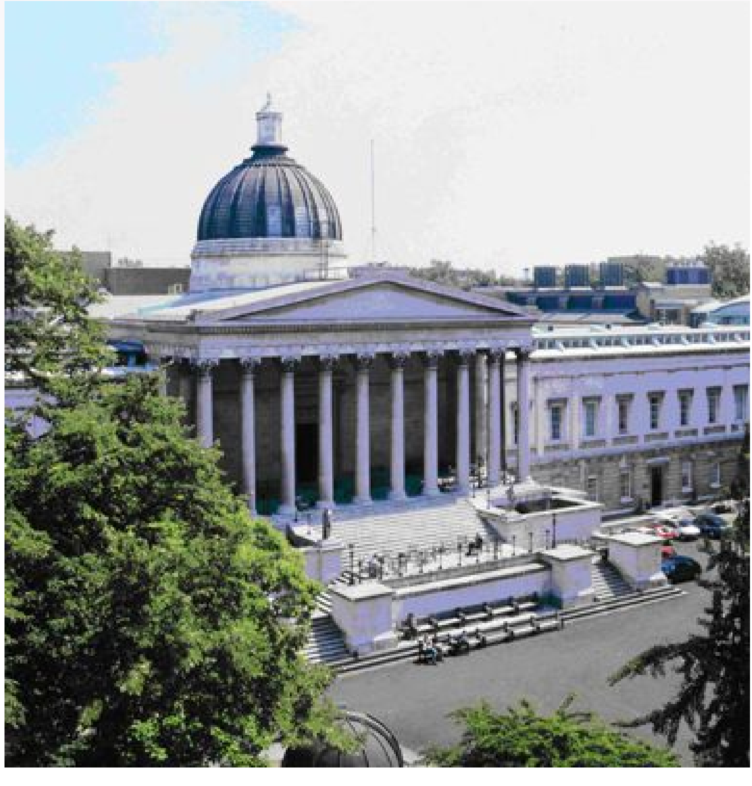
How to verify DIR?
Can we use DIR in the clinic and for which purpose?

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

Centre for Medical Image Computing



Validation of method

- Physical phantoms
- Digital phantoms
- Exogenous fiducials
- Internal anatomical landmarks
  - Pooling of ground truth data
  - Grand challenges
- Visual Inspection
- …

Verification during intervention/therapy etc

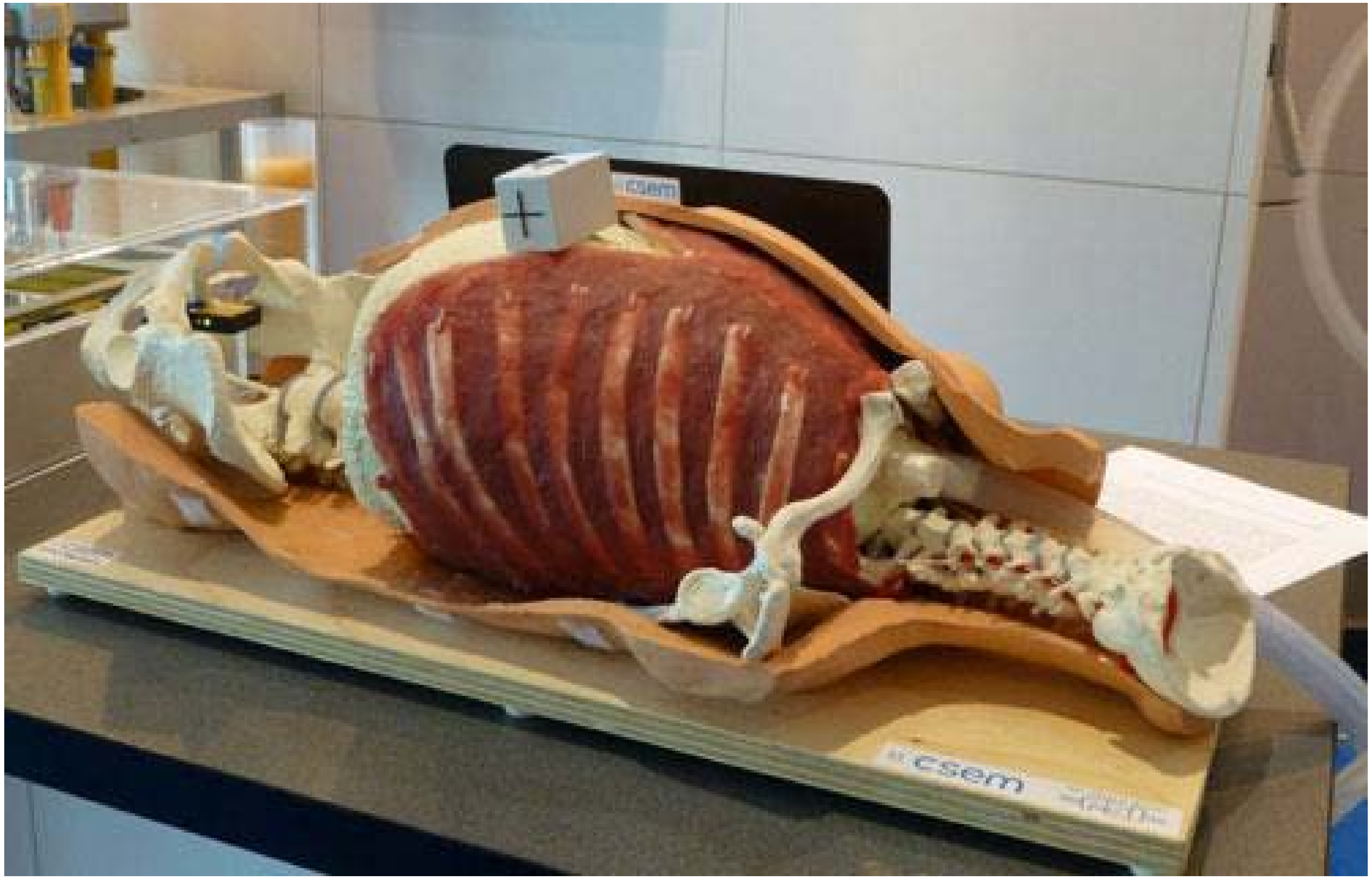
- Exogenous fiducials
- Internal anatomical landmarks
- Visual Inspection
- …

Understanding limitations,

spotting errors

Training!

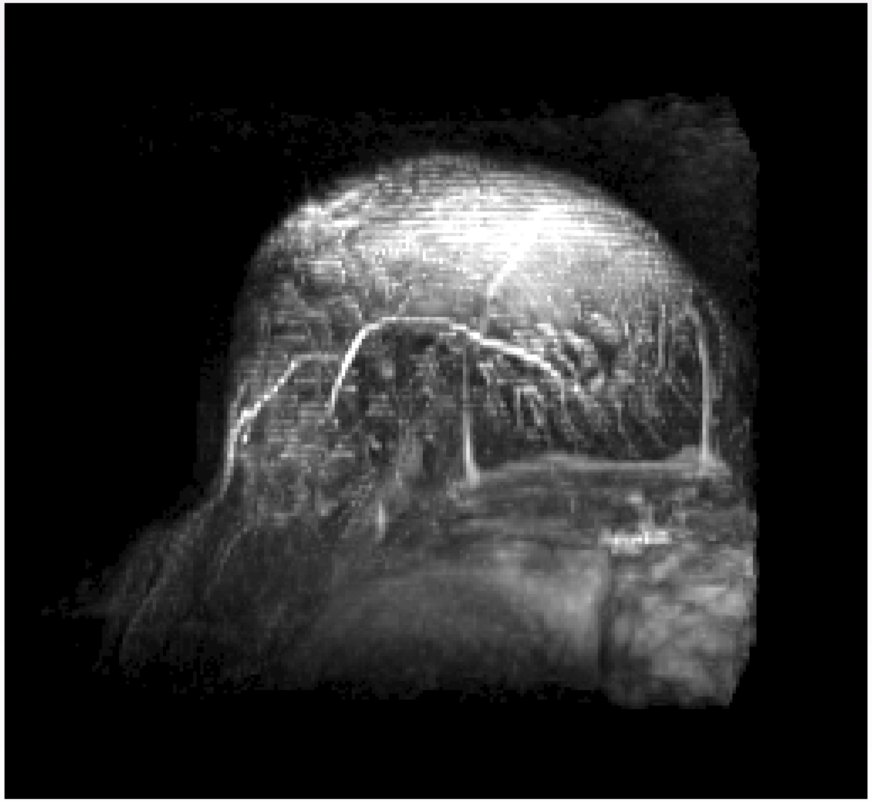
Experimental validation and clinical evaluation



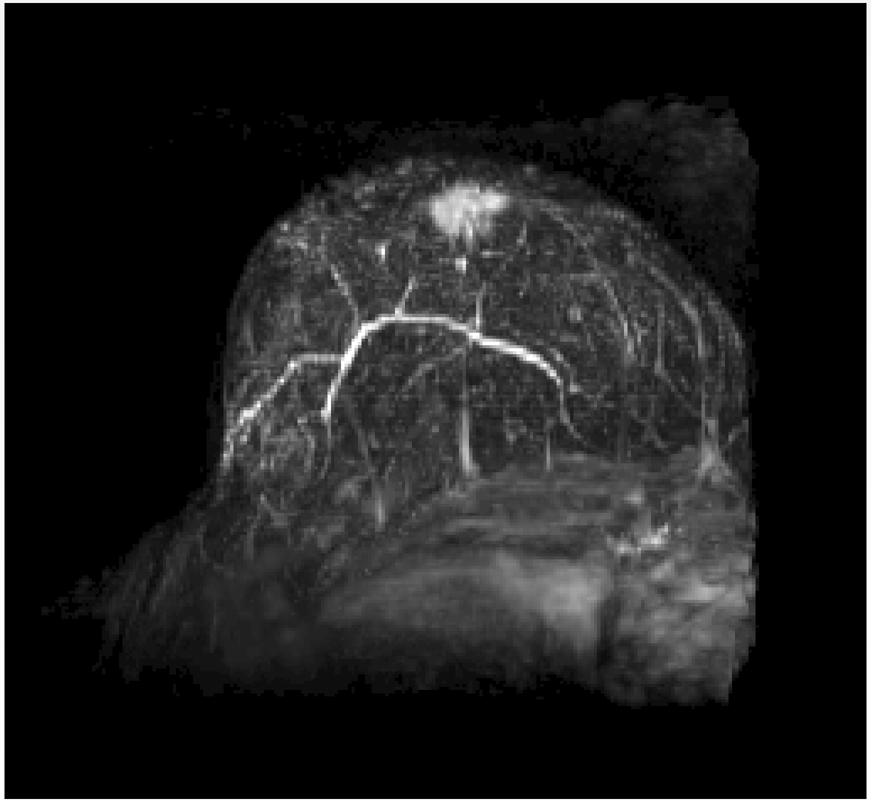
Anthropomorphic phantom: http://medicalphysicsweb.org/cws/article/research/53748

Alignment of temporal sequences of DCE-MRI

Free form deformations using B-splines with normalised mutual information as a similarity measure



Difference of original images



Difference of aligned images

Rueckert et al IEEE-Trans Med Imag, 1999

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

- 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

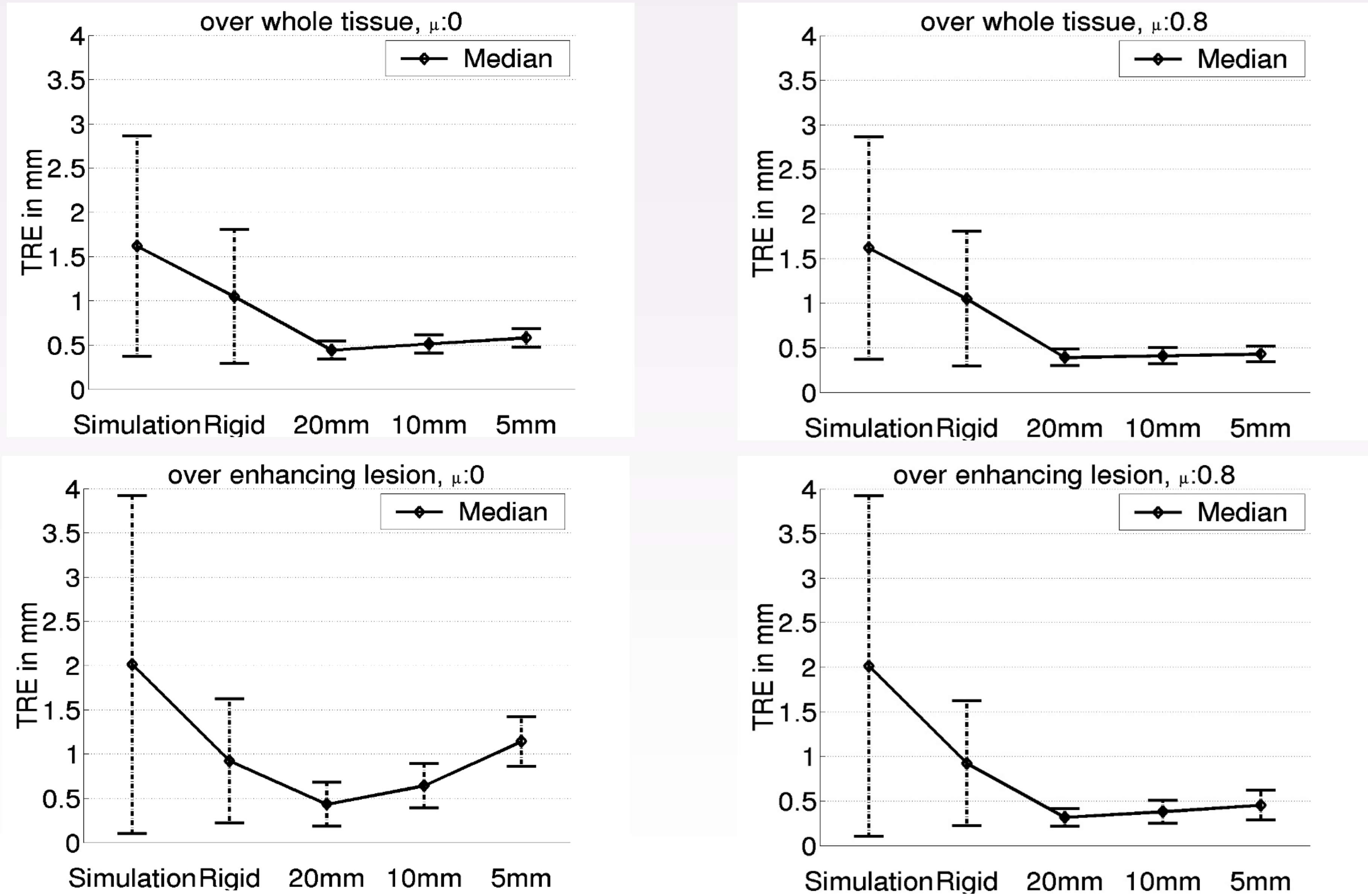
Open source code available at:
http://www.niftk.org

Modat et al, Computer Methods and Programs in Biomedicine, 2010

Target Registration Error

Whole breast tissue

Enhancing lesion



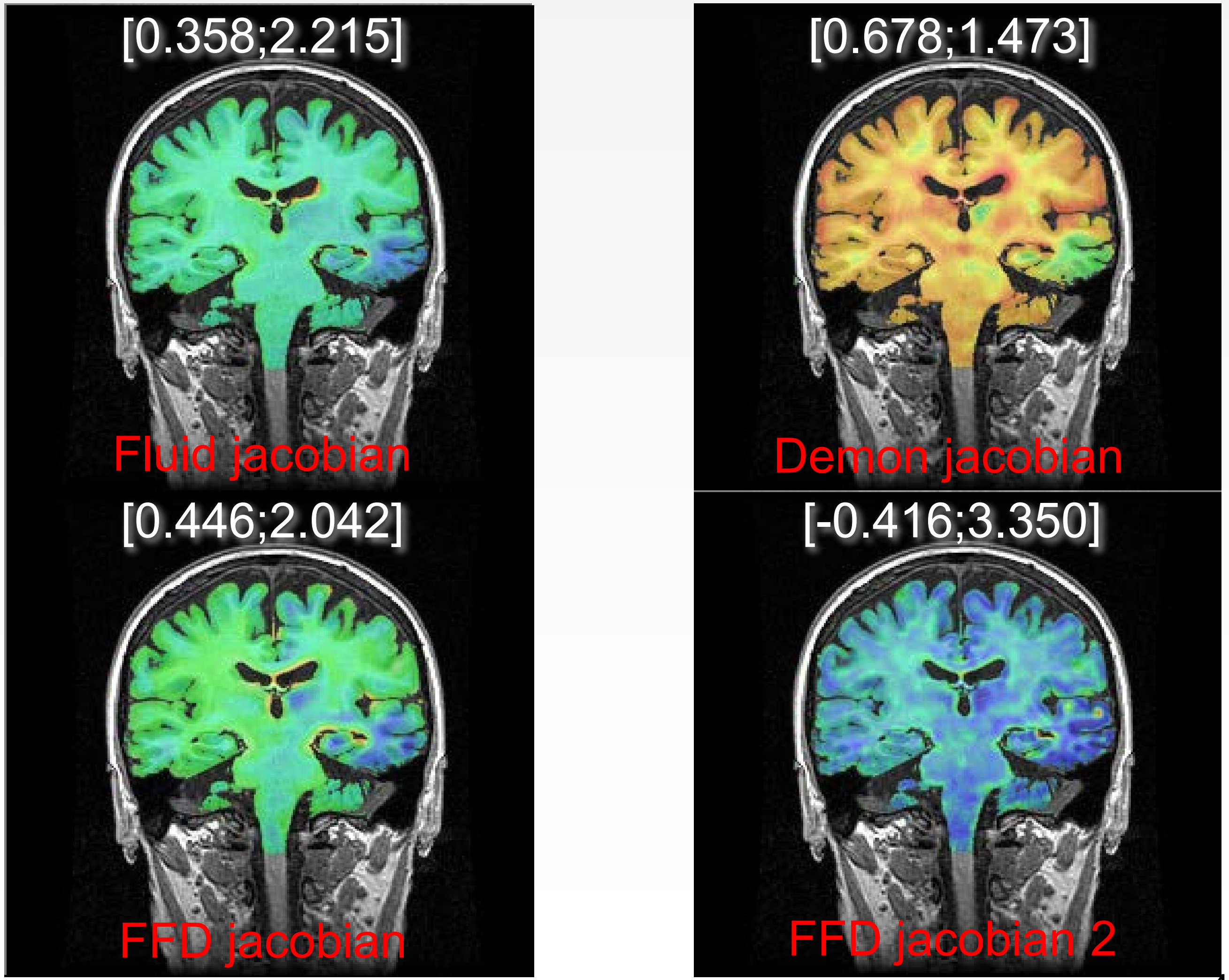
unconstrained

volume preserving (μ = 0.8)

Schnabel et al IEEE-TMI 2003, Tanner et al Med Phys 2006

TLED-Reg Motivation

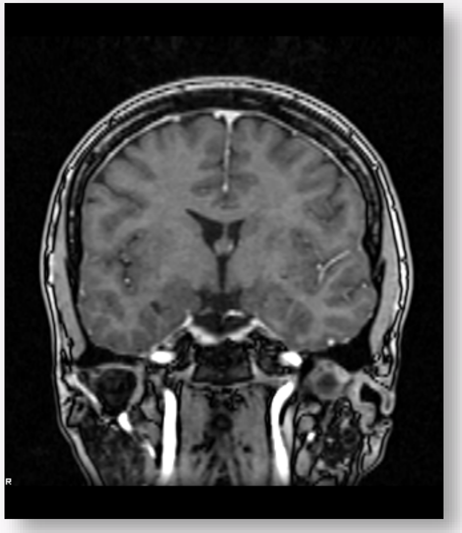
- As many atrophy rates as algorithms:



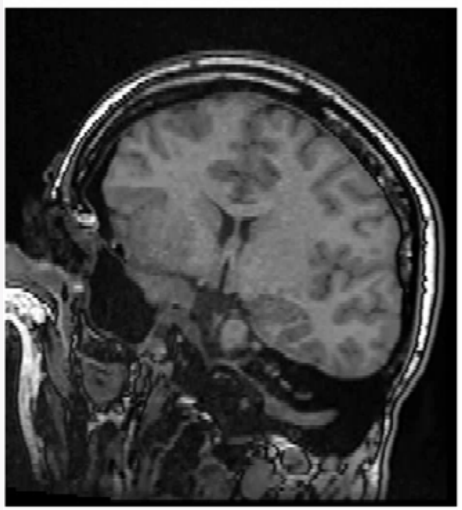
iMRI facility at National Hospital, Queen Square, London

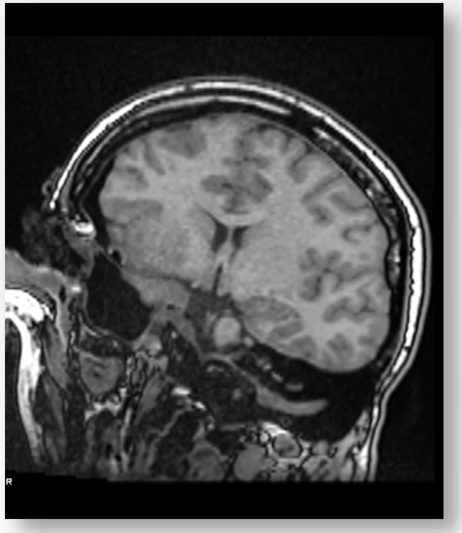
Planning and guiding avoidance of optic radiation

Daga, Duncan, Ourselin et al IEEE TMI 2012



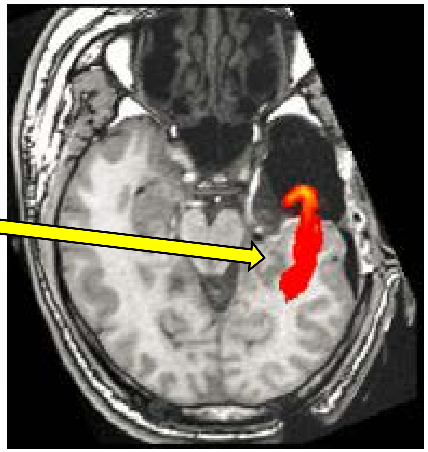
Pre-operative image and plan





Intra-operative image

Optic radiation



27% visual field loss

No visual field loss

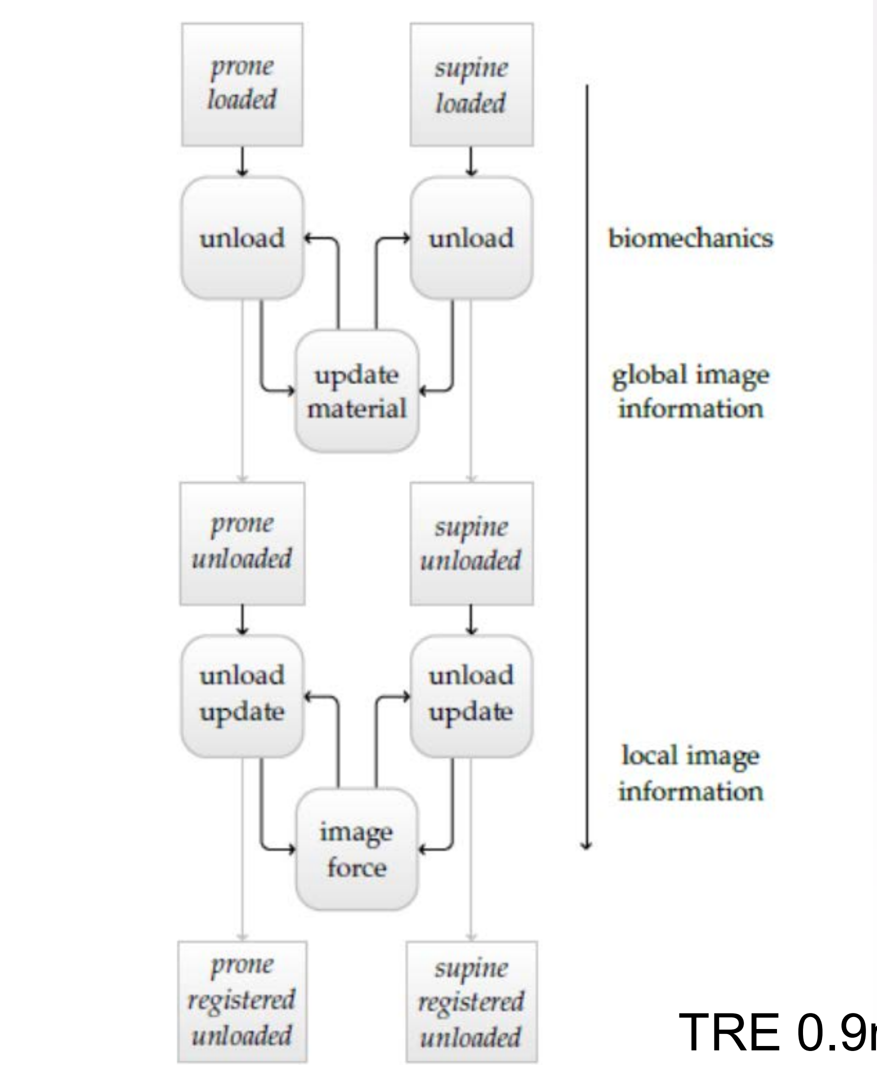
Breast Cancer & Clinical Needs

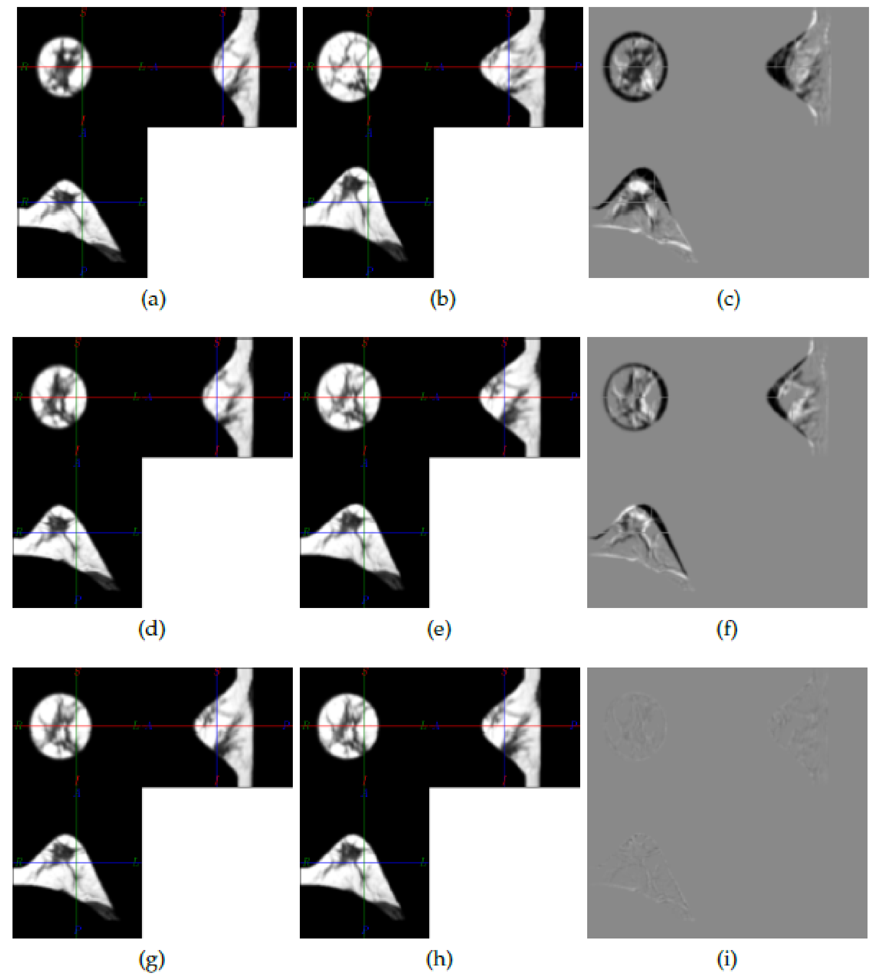
(FP7-ICT-2011-9)

- 78% Patients survive breast cancer for more than 10 years (Cancer Research UK)
- ~20% of patients undergoing lumpectomy have inadequate margins
- ~ 30% of patients suffer from suboptimal or poor aesthetic outcome

Carter et al 2005; Vouvrakis, Keshtgar, Hipwell et al 2015

Alignment of 3D prone and supine MR of breast via the unloaded configuration (simulated data)

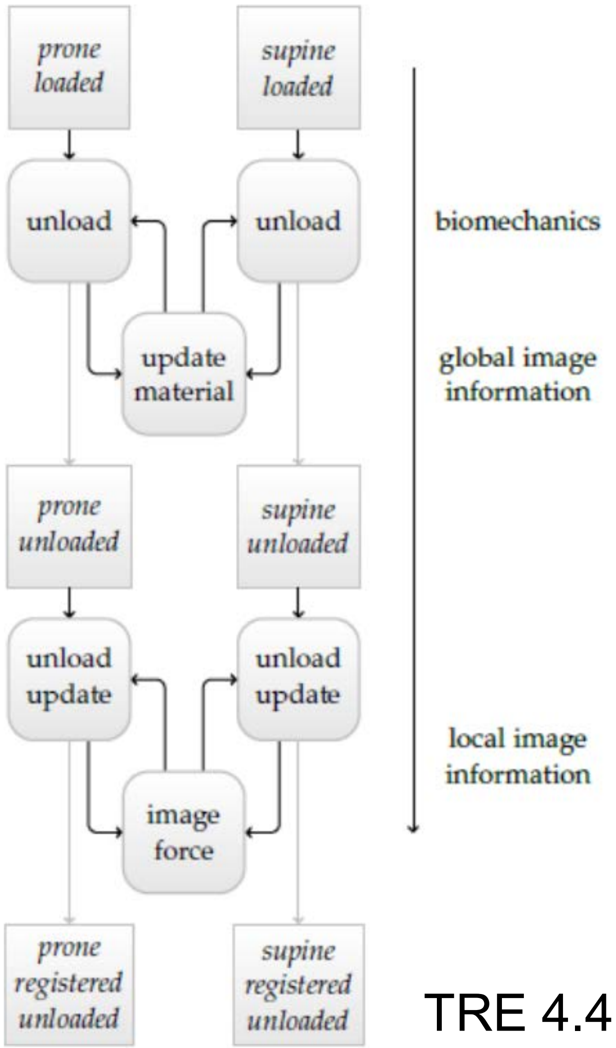


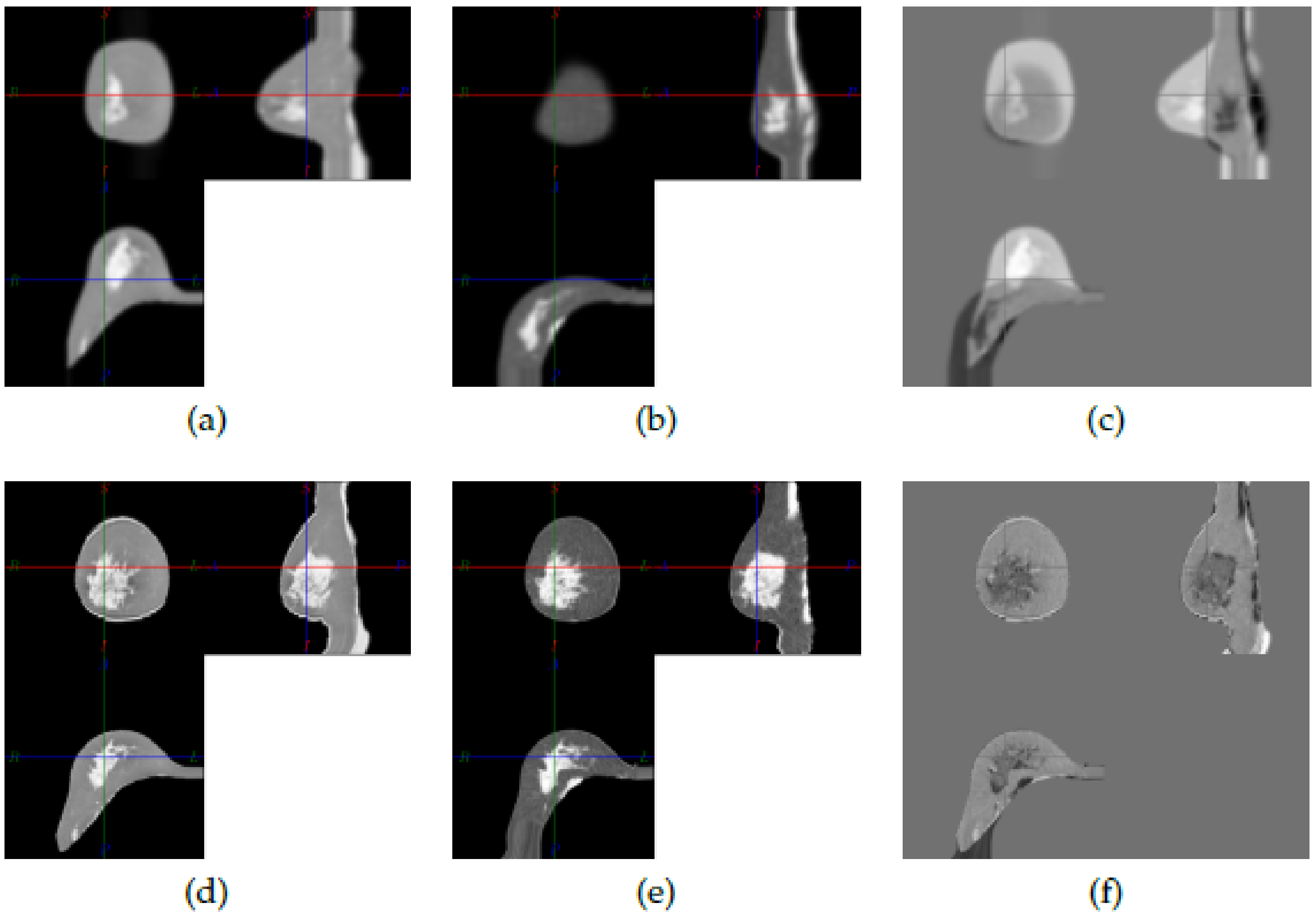


TRE 0.9mm using an array of 500 randomly distributed points

Eiben et al Annals of Biomed Eng (2015)

Alignment of 3D prone MRI and supine CT of breast via synthetic MRI and the unloaded configuration (real data)





TRE 4.4mm by user identified points (inter-observer error 7.1mm)

Eiben et al Annals of Biomed Eng (2015)

Surgical Simulator:
Registration to 3D reconstructed visible surface

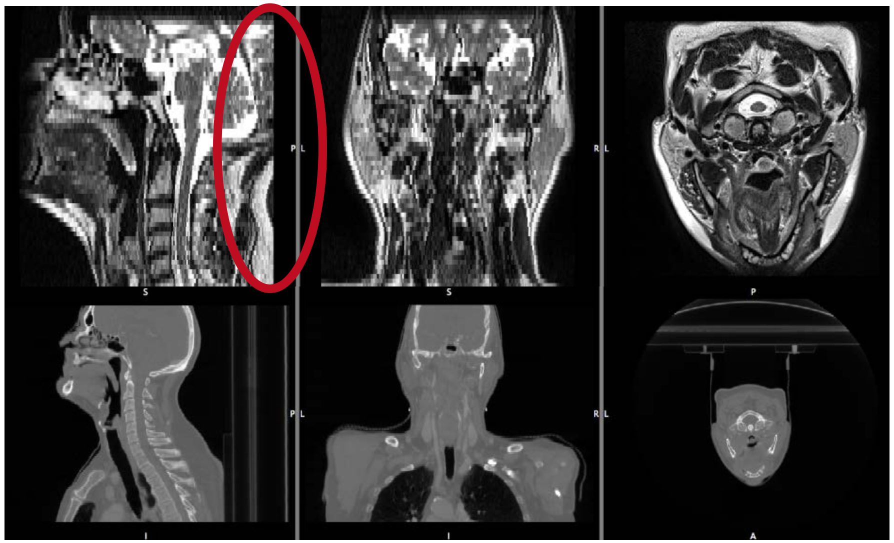
Magnetic
Resonance
Image
(patient prone)

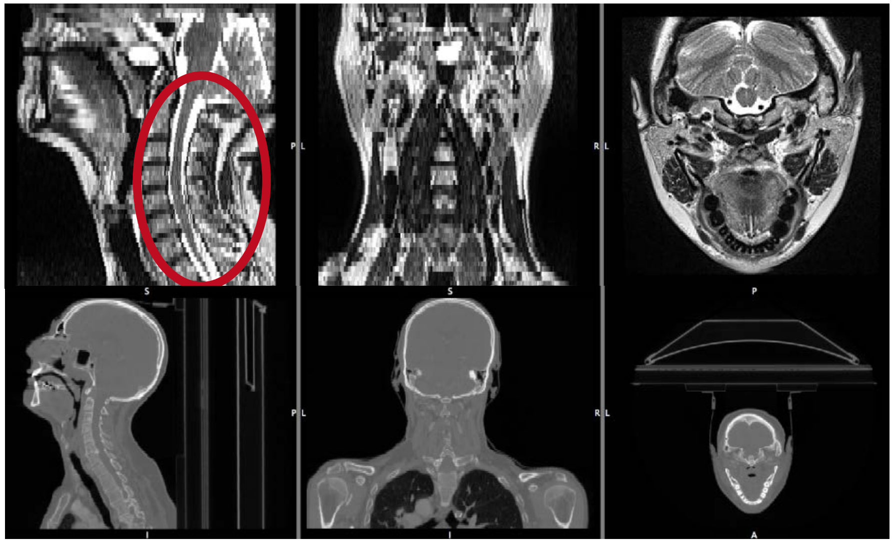
TRE 10.0mm (prone to supine)
using user identified points from supine CT

Eiben PhD Thesis Nov 2015

CT SYNTHESIS IN THE HEAD & NECK REGION

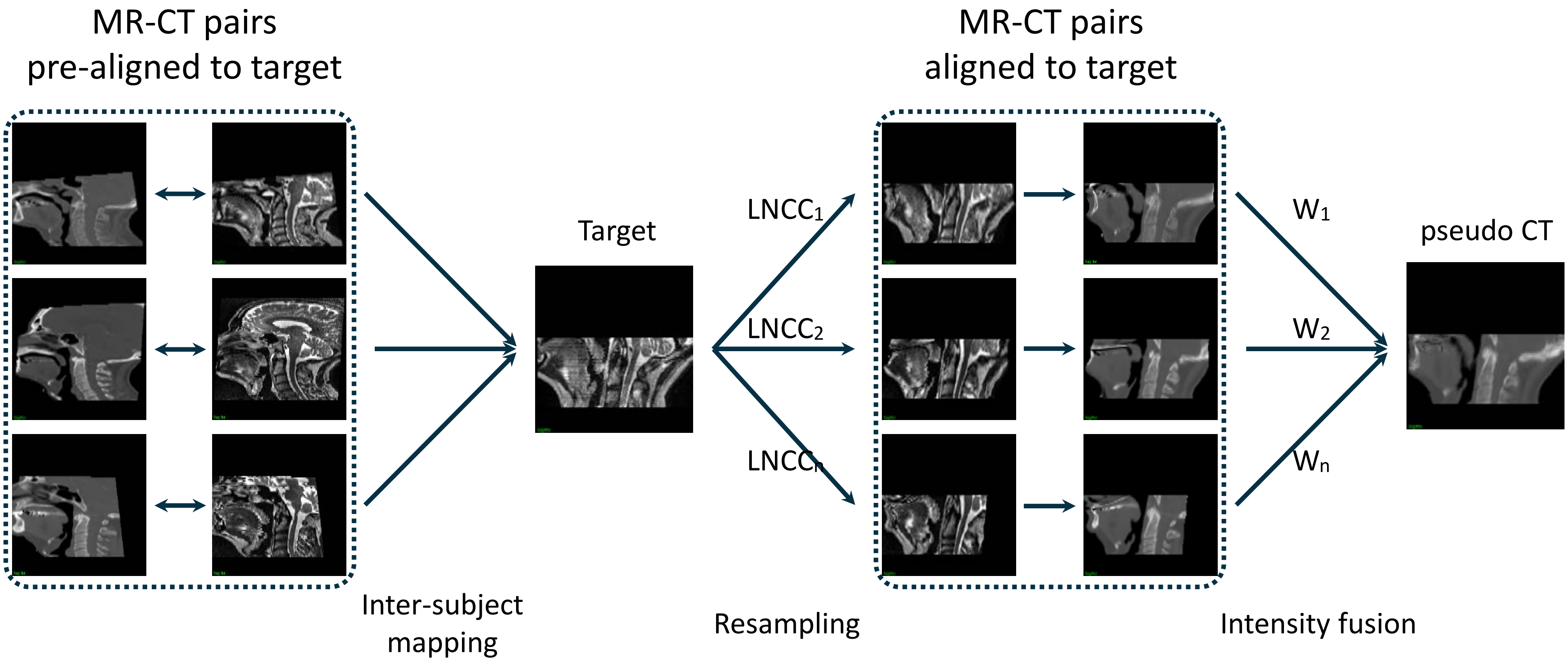
- Challenges:
  1. Mixture of tissues
  2. Wide range of fields of view
  3. Large-scale postural changes





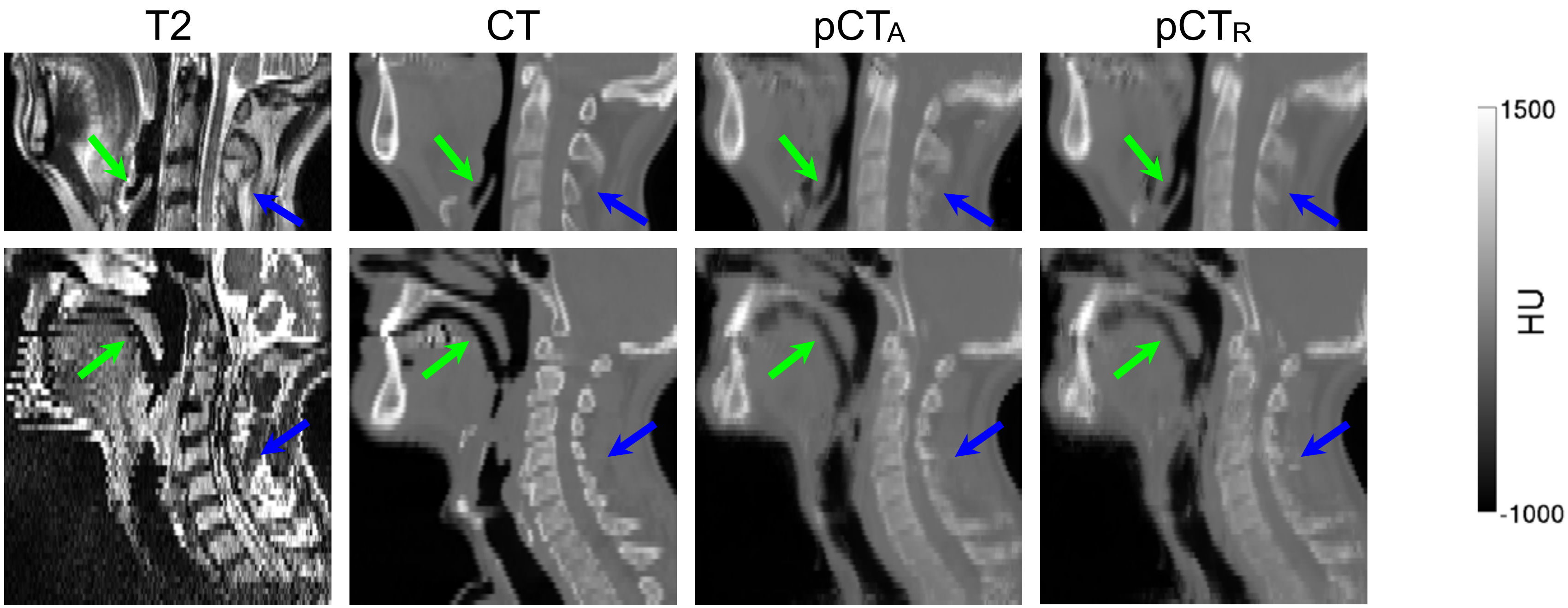
2. MULTI-ATLAS CT SYNTHESIS

Burgos *et al.*, EJNMMI 2015



EXAMPLES OF CT SYNTHESIS IN THE HEAD & NECK

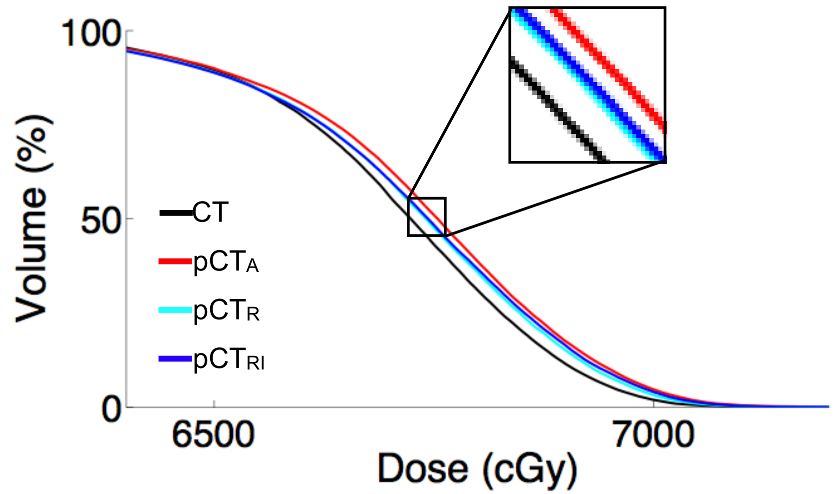
- Three pseudo CTs per subject
  - pCT_A, obtained using a single affine between the atlases and target
  - pCT_R, obtained using the robust affine



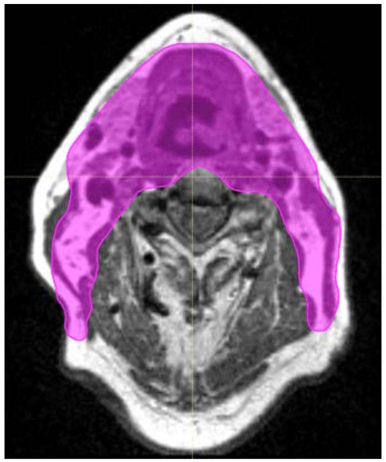
APPLICATION TO RADIOTHERAPY TREATMENT PLANNING

- Case study: dosimetry calculations
  - Dose volume histograms (DVH) in the planning target volume (PTV)
  - Gamma analysis

DVH of PTV



PTV region overlaid on T2



Gamma maps

pCTA pCTR pCTRI

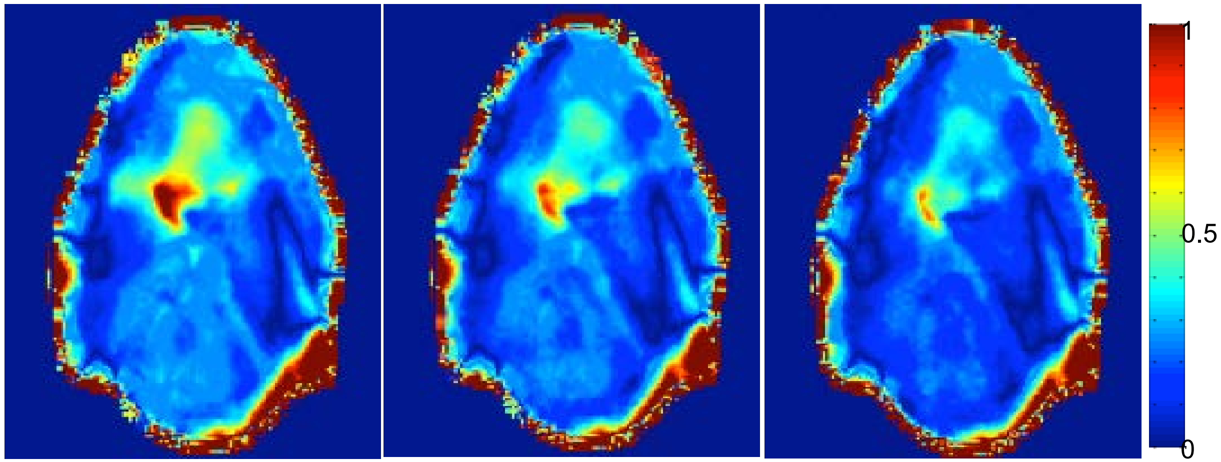
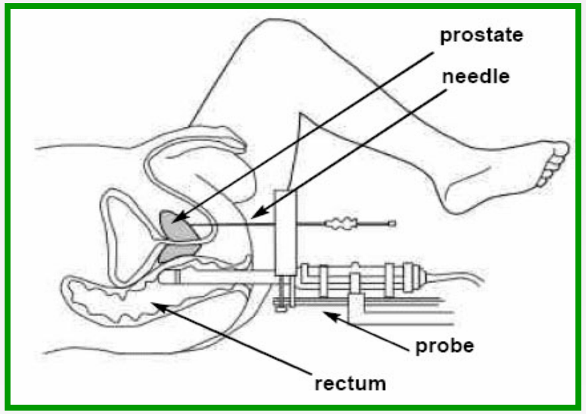
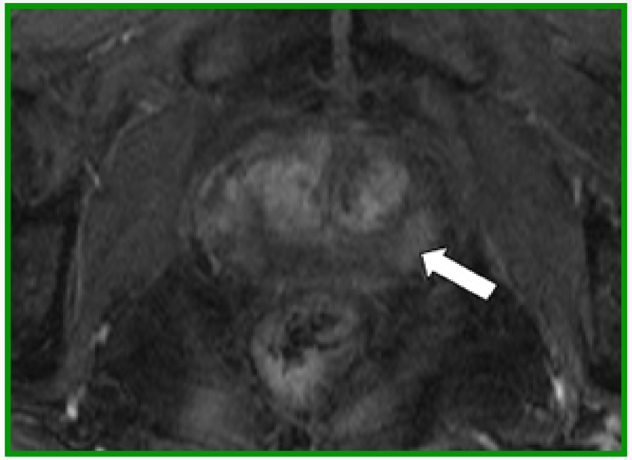
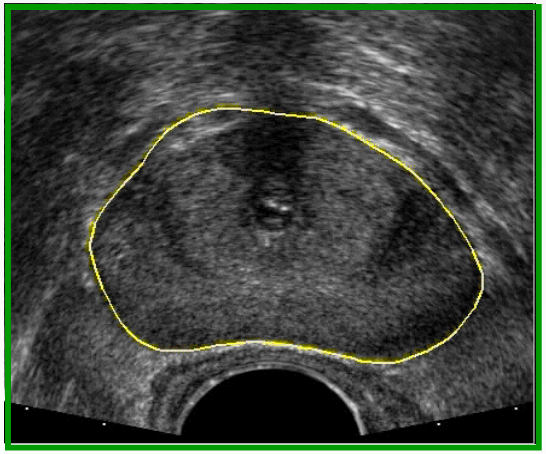


Image Directed Biopsy and Partial Prostate Ablation

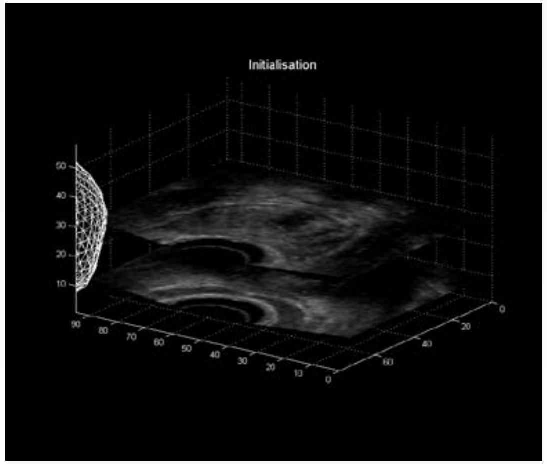


- Multimodal MR to delineate focal cancer
- Biopsy
- Focal therapy (PDT or HIFU) delivered (via needle or transrectally) with transrectal ultrasound guidance





TRE 1.8mm (RMS)
+/- 0.7mm



Clinical trial commenced, > 100 patients

EPSRC, NIHR i4i, Wellcome DoH HICF,

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

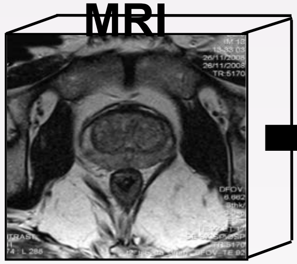
Real-time tracking of the prostate using US and MRI

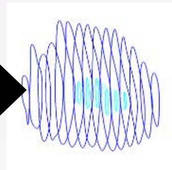
PRE-PROCEDURE

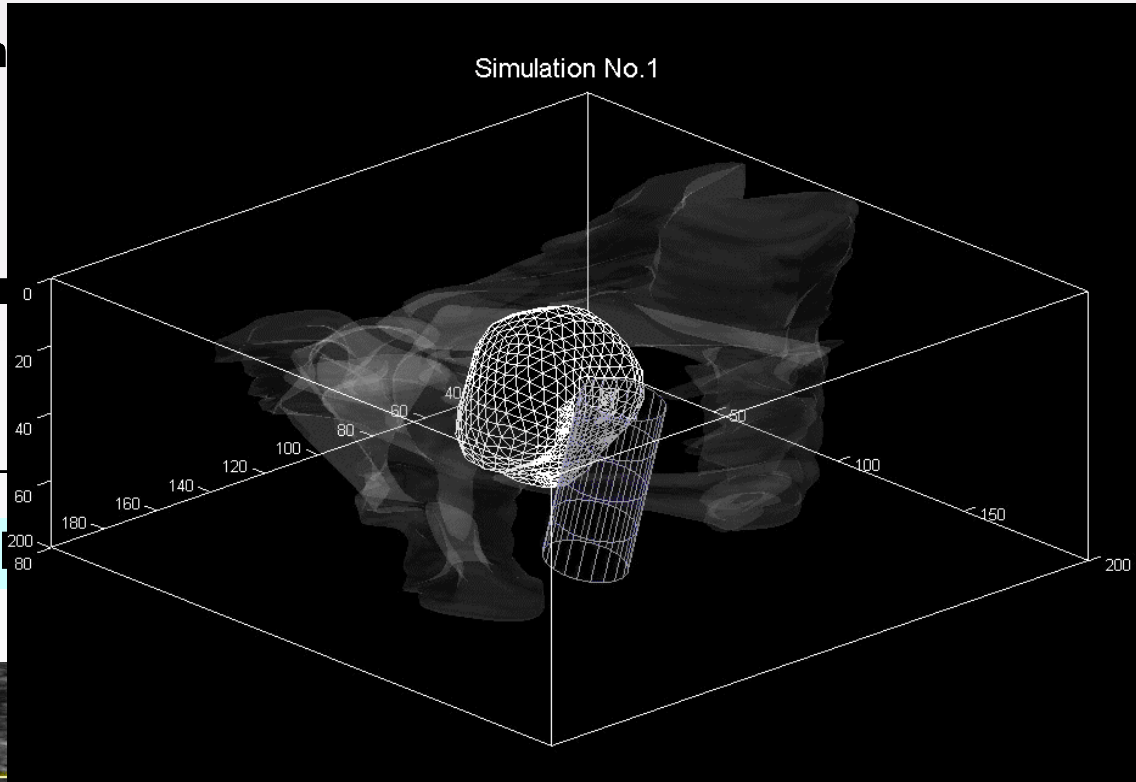
Referen

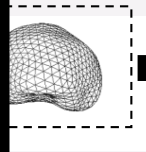
es

MRI



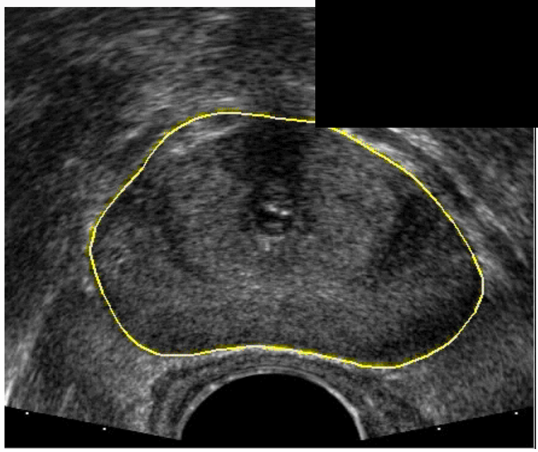


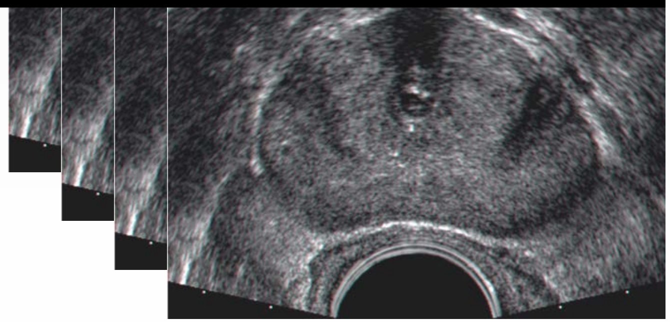




Patient-specific SMM

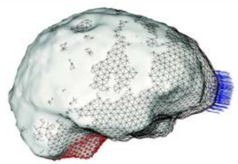
DURING PROCEDUR



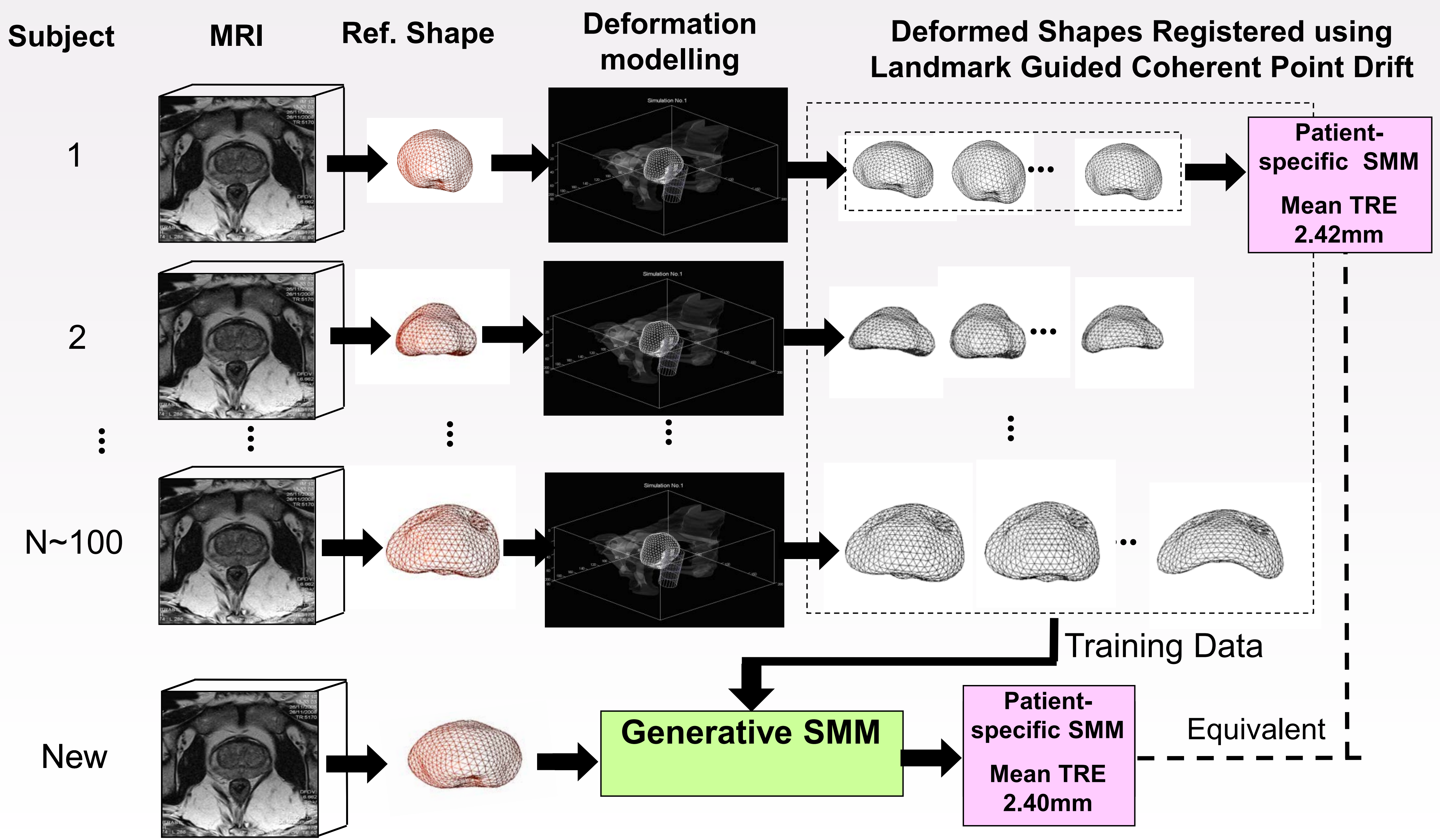


Register

NiftySim

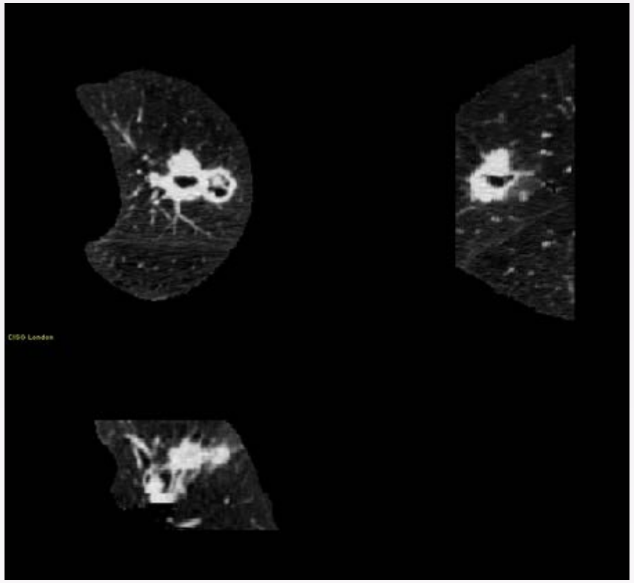


Automatic generation of deformable organ models



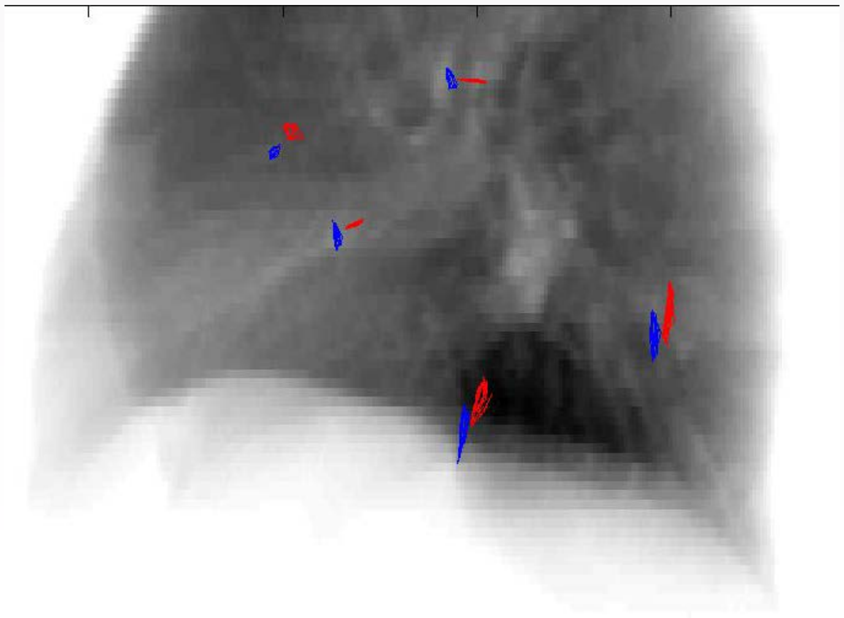
Hu et al. Medical Image Analysis, 2012 and patent

Motion compensation in lung radiotherapy



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

McClelland et al Medical Physics 2006



Problem: Significant inter-fractional variation in breathing patterns

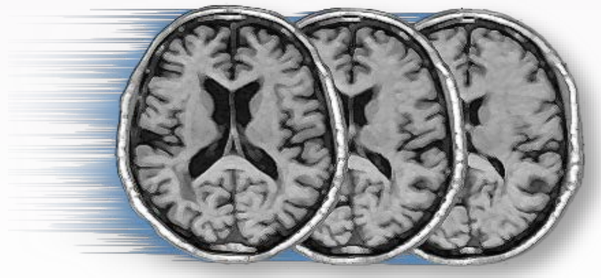
McClelland et al Phys Med Biol 2011

Lung registration using the NiftyReg package

EMPIRE'10

(workshop at MICCAI 2010)

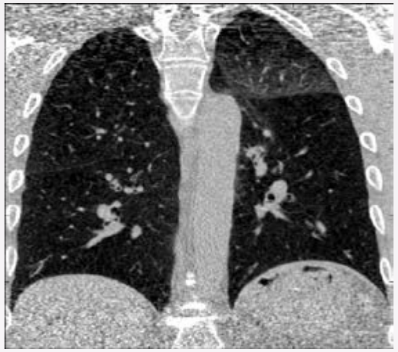
http://empire10.isi.uu.nl

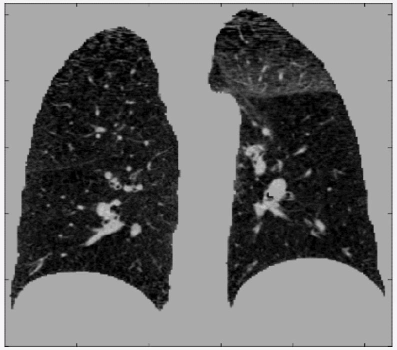


Marc Modat, Jamie McClelland and Sébastien Ourselin

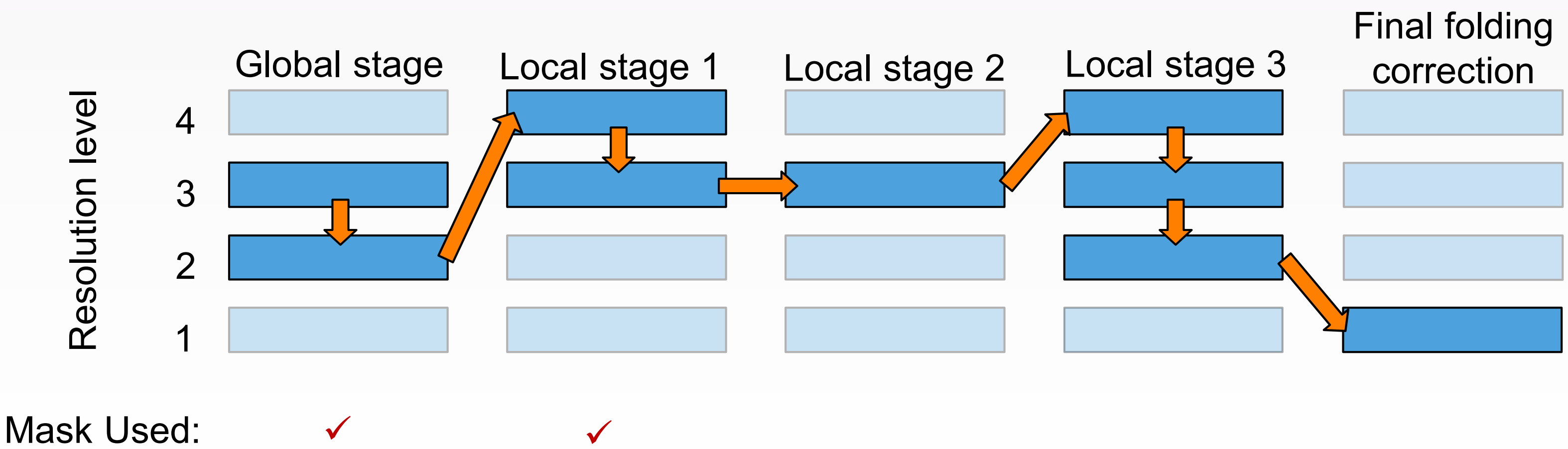
Centre for **M**edical **I**mage **C**omputing, University College London

Lung registration - Pipeline



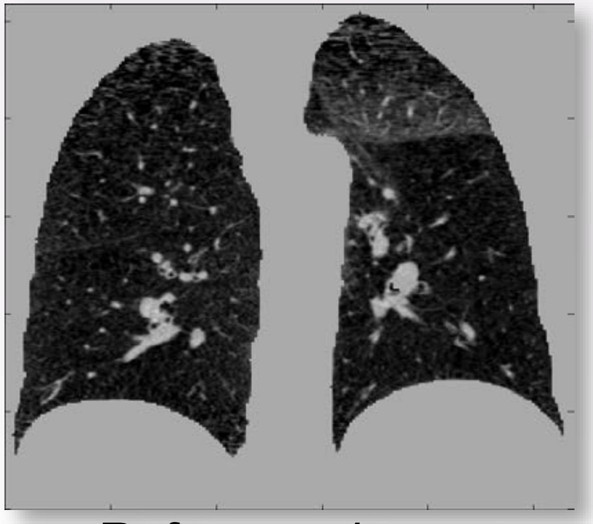


- Preprocessing (Nifti format and masking)

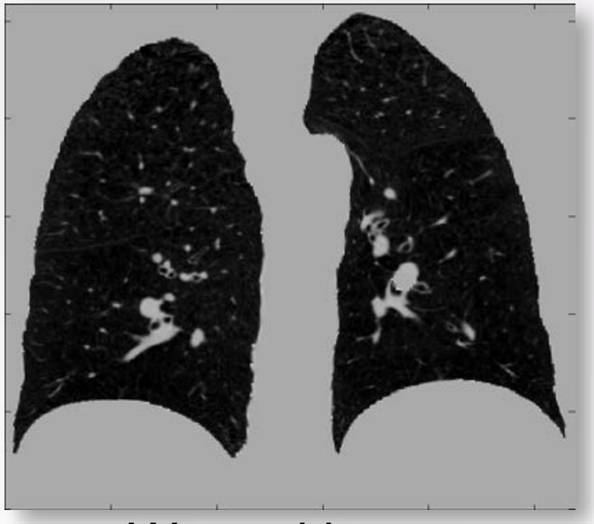


- 1 global registration step (block-matching)
- 3 local registration step (F^{3}D)

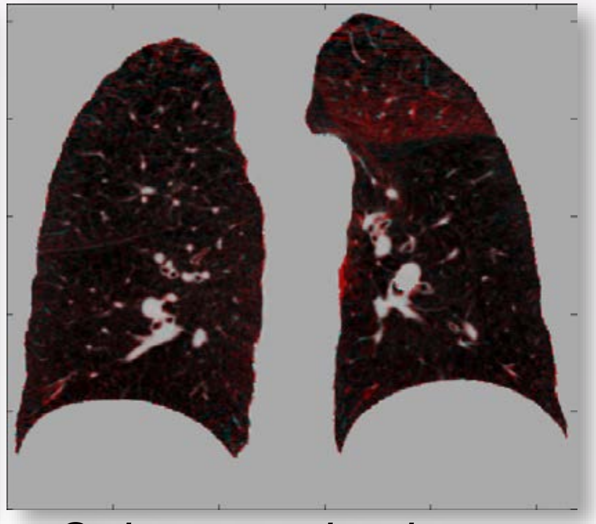
Lung registration - Local registration 3



Reference image



Warped image



Colour overlay image

TRE: landmarks 0.8mm and ranked 4th overall
(slightly worse at lung boundaries and fissures)

Lung registration - Computation time

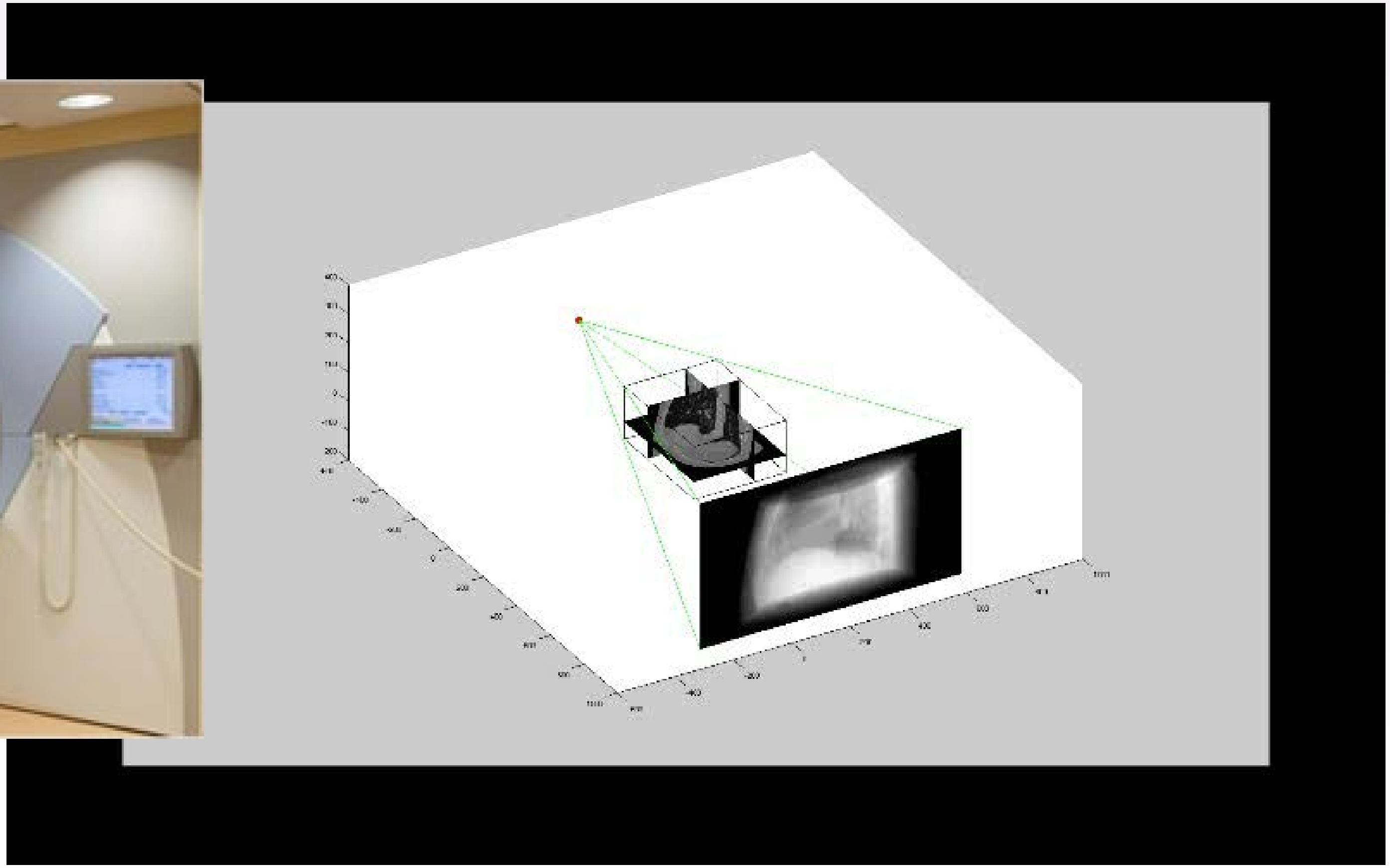
Computation time	CPU-based implementation	GPU-based implementation
Global registration	1.40 (0.57)	NA
Local registration 1	1.28 (0.47)	1.06 (0.41)
Local registration 2	1.32 (0.84)	0.83 (0.36)
Local registration 3	12.25 (5.13)	1.56 (0.27)
Folding correction	1.16 (0.57)	NA

Table 1: Mean computation time in minutes (and standard deviation) of the different registration stages.

What can still go wrong?

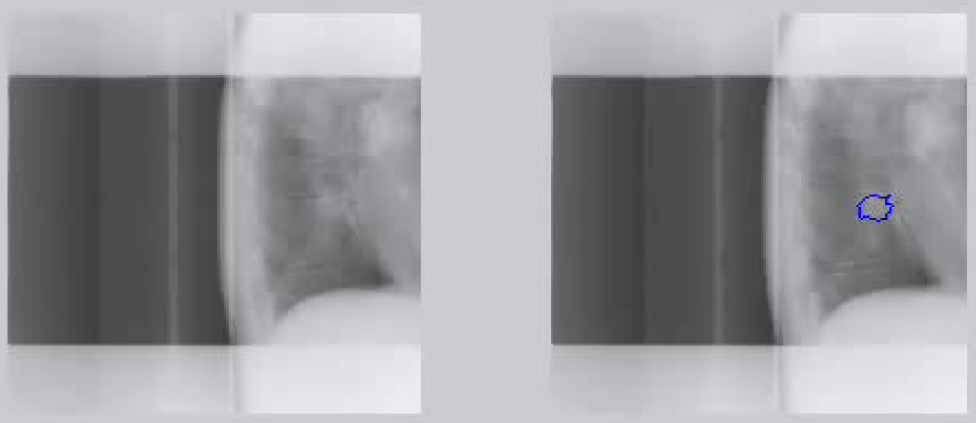
- Sliding of individual lobes
- Loss or gain of significant structure (tumour growth, re-opening airways etc)
- Very large intensity changes can still throw the algorithm

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



Original

Original +
tumour outline

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

Martin et al Phys Med Biol 2013

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

Cine CT data – BH as static reference

McClelland et al WBIR 2014

Reconstruction of 4D MR images from volunteer with normal, irregular breathing

McClelland 2015

Validation of method

- Digital phantoms
- Physical phantoms
- Exogenous fiducials
- Internal anatomical landmarks
  - Pooling of ground truth data
  - Grand challenges
- Visual Inspection
- …

Verification during intervention/therapy etc

- Exogenous fiducials
- Internal anatomical landmarks
- Visual Inspection
- …

Understanding limitations, spotting errors

Training!

Acknowledgements

- John Hipwell, Lianghao Han, Thomy Mertzanidou, Seb Ourselin, Ninon Burgos, Jorge Cardoso, Marc Modat, Dean Barratt, Yipeng Hu, Jamie McClelland, James Martin, Laura Panagiotaki, Danny Alexander *CMIC UCL*
- Mark Emberton, Hash Ahmed, Steve Halligan, Shonit Punwani, *UCLH*
- Mo Keshtgar, *Royal Free Hospital*
- David Landau, *Guy's & St. Thomas',* Uwe Oelfke, Steve Webb, *Institute of Cancer Research*
- *EPSRC, MRC, Cancer Research UK, TSB/UKTI, NIHR, The Wellcome Trust, DoH, Prostate Cancer UK*
- *Philips Medical Systems, Siemens, VisionRT, Leica, Brainlab, Elekta,*

Thank you

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