The Promise and Potential Pitfalls of Deformable Image

Clinical applications in the Head&Neck: *Verification using 3D dosimetry*

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Disclosures

- NCI R01 funding
  - RPC collaboration (IROC)
- Several sponsored research agreements involving the application of 3D dosimetry

Outline

- Basics of H&N IMRT
  - Key challenges
- DIR can help with ………
  - Contouring: - greater efficiency and accuracy ?
  - Dose accumulation: intra-Tx dose acceptable ?
  - Adaptive planning: create a more optimal plan ?
  - Treatment response assessment ?
- Role of 3D Dosimetry in DIR Validation

An old-school H&N treatment plan !

- Problem …
  - This plan is not conformal enough !

Theoretical birth of IMRT

- **1988** Brahme – 1^{st} inverse planning.
- **1989** Webb - simulated annealing.

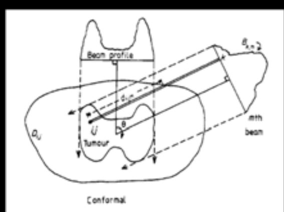


Figure 1. The geometry of the problem.

Optimisation of conformal radiotherapy dose distributions by simulated annealing

S Webb

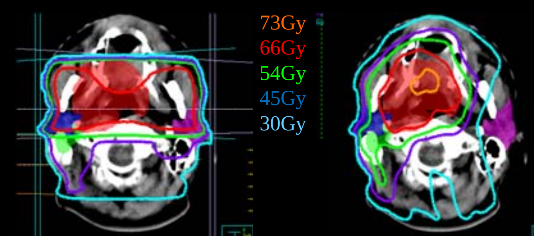
Joint Department of Physics, Institute of Cancer Research and Royal Marsden Hospital, Downs Road, Sutton, Surrey, UK

1989

Anders Brahme

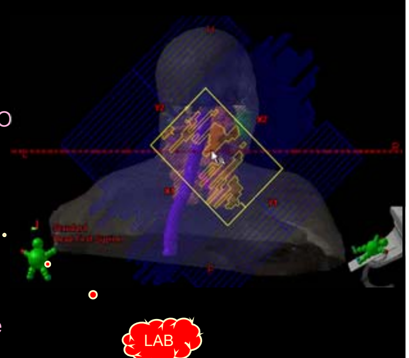
Steve Webb

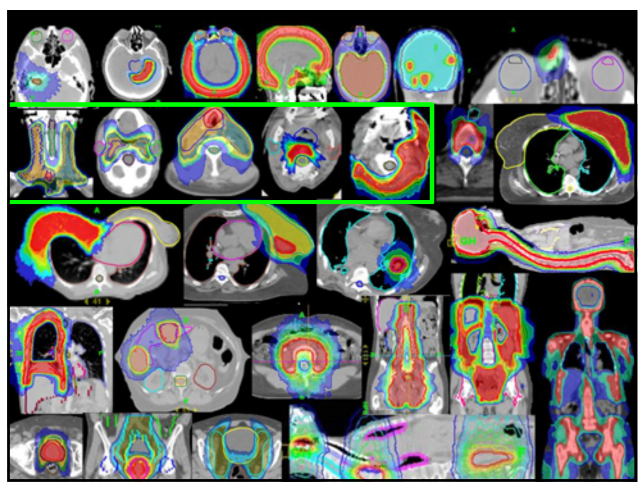
- Problem …
  - This plan is not conformal enough !
- Solution – fluence modulation



We are now masters of fluence !

- Fluence modulation
  - IMRT, VMAT
  - Tomotherapy
  - Cyberknife, VERO
- New challenges
  - PTV definition
  - Adaptive therapy
  - Efficiency
  - Optimal Plan
  - Knowledge guide
  - Commissioning\ Verification





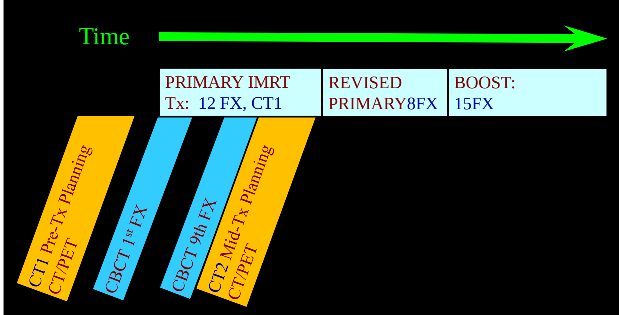
The role of DIR in H&N RT

- DIR can help with ………
  - Contouring: greater efficiency and accuracy ?
  - Dose accumulation: intra-Tx dose acceptable ?
  - Adaptive planning: create a more optimal plan ?
  - Treatment response: enable more precise assessment ?

Clinical Example

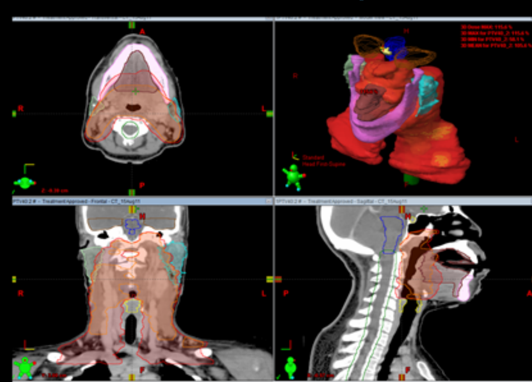
- Nasopharynx, with Bilateral Necks
  - T4N3a
    - Primary - 20fx of 2Gy/day, 40Gy total
    - Boost   - 15fx of 2Gy/day, 30Gy total
- H&N with substantial tumor shrinkage
  - Adaptive Planning: How to ensure adequate
    - PTV coverage
    - OAR sparing
  - Dose Warping and Dose Accumulation

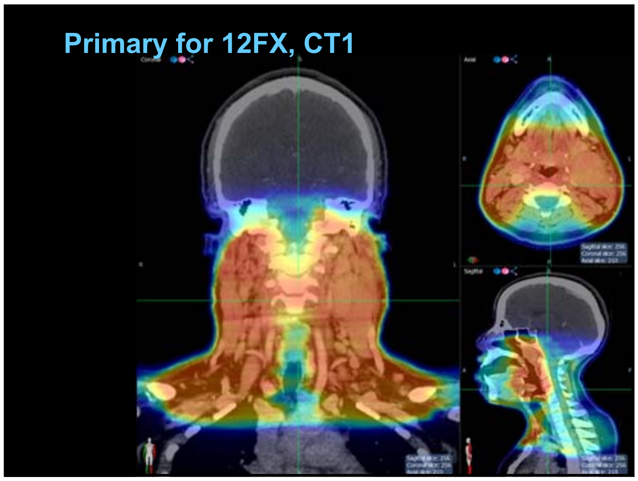
Treatment timeline

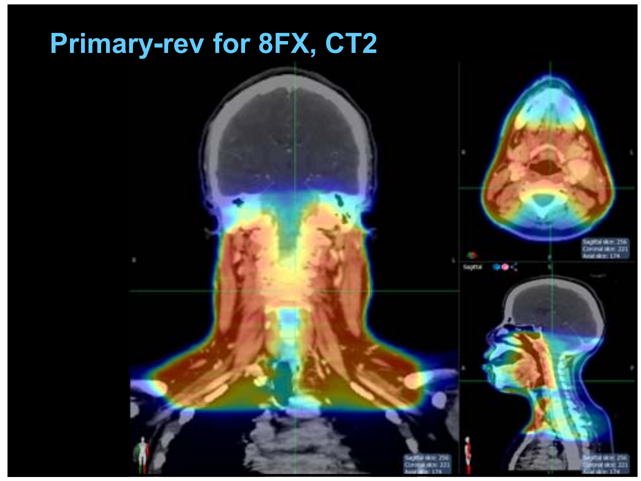


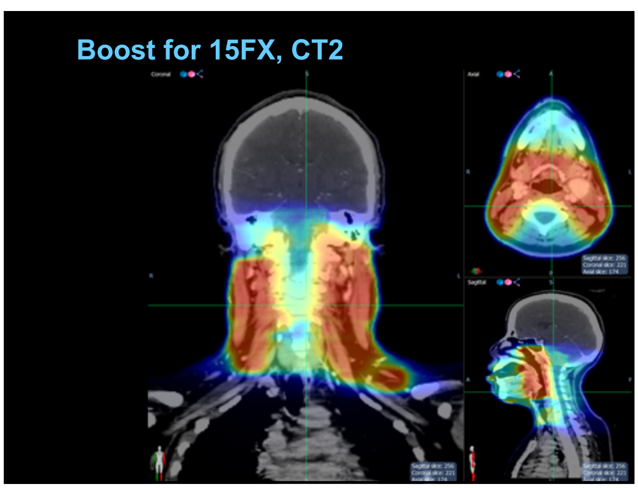
Shiva Das

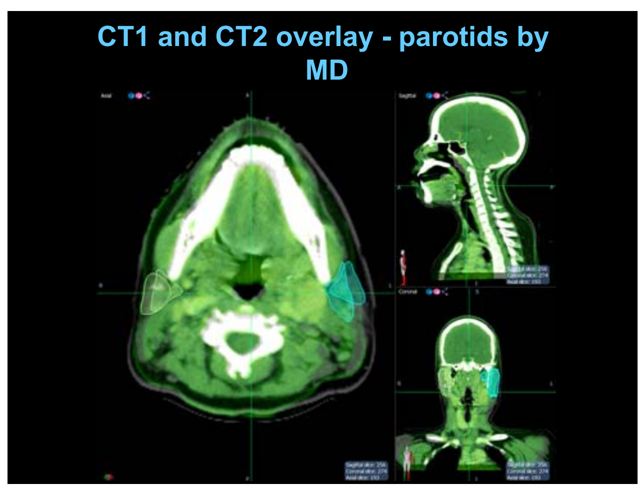
Overview of the plan

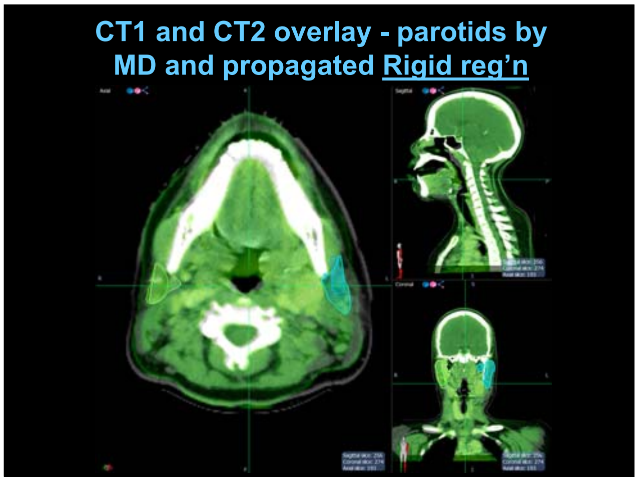


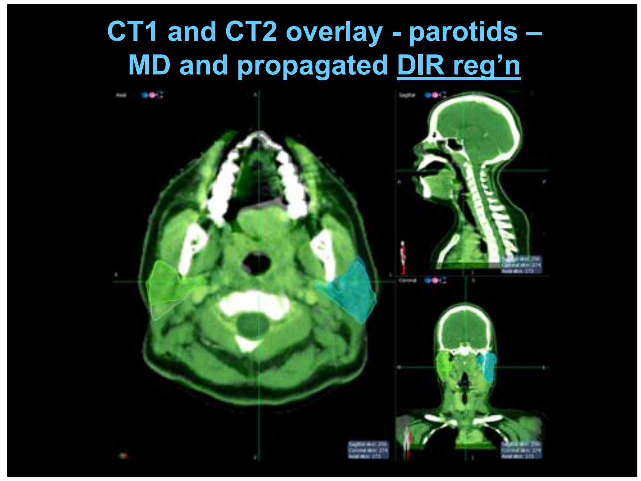

Primary for 12FX, CT1

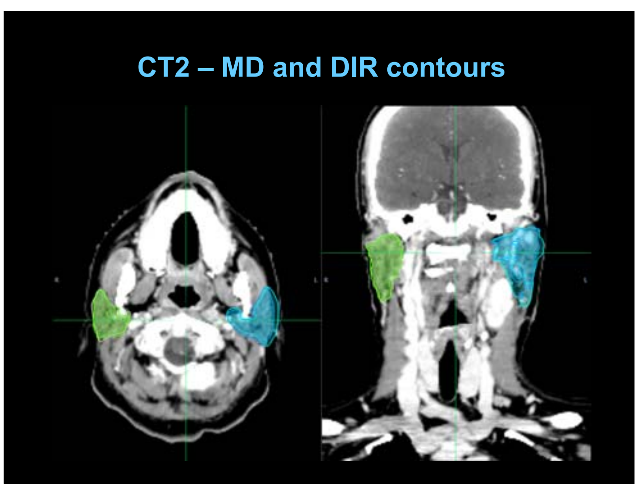

Primary-rev for 8FX, CT2

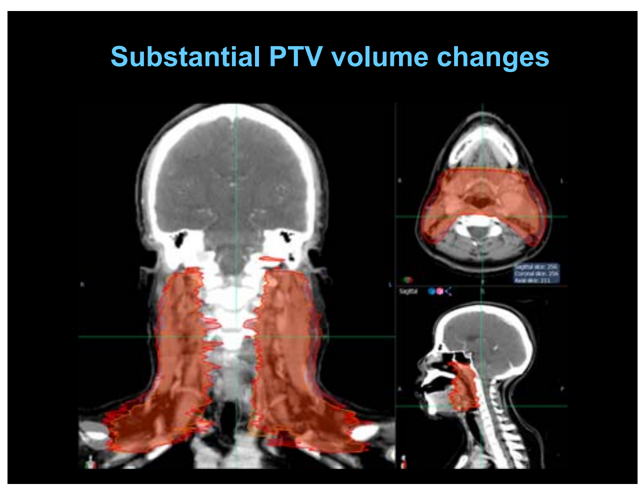

Boost for 15FX, CT2

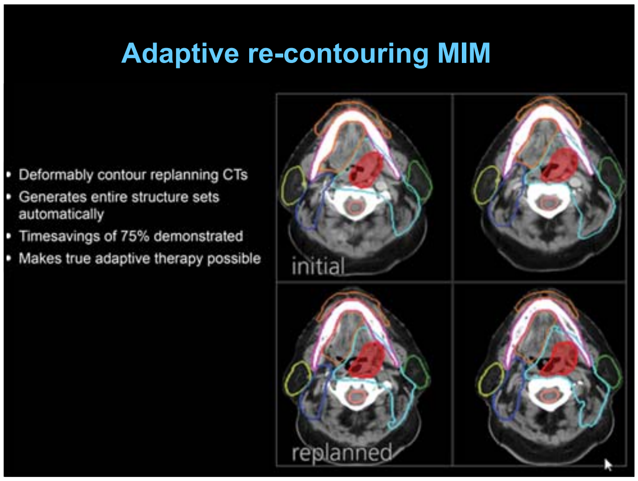

CT1 and CT2 overlay - parotids by MD


CT1 and CT2 overlay - parotids by
MD and propagated Rigid reg'n

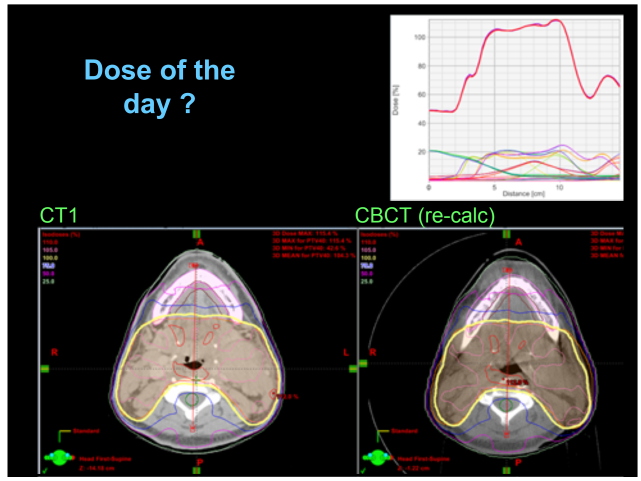

CT1 and CT2 overlay - parotids –
MD and propagated DIR reg'n


CT2 – MD and DIR contours

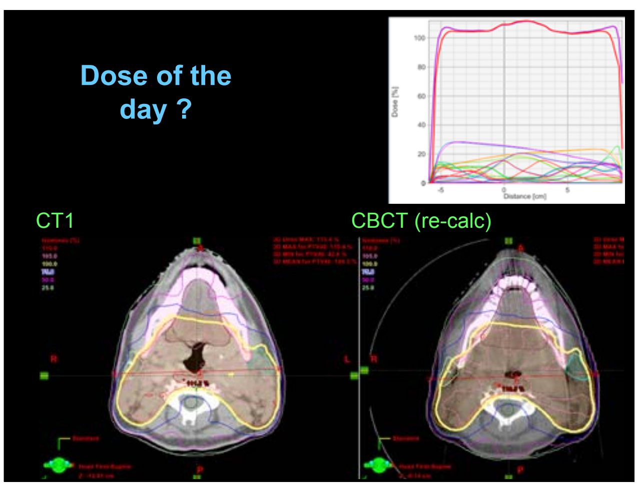

Substantial PTV volume changes



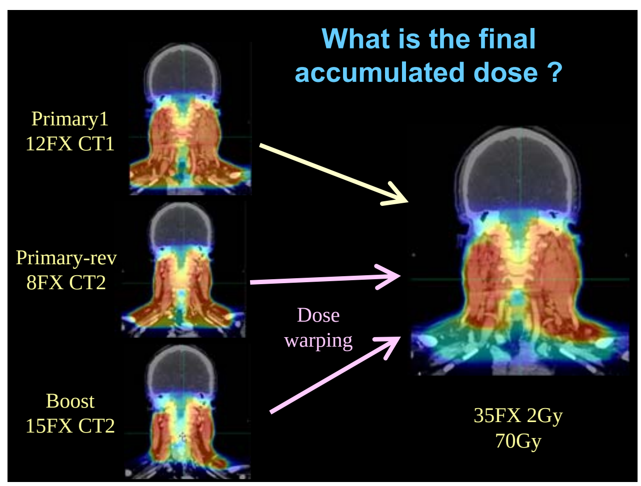
Adaptive re-contouring MIM
Deformably contour replanning CTs
Generates entire structure sets automatically
Timesavings of 75% demonstrated
Makes true adaptive therapy possible
initial
replanned



Dose of the day ?
CT1
CBCT (re-calc)

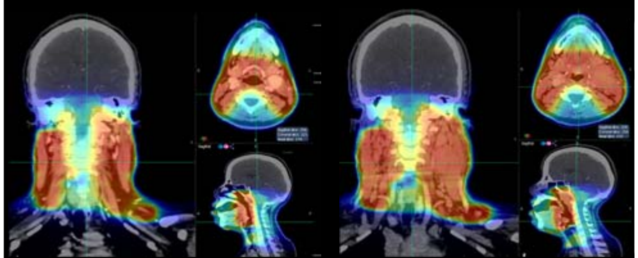


Dose of the day ?
CT1
CBCT (re-calc)



What is the final accumulated dose ?
Primary1
12FX CT1
Primary-rev
8FX CT2
Boost
15FX CT2
Dose warping
35FX 2Gy
70Gy

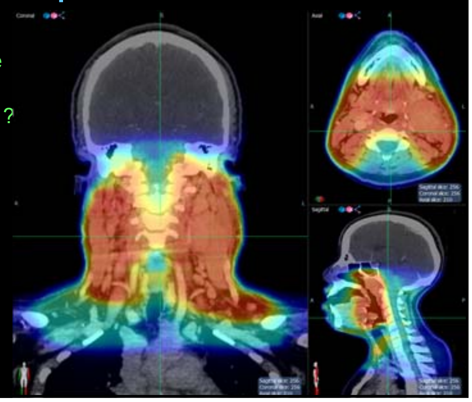
Boost dose CT2 warped to CT1



CT2 (after 9th FX)   CT1

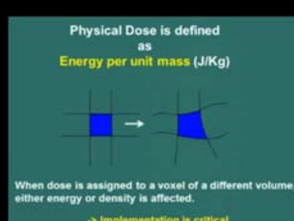
Plan Sum - Primary and Boost dose warped onto CT1

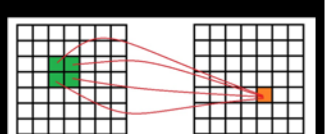
- But what have we done ?
- How accurate ?



Challenges of dose warping ?

- DIR assumes
  - Every point in one image has a corresponding point in the other
- Not valid when ….
  - Tissue shrink/swells
  - Dose in deformed voxel ?

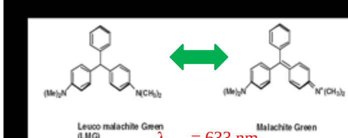




Velocity (Theo Lazarkis)

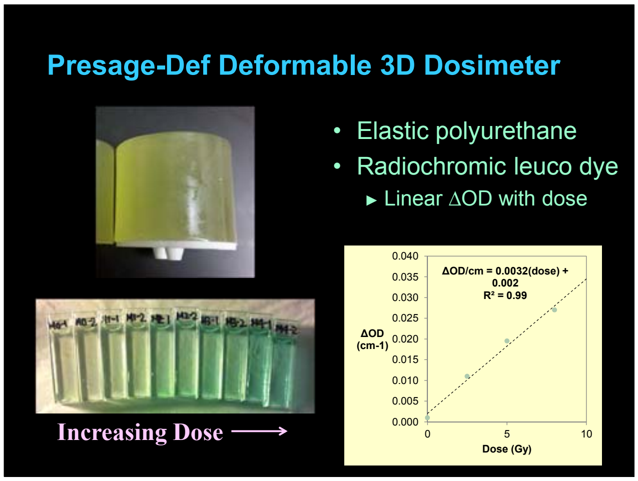
Can 3D Dosimetry help ?

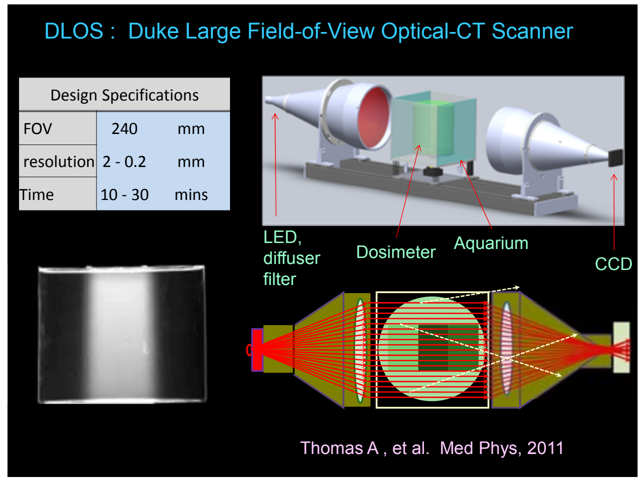
- Radiochromic Plastic: Presage
- Contrast: light absorption
- Good dosimetry properties
- Flexible

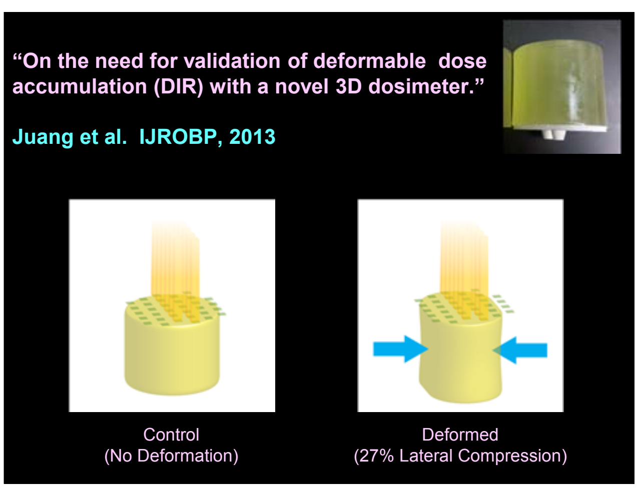


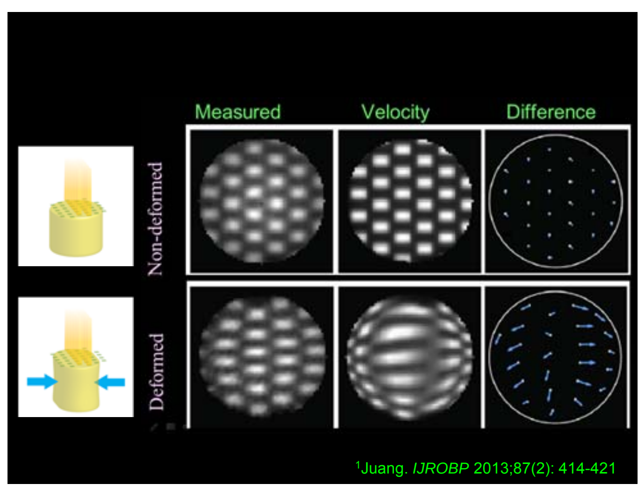
5 Beam Tx

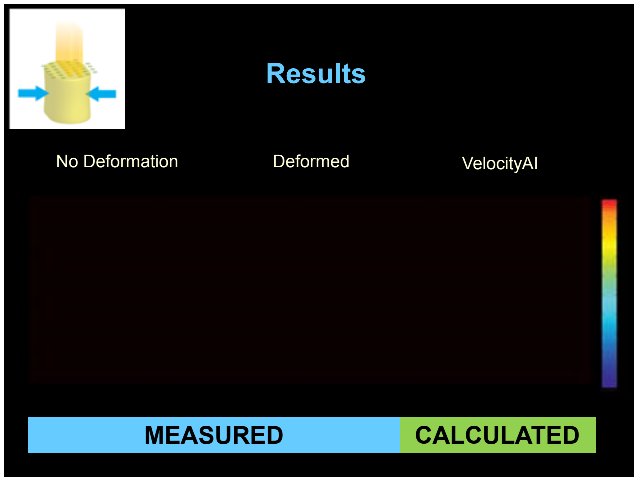
Heuris Inc, www.presage3d.com

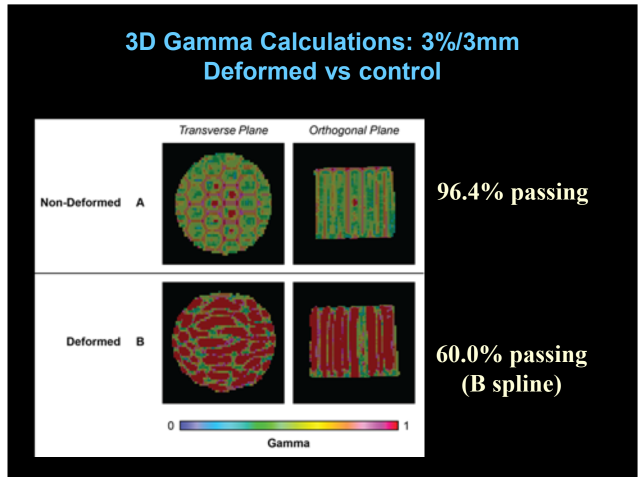

Presage-Def Deformable 3D Dosimeter
• Elastic polyurethane
• Radiochromic leuco dye
▸ Linear ΔOD with dose
ΔOD/cm = 0.0032(dose) + 0.002
R² = 0.99
ΔOD (cm-1)
Dose (Gy)
Increasing Dose

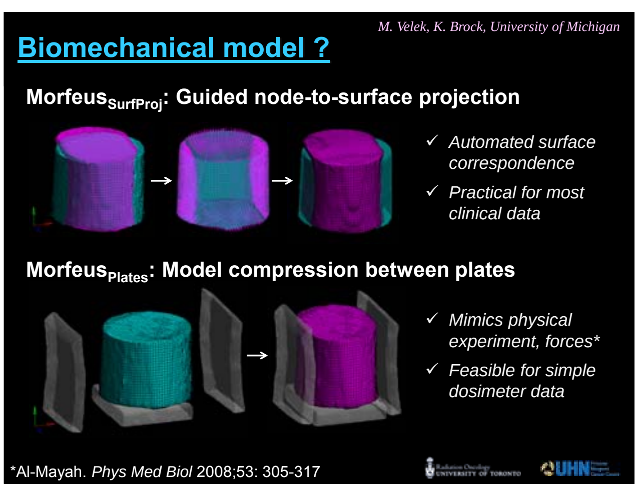

DLOS : Duke Large Field-of-View Optical-CT Scanner
Design Specifications
FOV 240 mm
resolution 2 - 0.2 mm
Time 10 - 30 mins
LED, diffuser filter
Dosimeter
Aquarium
CCD
Thomas A , et al. Med Phys, 2011

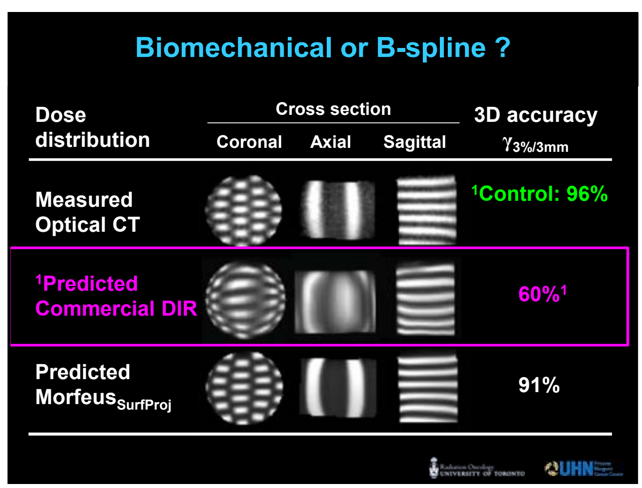

"On the need for validation of deformable dose accumulation (DIR) with a novel 3D dosimeter."
Juang et al. IJROBP, 2013
Control
(No Deformation)
Deformed
(27% Lateral Compression)

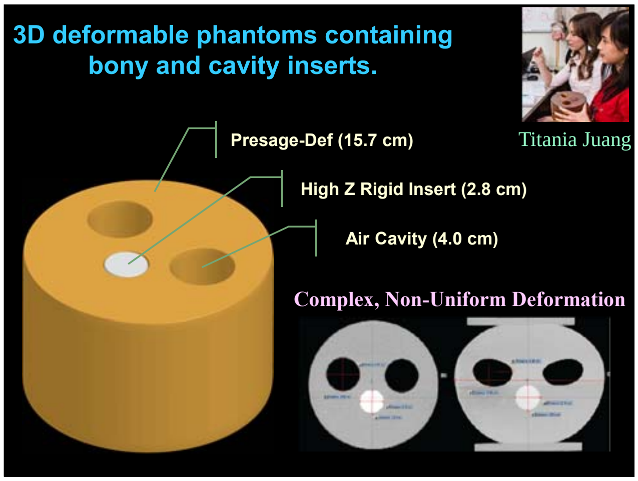

Measured
Velocity
Difference
Non-deformed
Deformed
1Juang. IJROBP 2013;87(2): 414-421

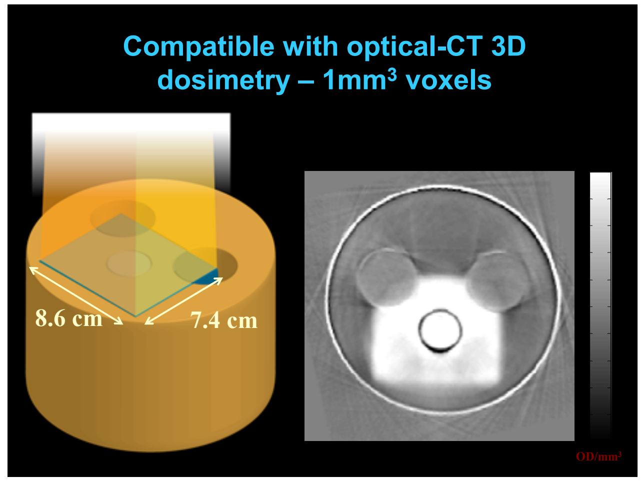

Results
No Deformation
Deformed
VelocityAI
MEASURED
CALCULATED

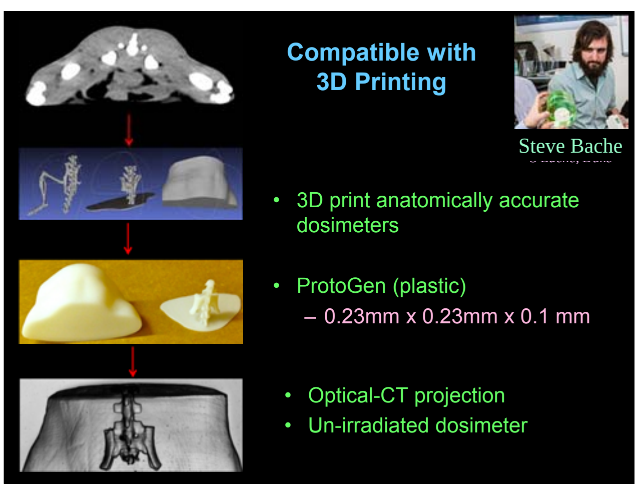

3D Gamma Calculations: 3%/3mm
Deformed vs control
Transverse Plane
Orthogonal Plane
Non-Deformed A
Deformed B
0
1
Gamma
96.4% passing
60.0% passing
(B spline)

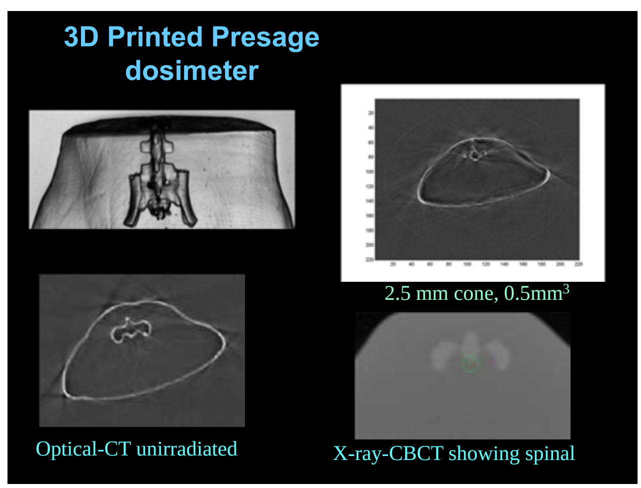

M. Velek, K. Brock, University of Michigan
Biomechanical model ?
Morfeus SurfProj: Guided node-to-surface projection
✓ Automated surface correspondence
✓ Practical for most clinical data
Morfeus Plates: Model compression between plates
✓ Mimics physical experiment, forces*
✓ Feasible for simple dosimeter data
*Al-Mayah. Phys Med Biol 2008;53: 305-317


Biomechanical or B-spline ?
Dose distribution
Cross section
Coronal
Axial
Sagittal
3D accuracy
γ3%/3mm
Measured Optical CT
1Control: 96%
1Predicted Commercial DIR
60%1
Predicted Morfeus SurfProj
91%


3D deformable phantoms containing bony and cavity inserts.
Titania Juang
Presage-Def (15.7 cm)
High Z Rigid Insert (2.8 cm)
Air Cavity (4.0 cm)
Complex, Non-Uniform Deformation

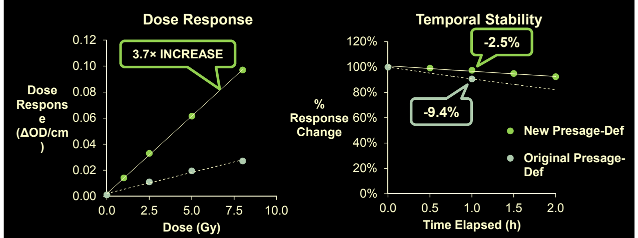

Compatible with optical-CT 3D dosimetry – 1mm³ voxels
8.6 cm
7.4 cm


Compatible with 3D Printing
Steve Bache
3D print anatomically accurate dosimeters
ProtoGen (plastic)
– 0.23mm x 0.23mm x 0.1 mm
Optical-CT projection
Un-irradiated dosimeter

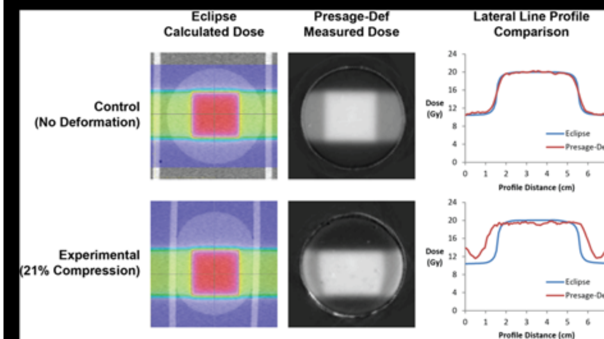

3D Printed Presage dosimeter
2.5 mm cone, 0.5mm³
Optical-CT unirradiated
X-ray-CBCT showing spinal

Recent developments

- New Presage-Def formulation
  - Improved dose sensitivity and response stability
  - Higher durometer (30-50A versus 10-20A)

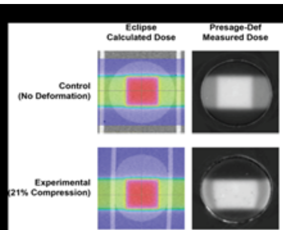


Presage-Def 4-field box dosimetry



Can we measure dose in a deformed dosimeter ?

- Integral dose within 75% isodose line consistent with planned dose in both DIR and control



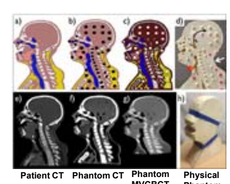
	Control Integral Dose (Gy·cm³)	Deformation Integral Dose (Gy·cm³)
Eclipse	558.5	549.4
Presage-Def	537.0	527.5
% Difference	**3.9%**	**4.0%**

UCSF University of California San Francisco

3D H&N Deformable Phantom
For DIR Performance Evaluation

The phantom splits along the sagittal plane to reveal optical markers that are used to measure the ground truth deformation between the undeformed and deformed phantom.

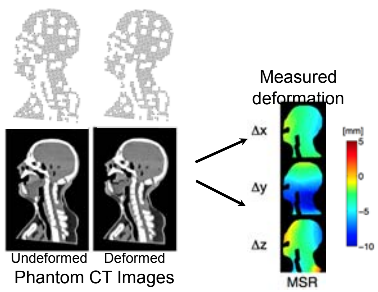
This enables the ground-truth deformed dose to be known, which is the basis for checking the accuracy of any DIR algorithm.



Singhrao K., Kirby N. and Pouliot J., *A three-dimensional head-and-neck phantom for validation of multi-modality deformable image registration for adaptive radiotherapy*, Med. Phys. 2014. (submitted).

Jean Pouliot, University of California San Francisco

The Ground Truth



Use your **favorite DIR** on the two phantom images and compare predicted deformation with measured deformation (ground truth)

Conclusions

- Promise
  - Efficiency – contouring
    - ATLAS's
    - Contour propagation
  - Efficacy - accuracy
    - Improve adaptive therapy
    - Dose accumulation
- Pitfalls ?
  - Contour accuracy
    - Physician approval essential
  - Dose accumulation
    - Extreme caution
    - Validate/commission your algorithm TG132
  - Know your algorithm ?!