE:
3mm (TRE RMS)

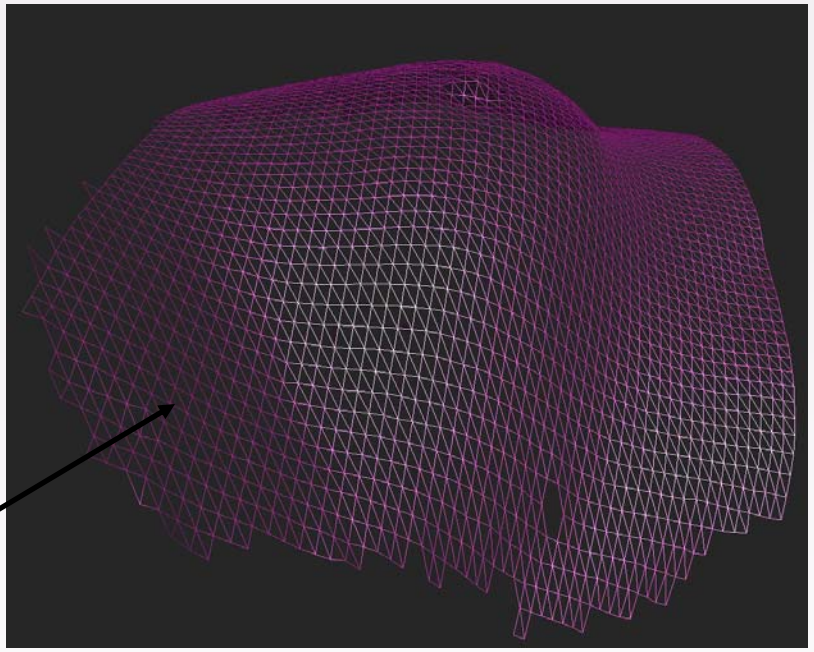


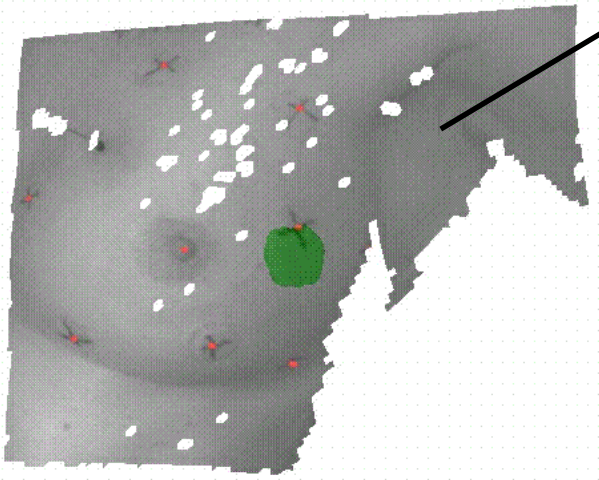
Rigid + Fluid

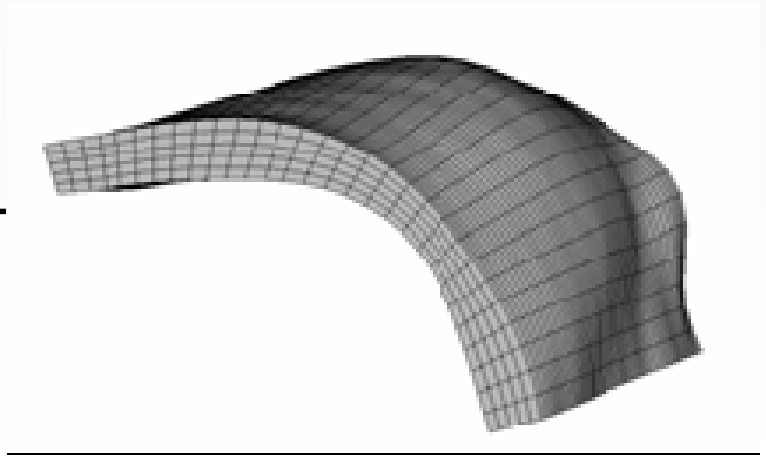


Rigid + FEM + Fluid

Guidance for breast surgery



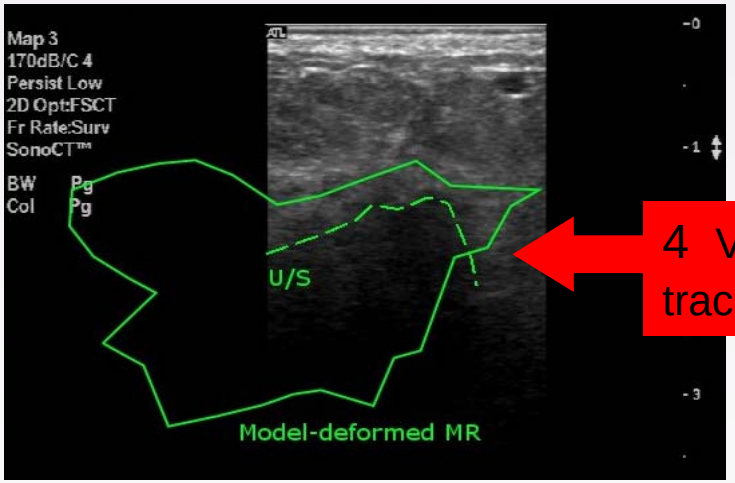




Tim Carter, Nick Beechy-Newman (Guy's Hospital) and Dave Hawkes

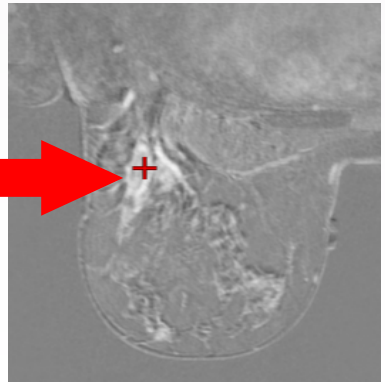
Image-Guided Breast Surgery

1 Stereo camera used to acquire 3D surface of breast

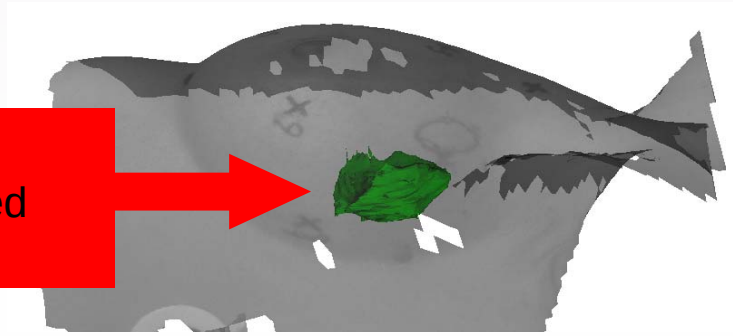


4 Validated using tracked ultrasound

2 Biomechanical model used to calculate displacement of cancer between prone DCE-MRI and surgery



3 Position of cancer displayed intraoperatively



(Carter et al MICCAI 2008)

Compensation for Deformation and Motion in Image Directed Ablative Therapies

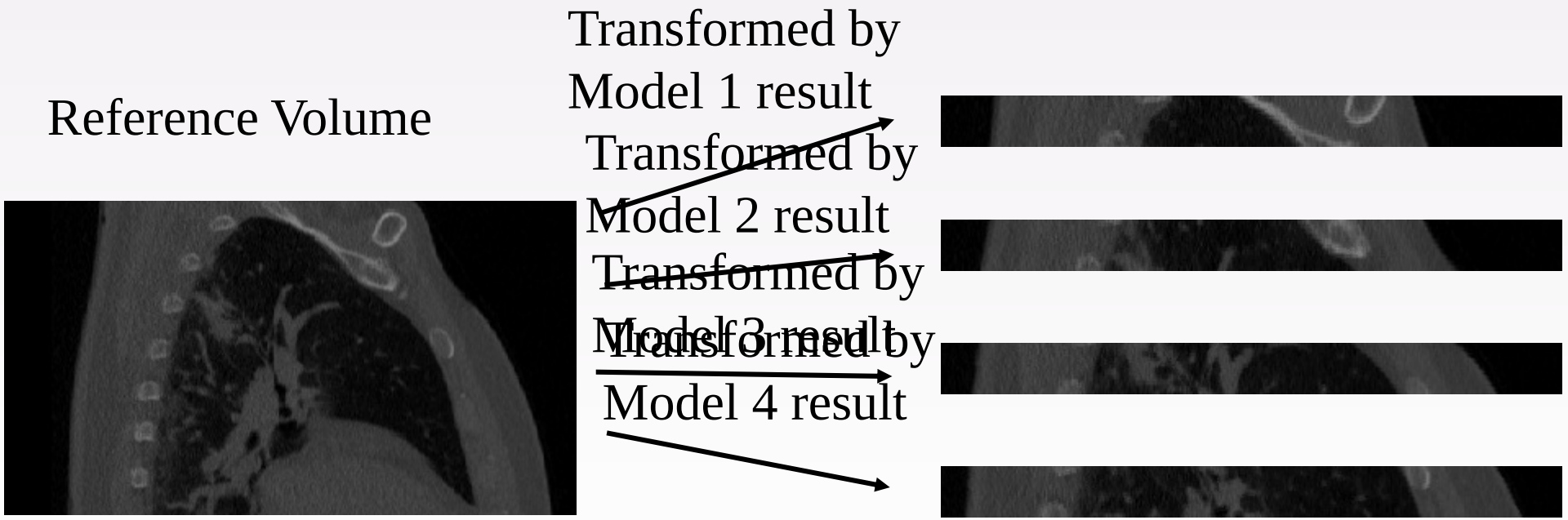
- Radiofrequency Ablation
- Photodynamic Therapy
- High Intensity Focussed Ultrasound
- Targetted Radiotherapy
- …..

“Real-time” update of plan

- Efficient implementations
- Fast processors (e.g. GPUs)
- Dimension Reduction

Image Targetted Radiotherapy in the Lung

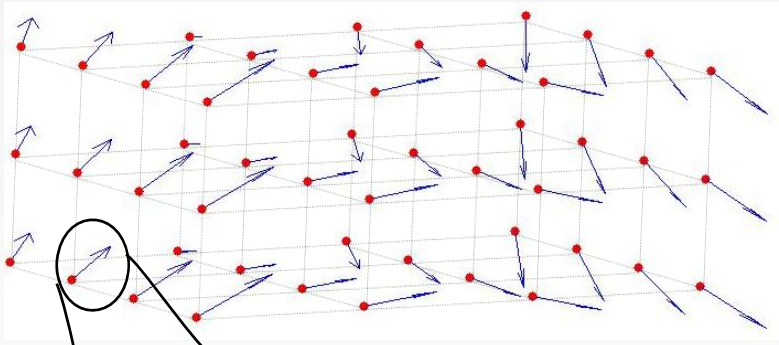
McClelland, Tarte, Blackwell and Hawkes, UCL
Webb and Brada, Institute of Cancer Research
Landau and Hughes, Guy's and St. Thomas

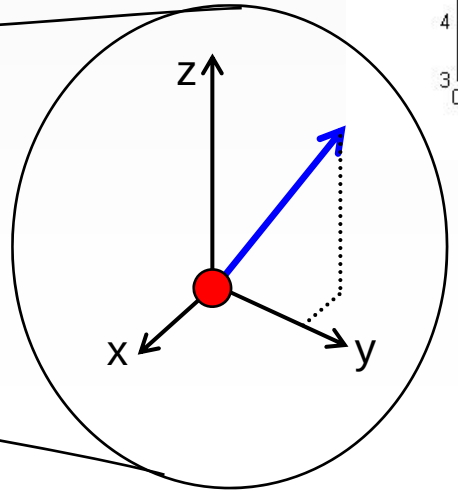


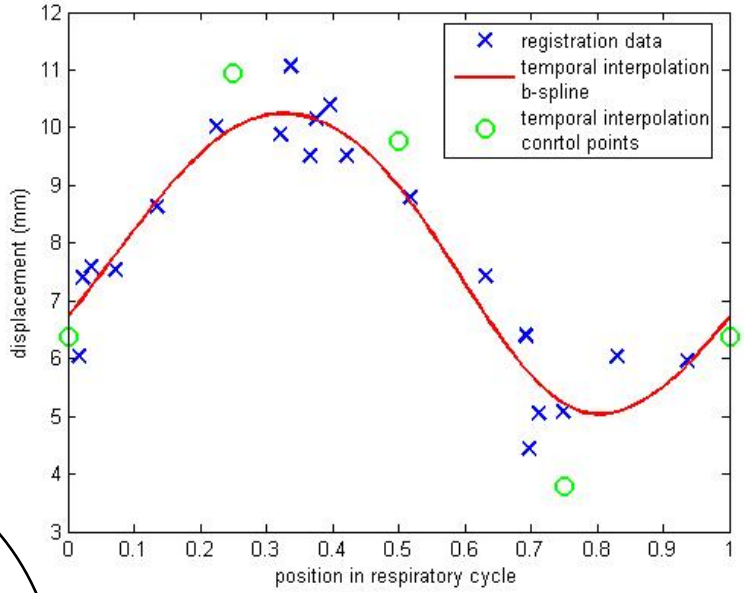
CANCER RESEARCH UK

McClelland et al Medical Physics 2006

Constructing the Motion Models – Temporal Fitting

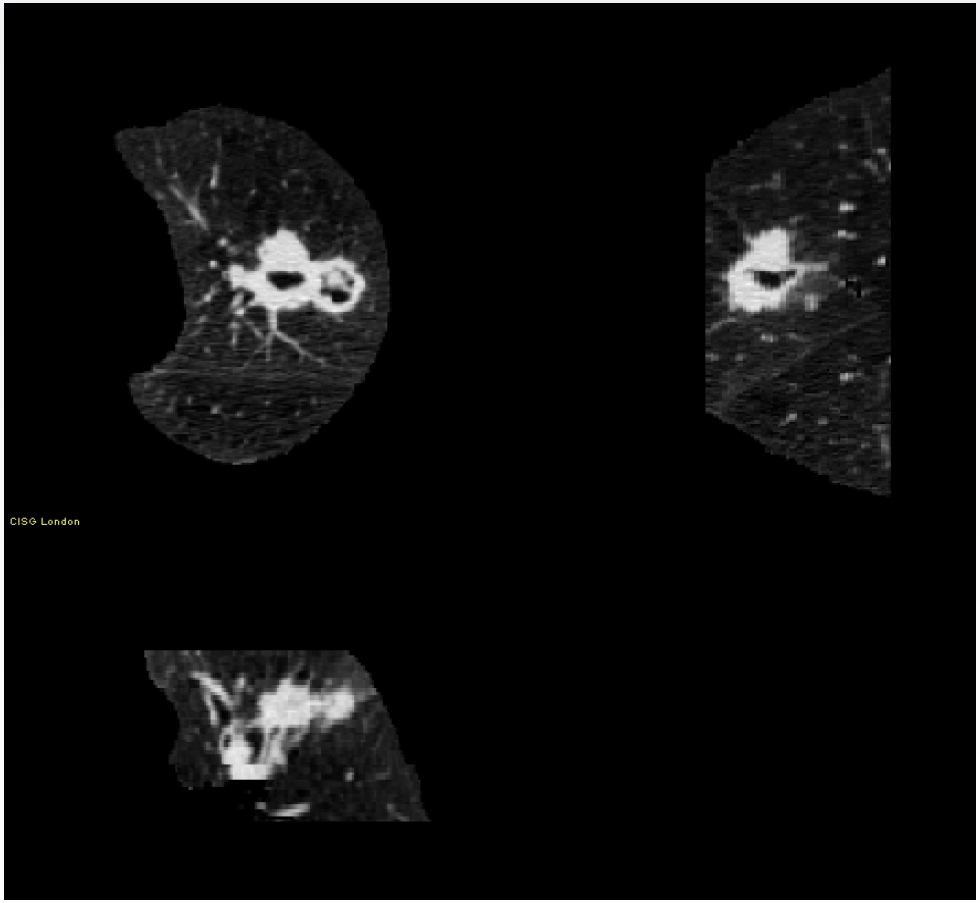


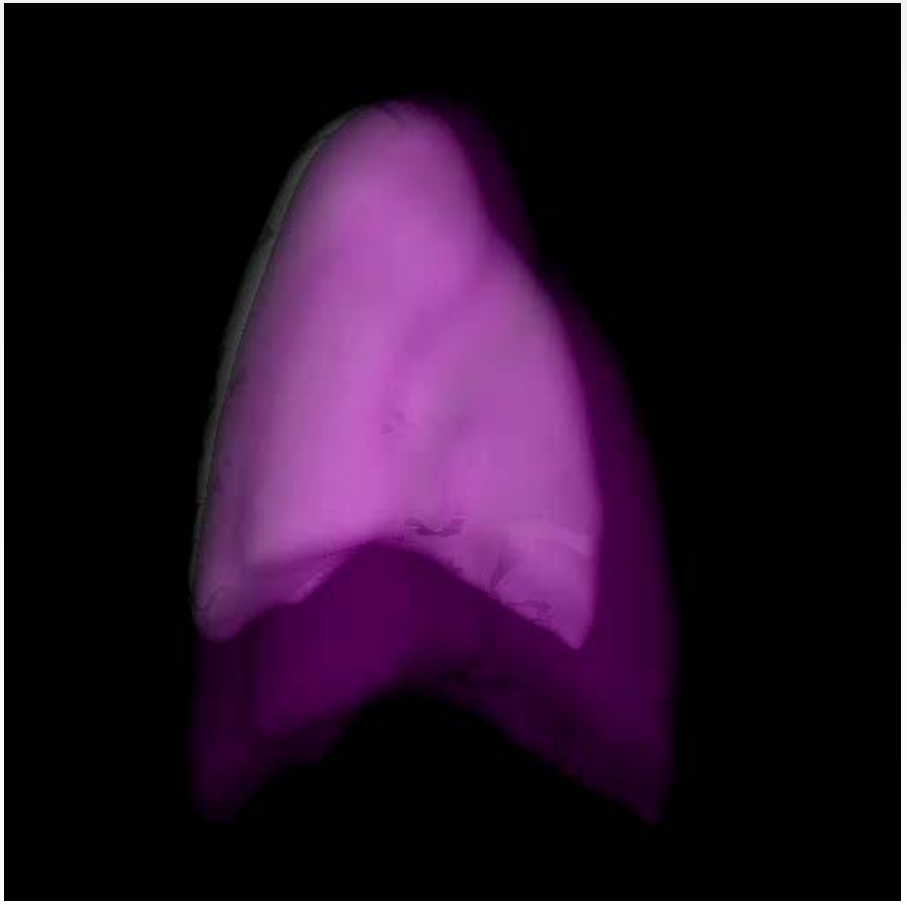




Motion modelling in lung radiotherapy

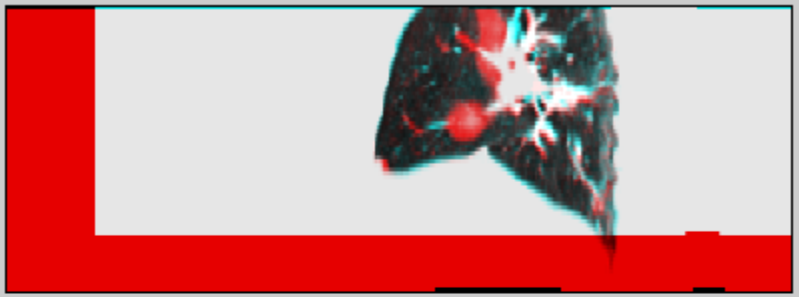
Blackall et al WCOMP 2003,
McClelland et al SPIE Med Imag 2005, ESTRO 2005, Medical Physics 2006



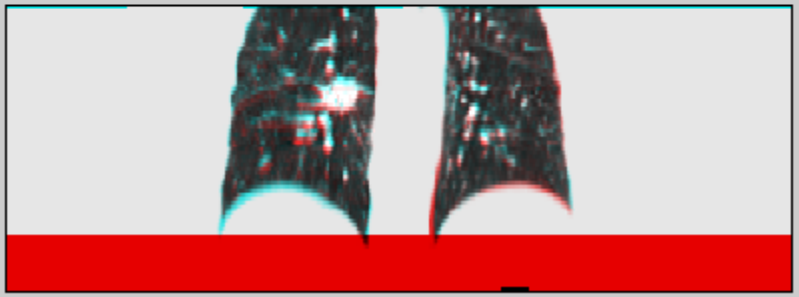


Model error 1.7mm (RMS), slice thickness 1.5mm (McClelland et al AAPM 2008)

Visually Assessing Motion Models Session 1 vs Session 2 – Patient 1



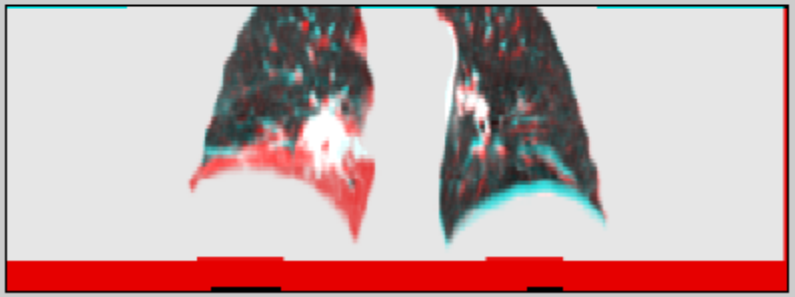
Sagittal view: Session 1 - Red, Session 2 - Cyan



Coronal view: Session 1 - Red, Session 2 - Cyan

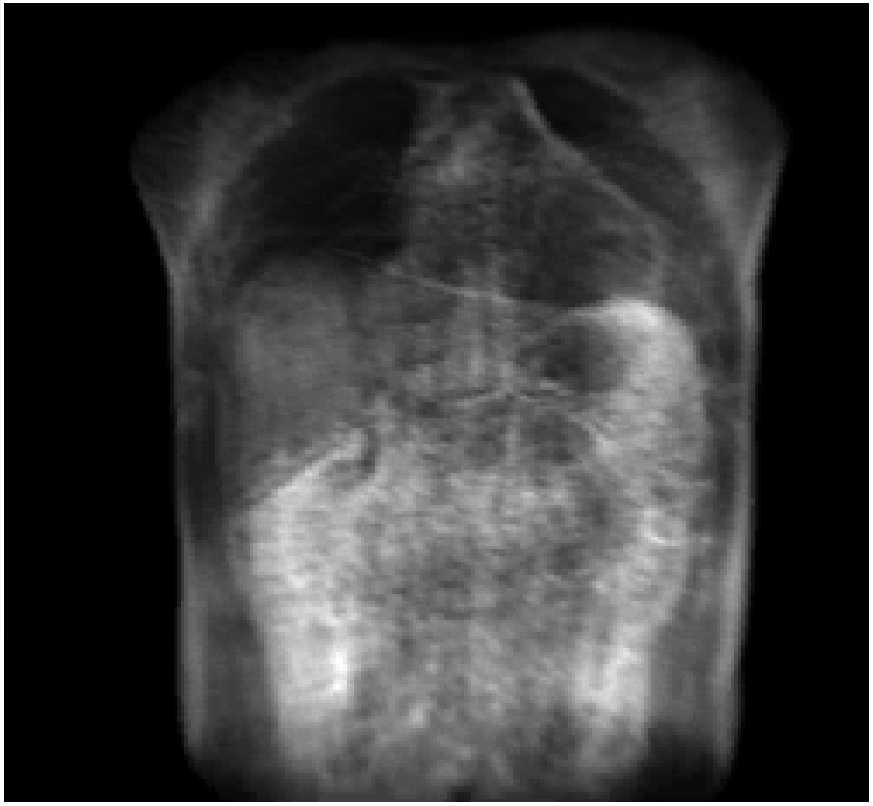
Visually Assessing Motion Models
Session 1 vs Session 2 – Patient 5

Sagittal view: Session 1 - Red, Session 2 - Cyan

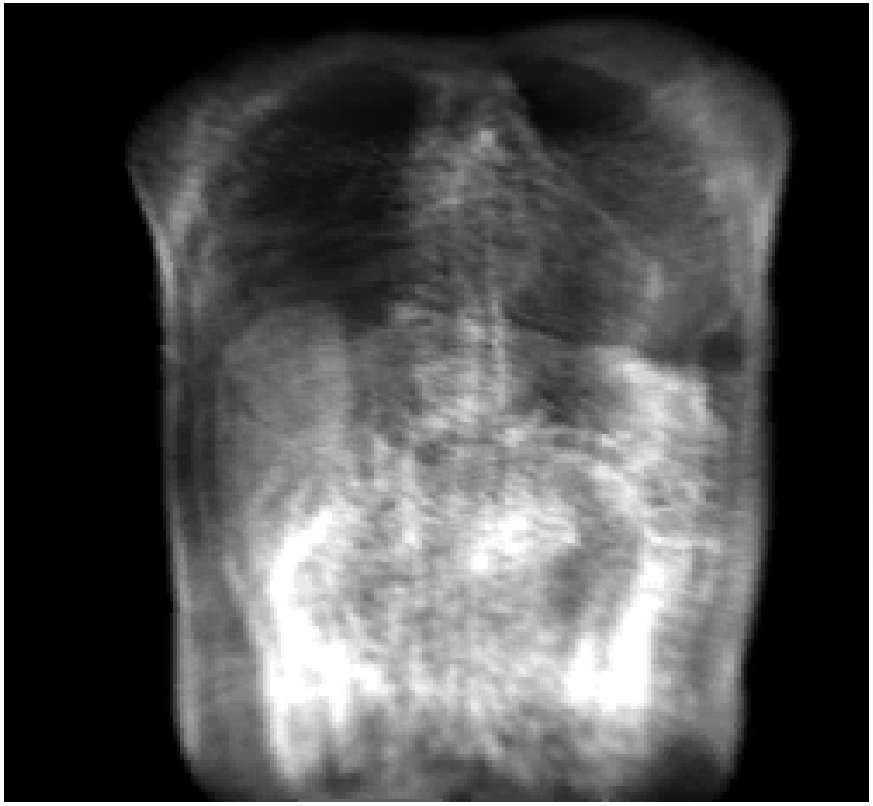


Coronal view: Session 1 - Red, Session 2 - Cyan

Breathing patterns: ‘DRRs’ of THRIVE data

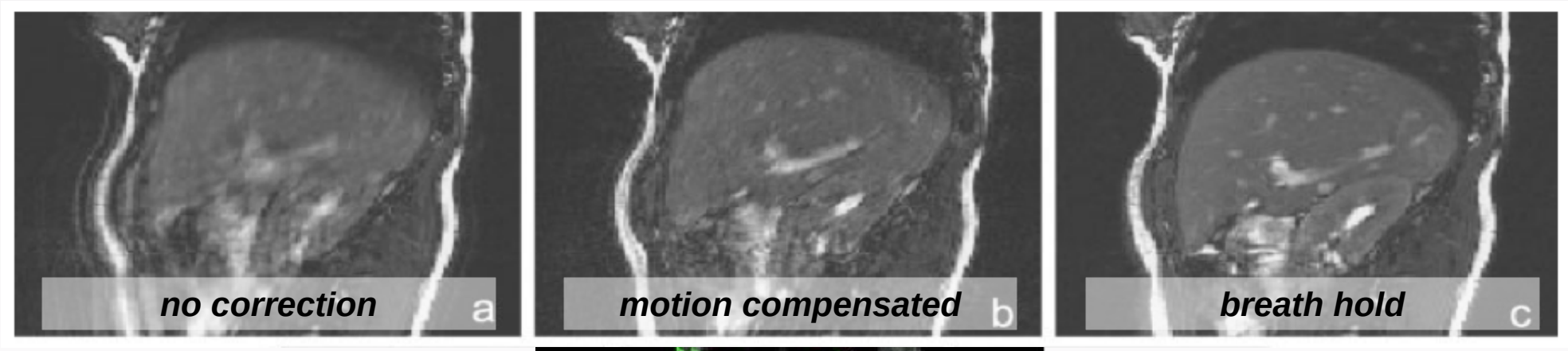


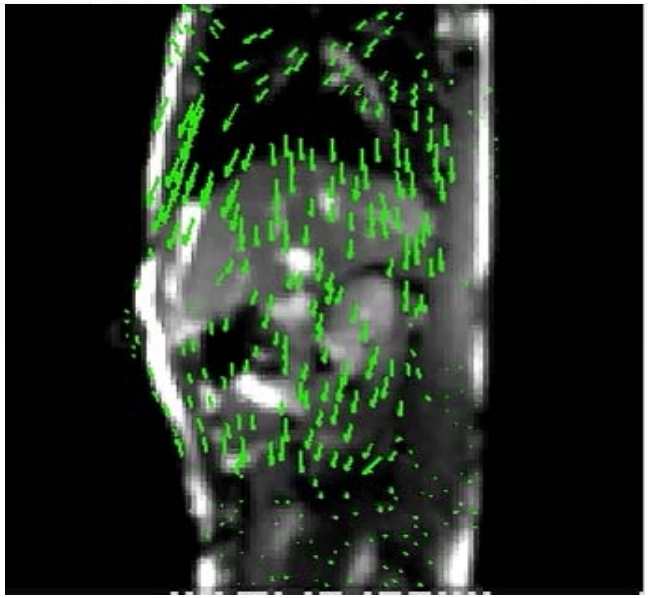
normal breathing



deep breathing

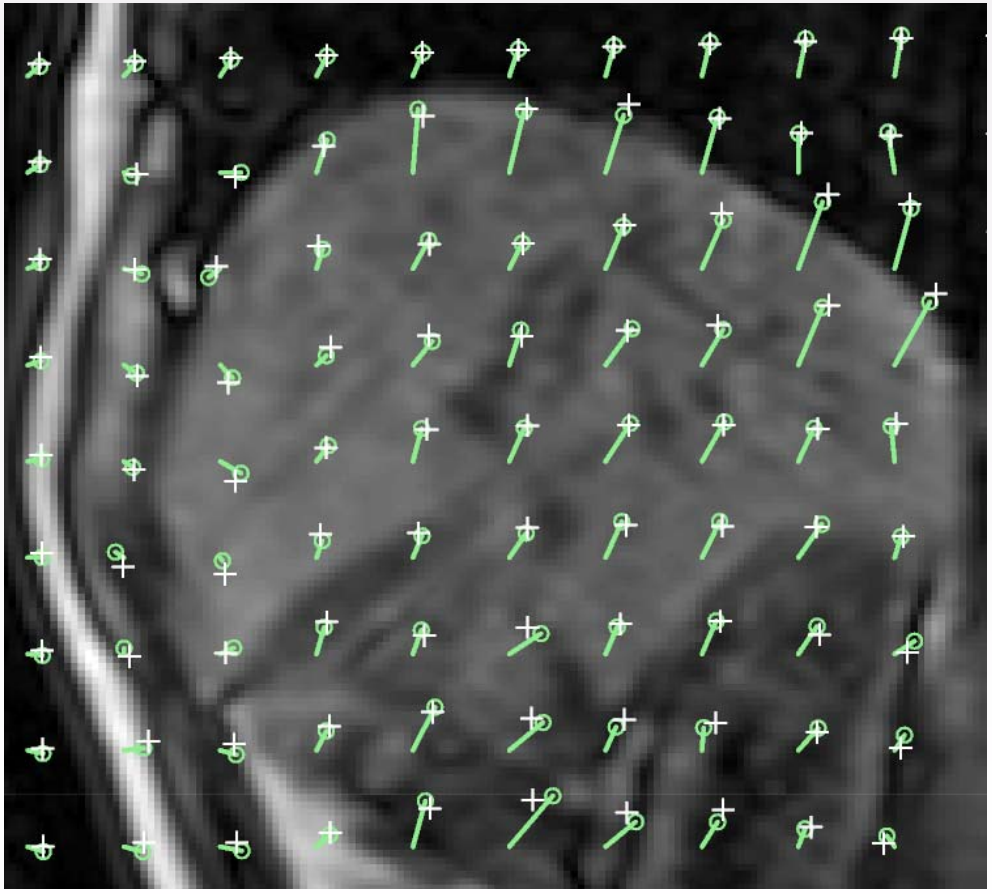
Motion compensation during reconstruction





Odille et al., 2008
MRM, 59:1401-1411
White et al, 2009
MRM in press

Verification of Motion Model



\+ Predicted position using model

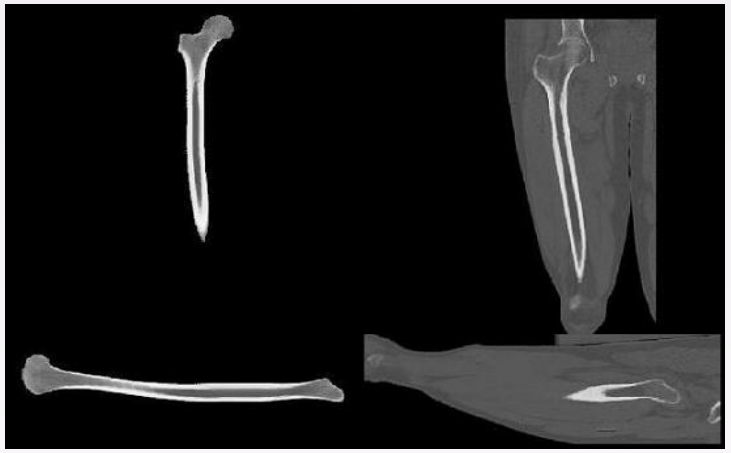
o Measured position using registration

White et al ISMRM 2007
Coollens et al ICCR 2007

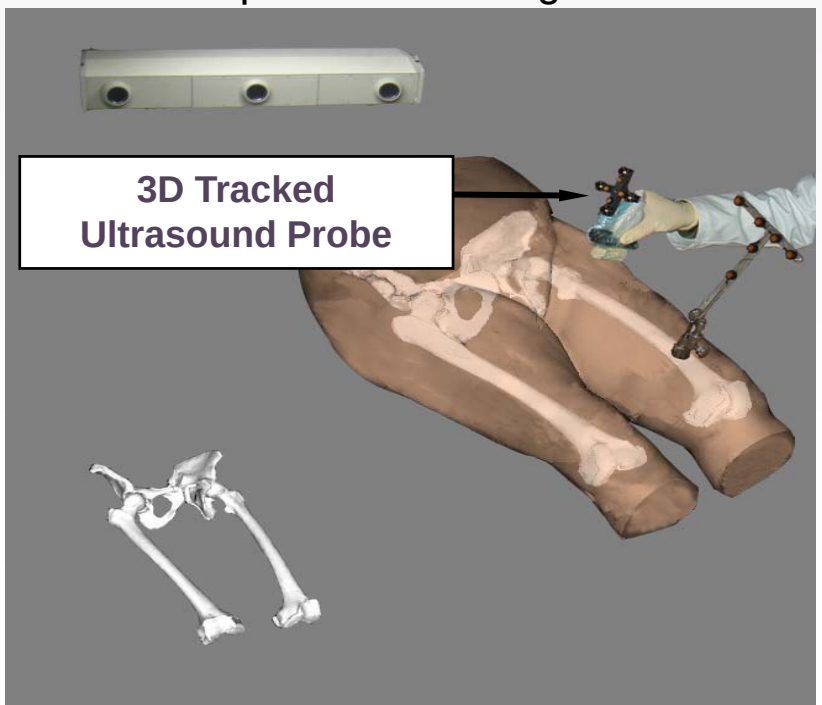
Shape modelling

Using shape model to replace CT scan

Chan et al SPIE 2003, MICCAI 2004,
Barratt et al MedIA 2008

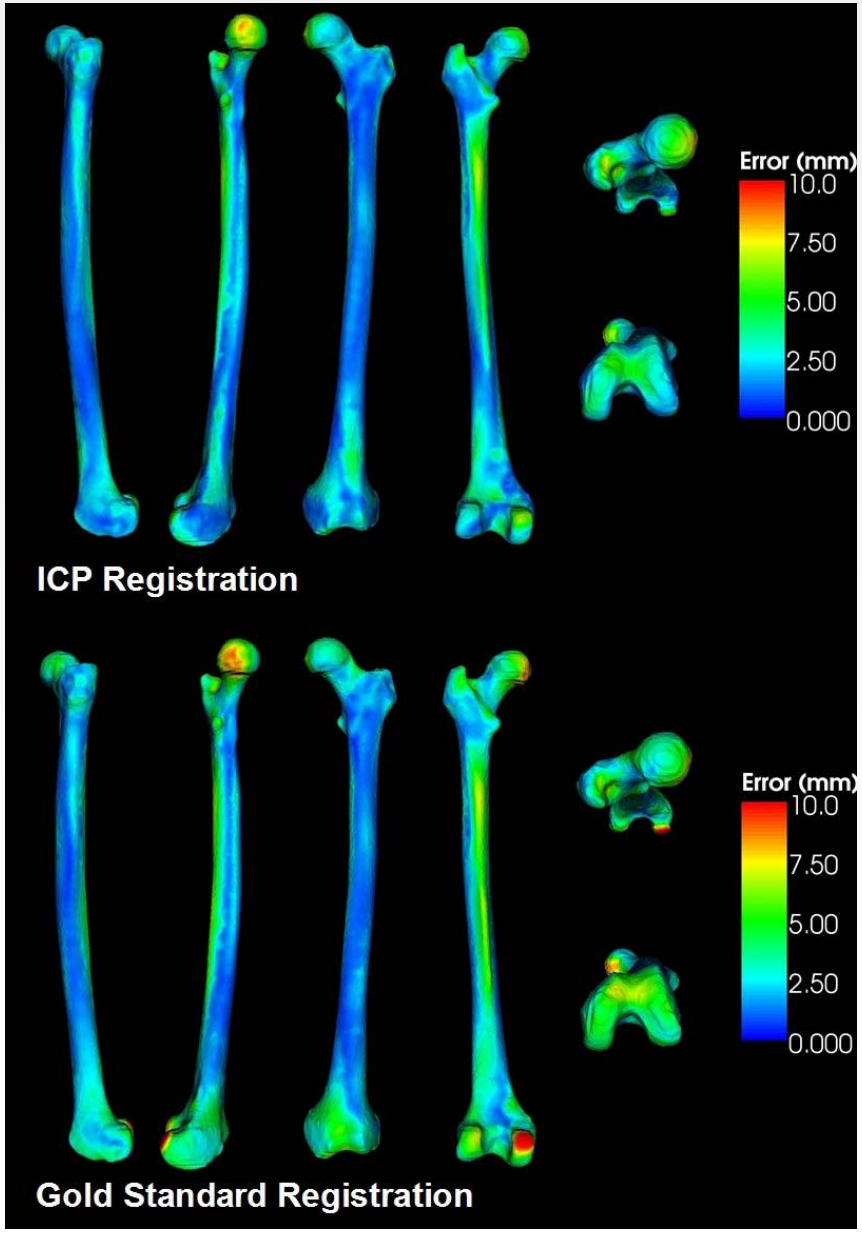


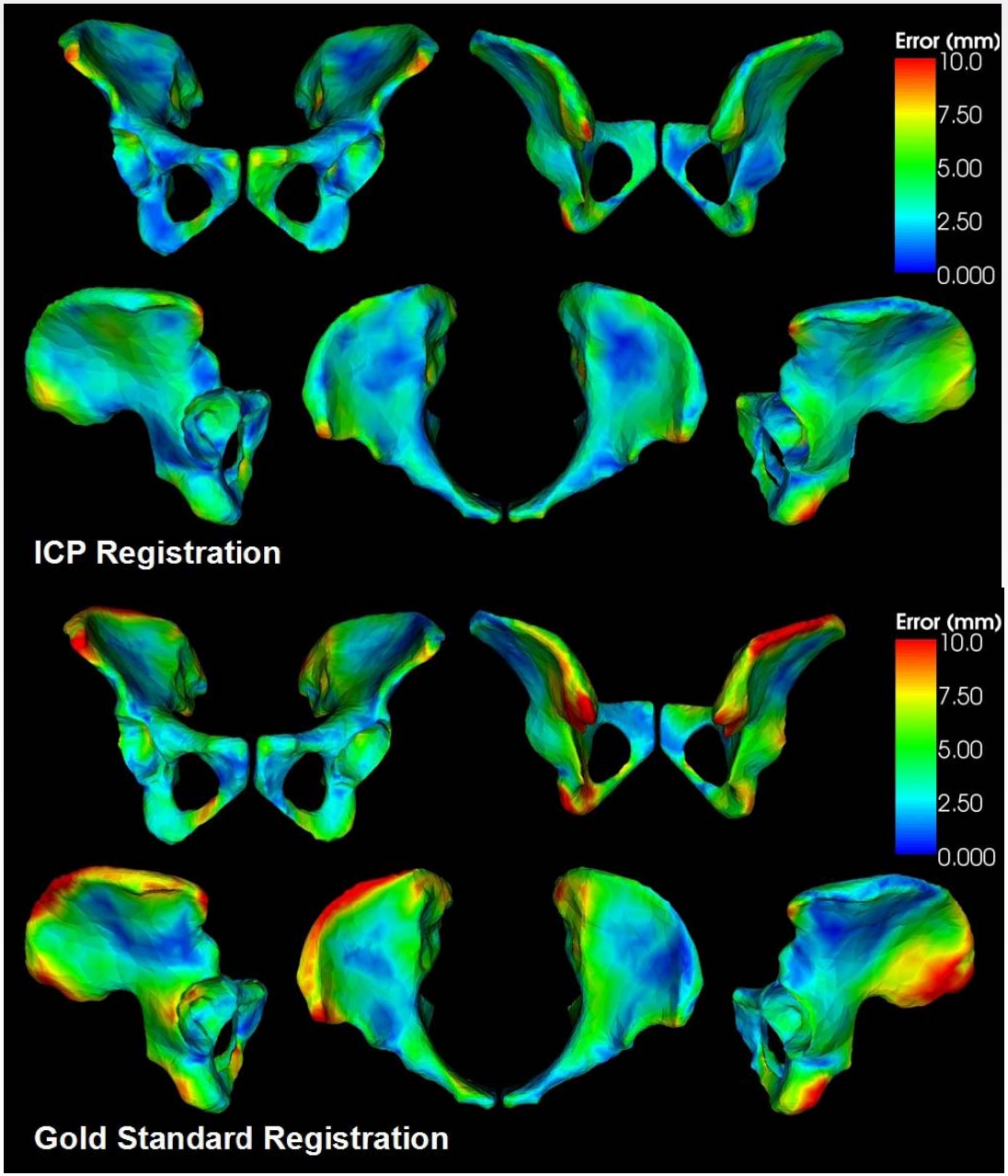
Template Training set



Complete 3D model instantiated from a series of ultrasound images

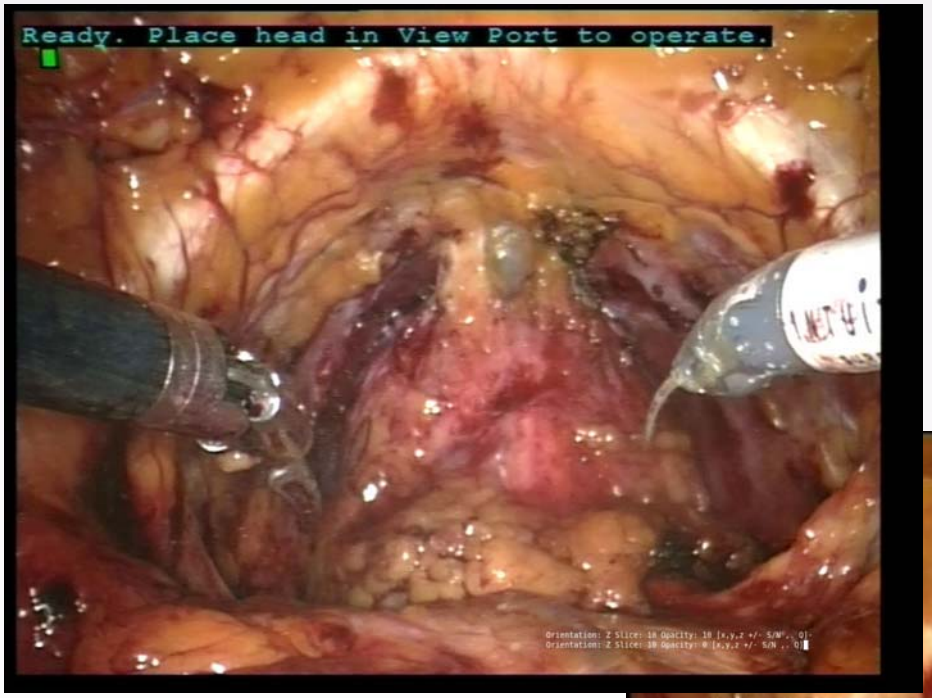
Error Maps of Instantiation Against CT of Cadaver

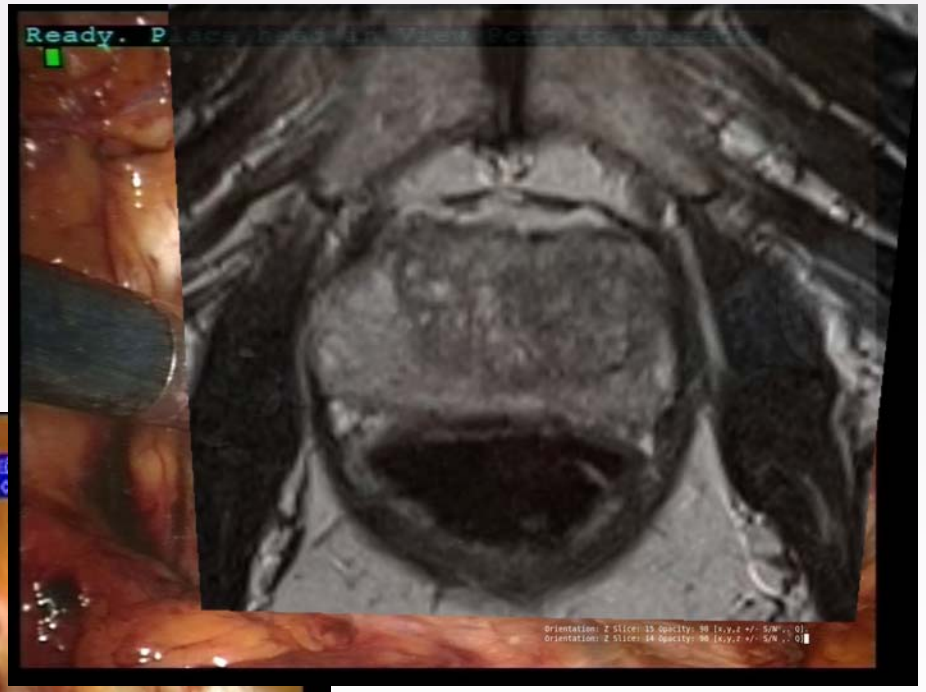




MR Guided Endoscopic Prostatectomy

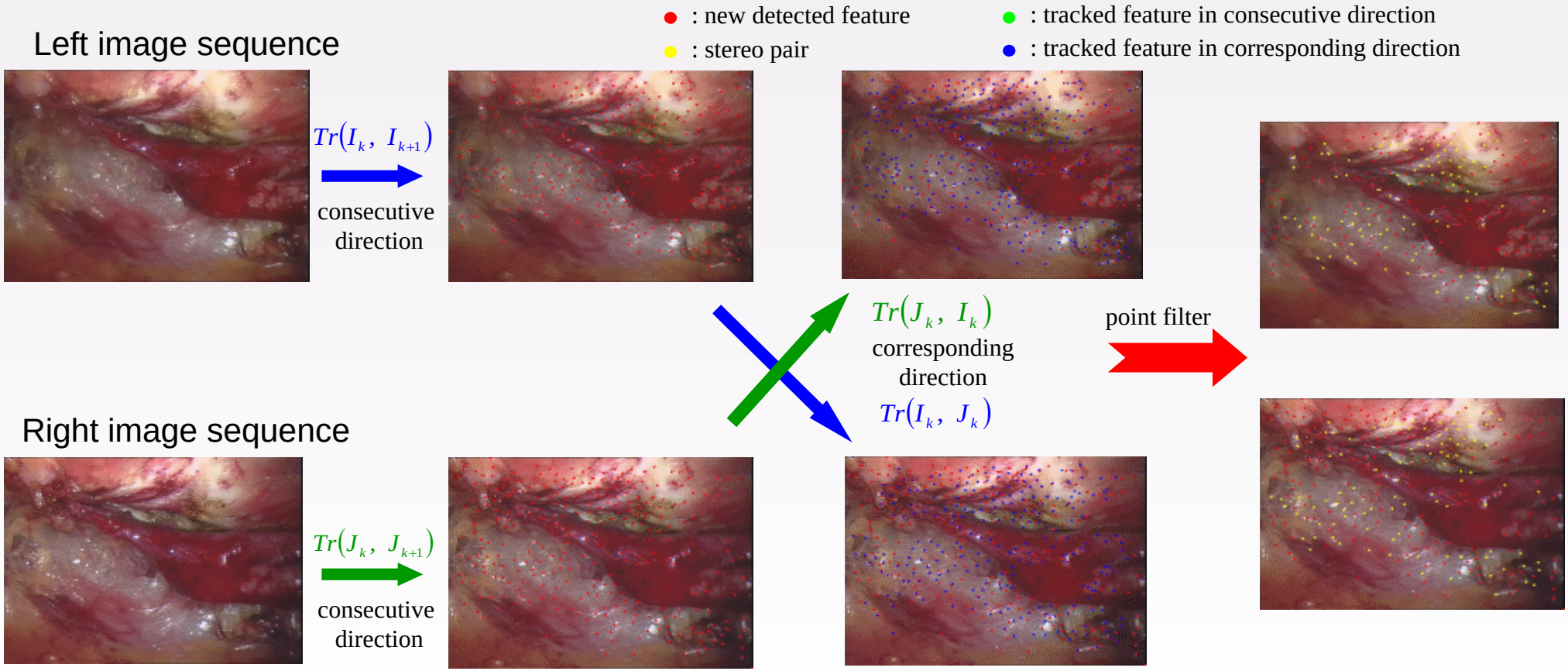
(Steve Thompson, Prokar Dasgupta et al 2008)





Overlay of MRI on Endoscopic view

Stereo tracking



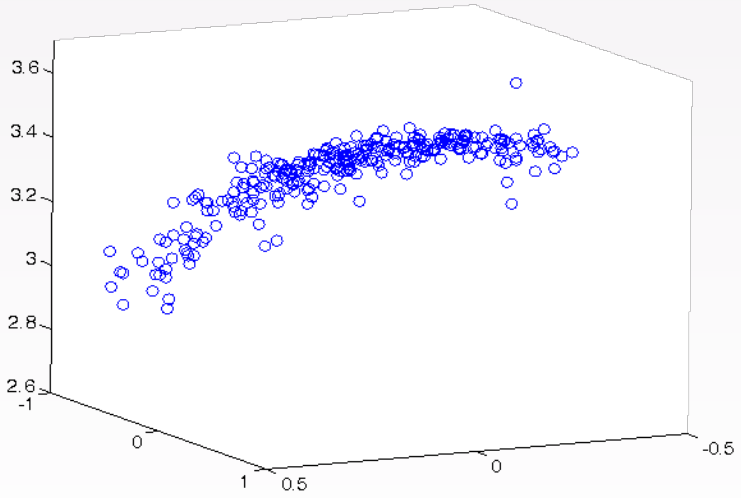
- Filter out points with poor correspondence using criterion:

$$\varepsilon = \left\| \mathbf{x}_{I(k)} - \mathbf{x}^{I}_{J(k)} \right\|_F + \left\| \mathbf{x}_{J(k)} - \mathbf{x}^{J}_{I(k)} \right\|_F \leq \delta$$

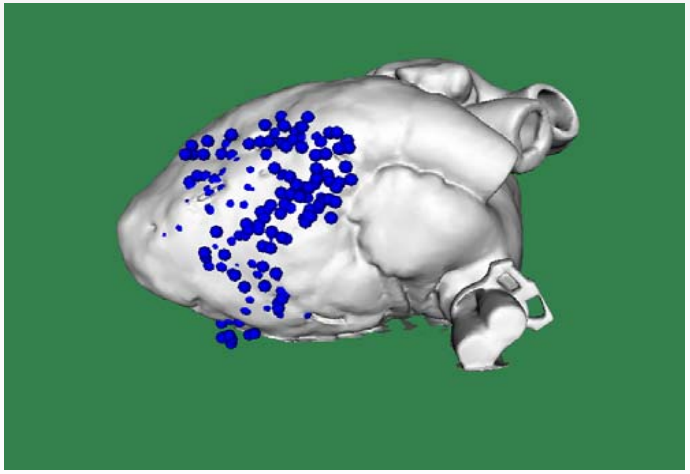
Mingxing Hu et al MICCAI 2007, 2008, 2009

3D Reconstruction from endoscopy images using Structure From Motion (SFM)

Mingxing Hu et al MICCAI 2007



3D point cloud



ICP registration, residual 1.87mm

Generating statistical deformation models from multiple FE simulations

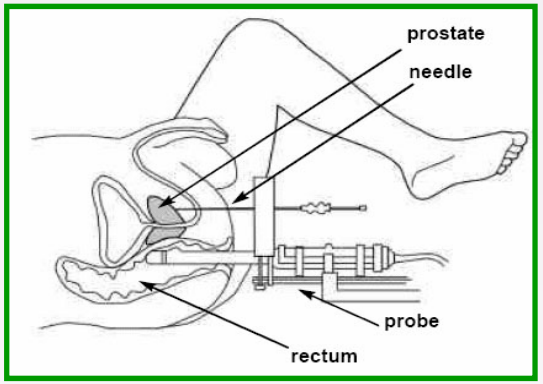
Statistical Motion Models (SMMs):

Application to focal therapy in the prostate

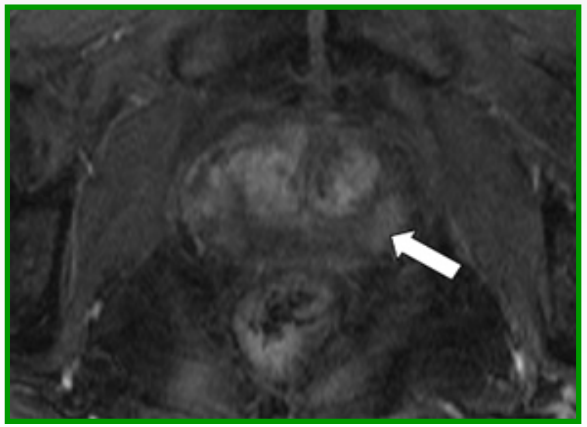
Yipeng Hu, Dean Barratt, Mark Emberton et al

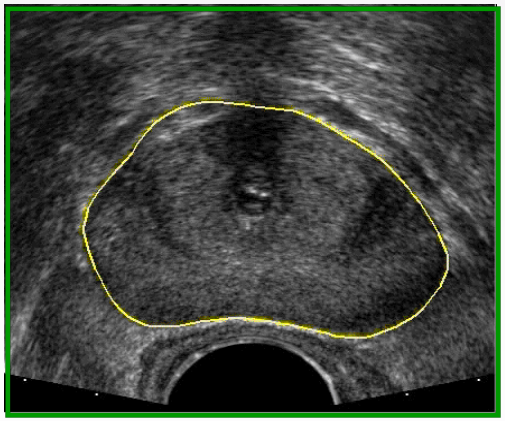
Ultrasound derived model to intra-operative ultrasound (MICCAI 2008)

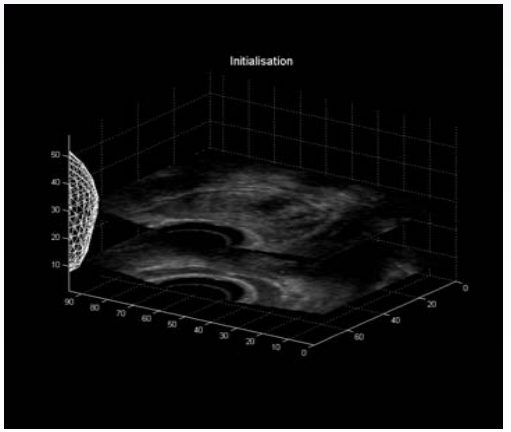
Image Directed Partial Prostate Ablation



- Cancer accurately targeted and critical structures avoided.







SMM built from 100's of FEM examples

- Pelvic anatomy
- Rectal anatomy
- Insufflations
- Mechanical properties

TRE 5 patients, 48 landmarks
1.8mm (RMS) +/- 0.7mm

The Future of Interventions is Imaging

- Integration of learnt models (shape, motion and biomechanics):
  - Reduce dimensionality of optimisation
  - Constrain possible solutions
  - New algorithm based on combination of image similarity and biomechanics (TLED)

- Next steps
  - Integration of Functional Information
  - Novel intra-operative Imaging and Sensing Devices for Navigation
  - Mechanical Devices for Improved Manipulation across Scales
  - Integration with Targeted Therapies

- Image Registration will remain the key enabling technology
- Systems must be Validated and Validation is hard

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CENTRE FOR MEDICAL IMAGE COMPUTING

Thank you

An Excellent Book:

Image Guided Interventions

Ed: Terry Peters and Kevin Cleary

Publ: Springer 2008

An Excellent Meeting: