Dose Mapping and Accumulation for HDR GYN Applications

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SAM: Practical Medical Physics

Deformable Image Registration for Dose Mapping and Dose Accumulation: Techniques and Challenges

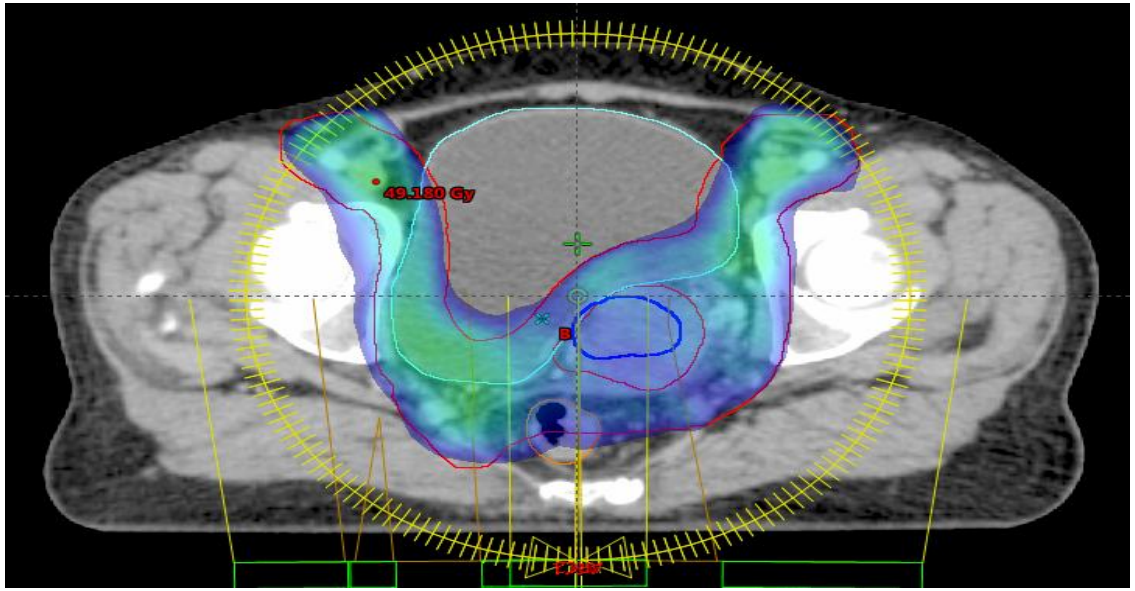
Overview

- Problem
  - Current practice
  - Limitations
- Solution: Deformable Image Registration Algorithms?
  - Challenges
- Dose accumulation
  - Literature review
  - Lessons learnt
- Clinical practice – Examples from our hospital.
- Take Home

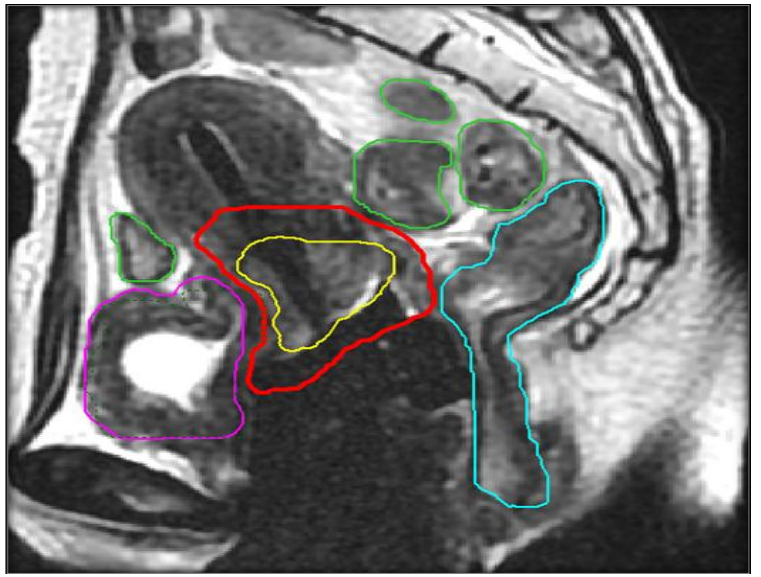
Management of Carcinoma of Uterine Cervix

- CTV_{HR} dose of ≥ $85Gy_{\alpha/\beta = 10}$ (D_{90}) EQD2

45 Gy EBRT



40 Gy BT



= **85 Gy**

- EBRT (3DCRT/IMRT/ VMAT) + BT (2D radiographs/CT/MR)

Cibula D et al, Radiother Oncol 2018

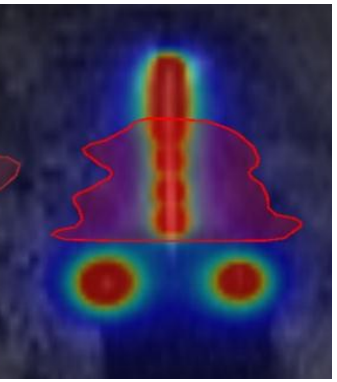
Dose Accumulation of BT + EBRT

- Fraction size

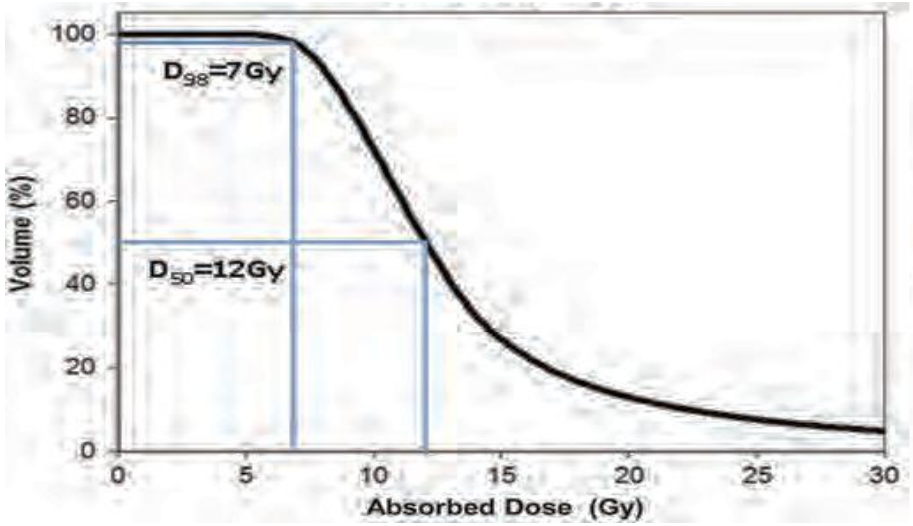
7Gy / fraction - weekly

2Gy/ fraction - daily

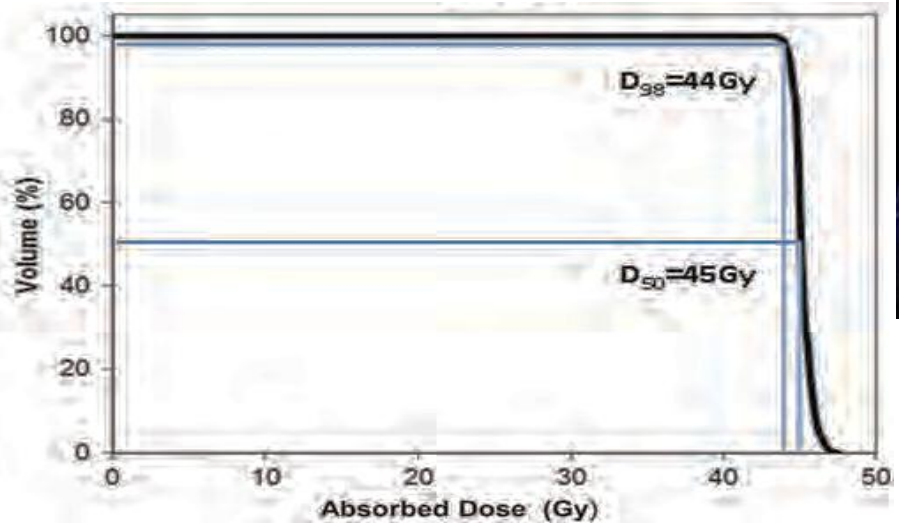
- Dose Gradient

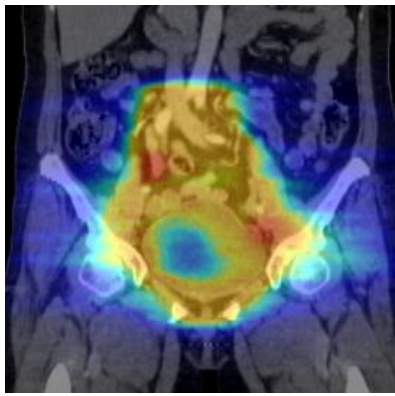


Brachytherapy DVH



External beam DVH





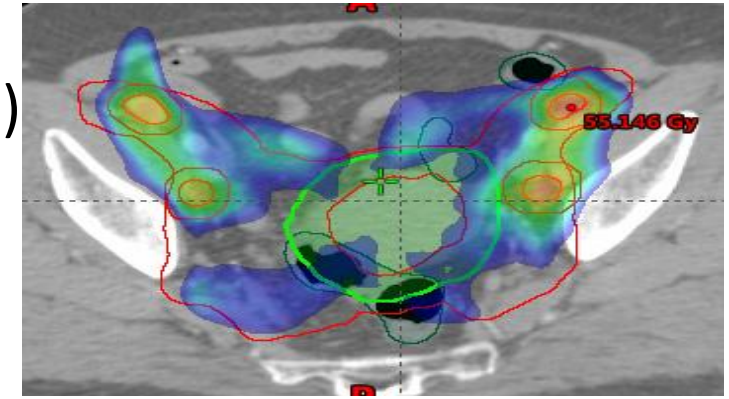
ICRU 89

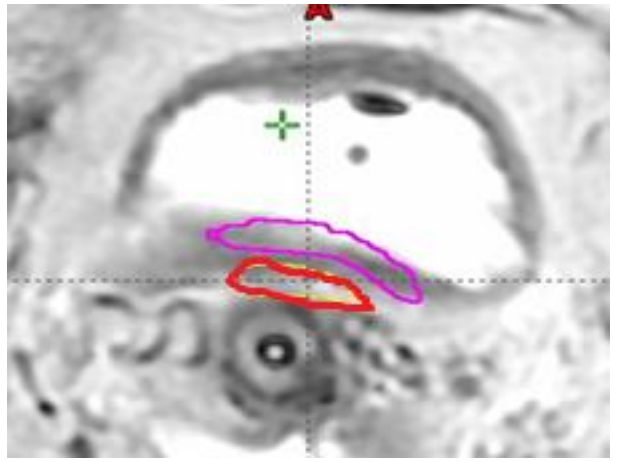
Current Practice and Limitations

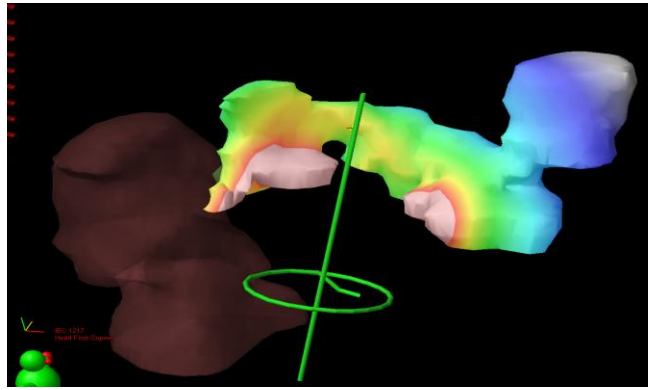
- Simple addition of biologically equivalent doses
  - LQ model (a/b = 10 for target, 3 for OARs)

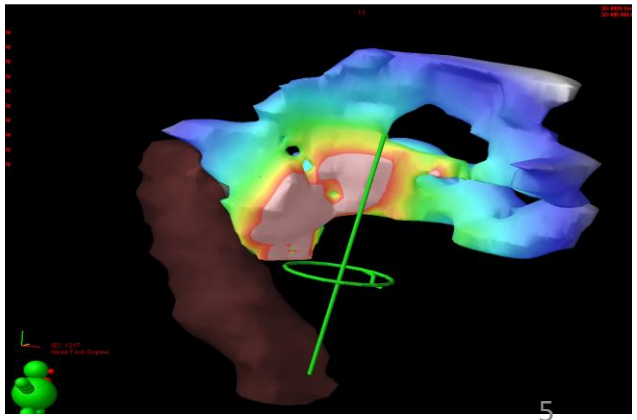
Limitations:

- **BT**: Does not take into account the spatial location of the hot spot (Worst case scenario).
- **EBRT** – Assumption (Homogeneous dose)
  - IMRT / VMAT
  - SIB (Nodes close to BT region)
  - MLB
  - Parametrial boost.







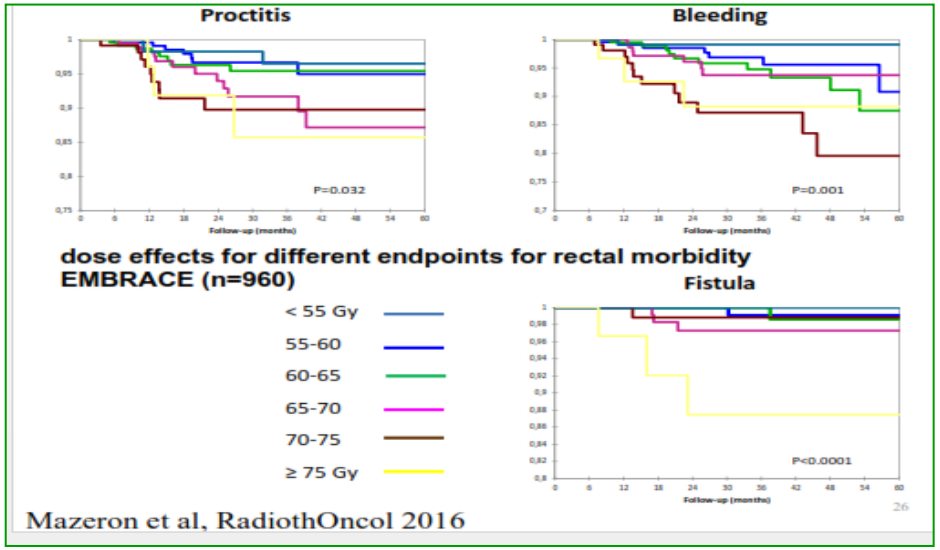


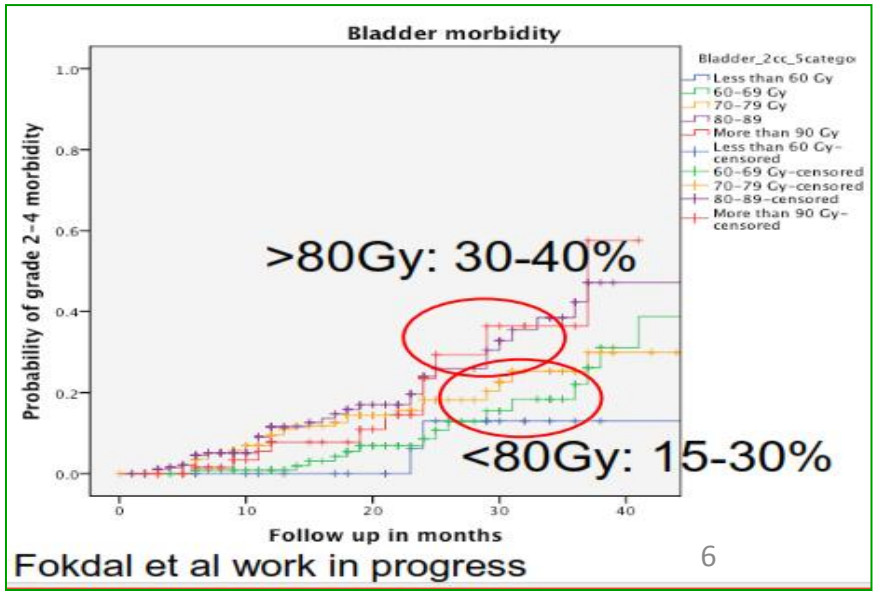
Uncertainty in dose estimation?

Picture courtesy: K Tanderup, Denmark

Dose effect relationship

- Linking of dose to OARs toxicities
  - Rectum: EQD2 D_{2cm3} to ≤ 65 $Gy_{\alpha/\beta = 3}$
  - Bladder: EQD2 $D_{2\ cm}{}^{3}$ to ≤ 80 $Gy_{\alpha/\beta = 3}$
  - Sigmoid: No dose effect established so far!
  - Bowel: 45-50 Gy, Dose effect likely to become established for diarrhoea.





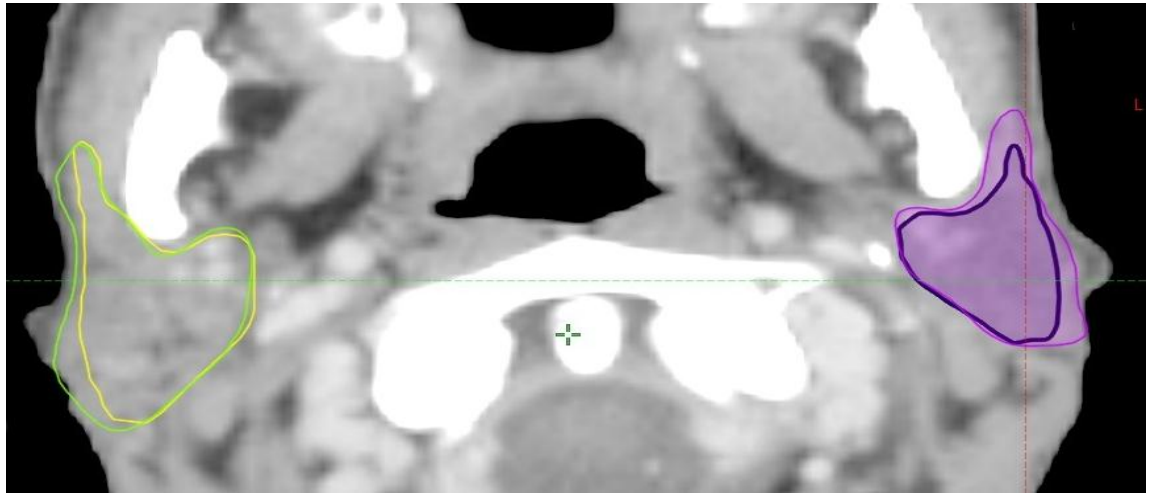
Picture courtesy: Prof R Poetter. MUW, Vienna

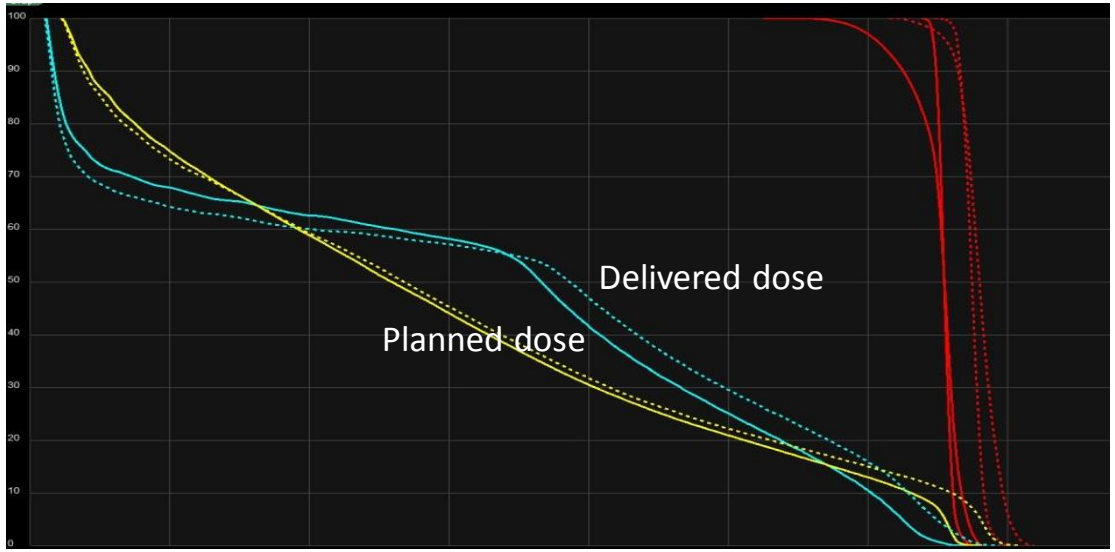
Problem

To reduce the uncertainty of dose accumulation in EBRT and BT, especially for OARs, so that, an accurate dose response relationship could be established.

Do we have a solution?

- Deformable Image Registration
  - Gaining momentum in EBRT
    - Contour mapping,
    - Adaptive Radiotherapy…
  - Dose accumulation - EBRT
    - Planned Vs Delivered dose
    - Dose of the Day
    - Prostate &HN
  - Gyn cancers : EBRT + BT ?

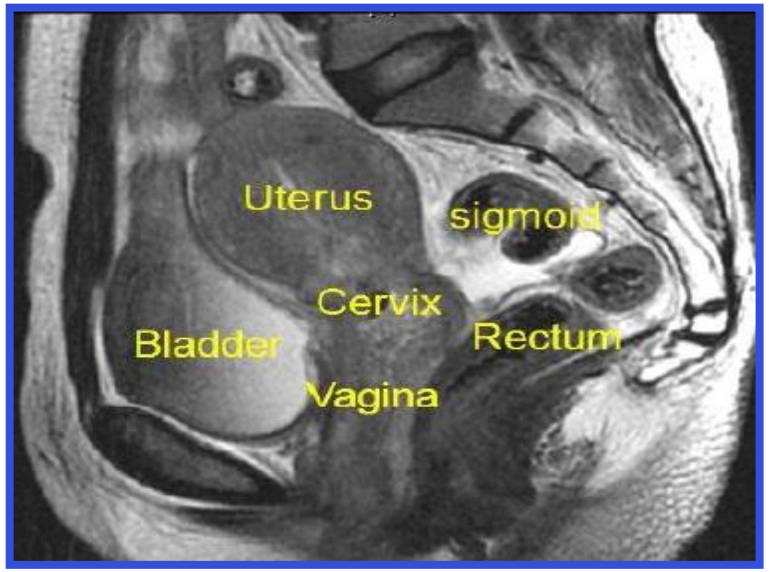




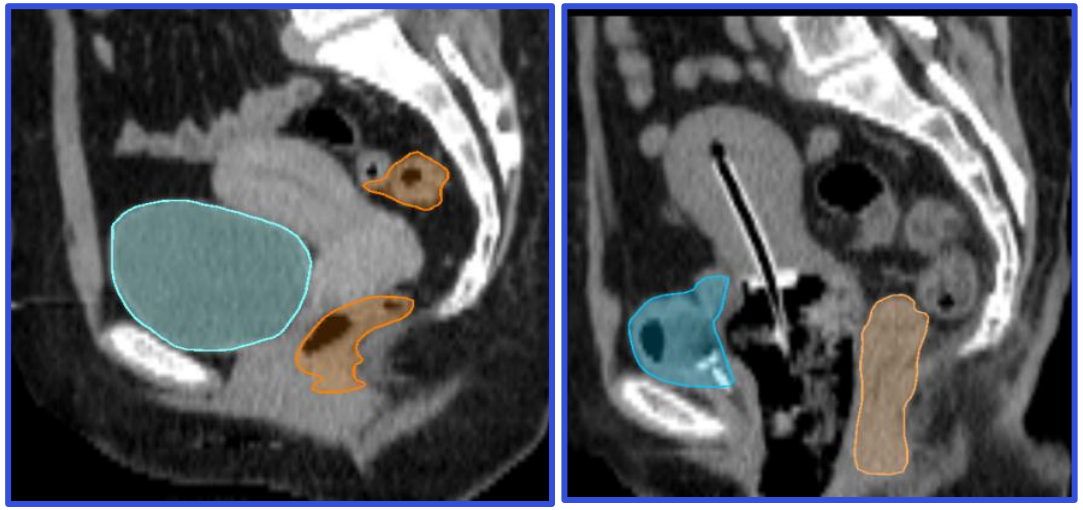
Bondar L et al. Med Phys.2010, S Ghose et al. Artificial Intelligence in Medicine 2015. Rigaud B et al. Med Phys.2018

DIR - More of a Problem than a solution!

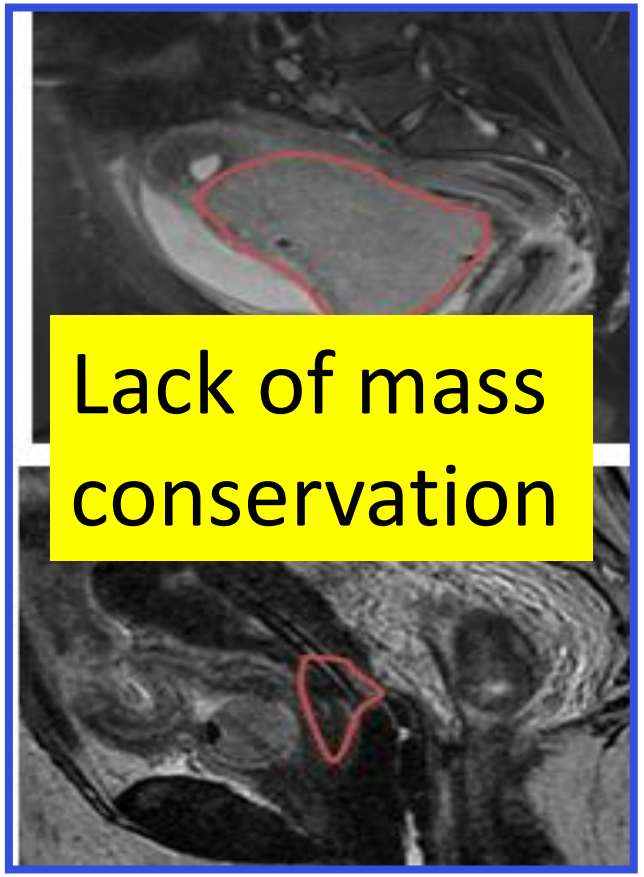
Large deformations-Sliding, content, shape



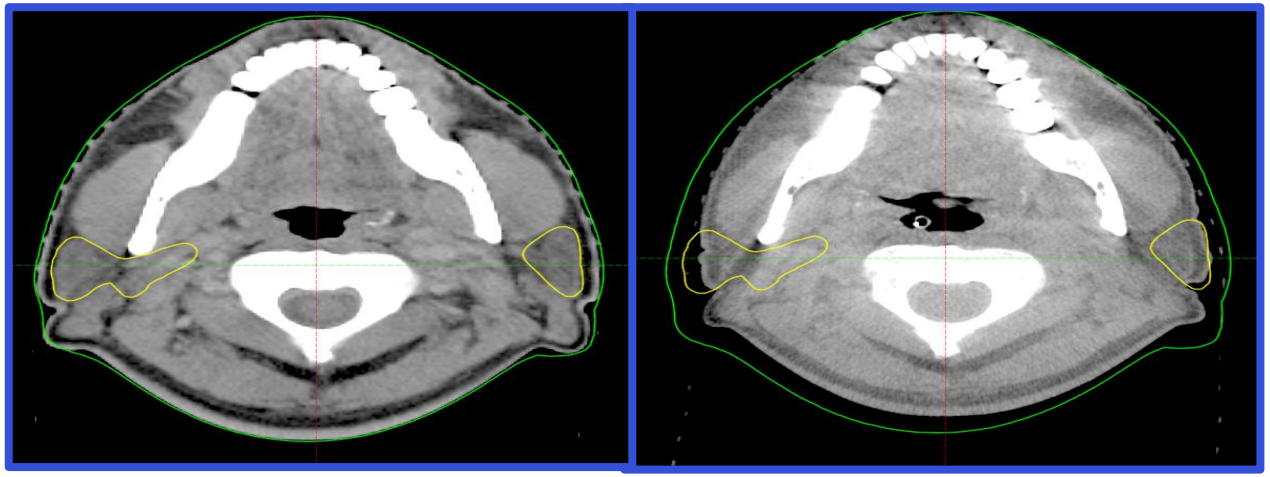
Applicator, Vaginal pack



Tumour Regression



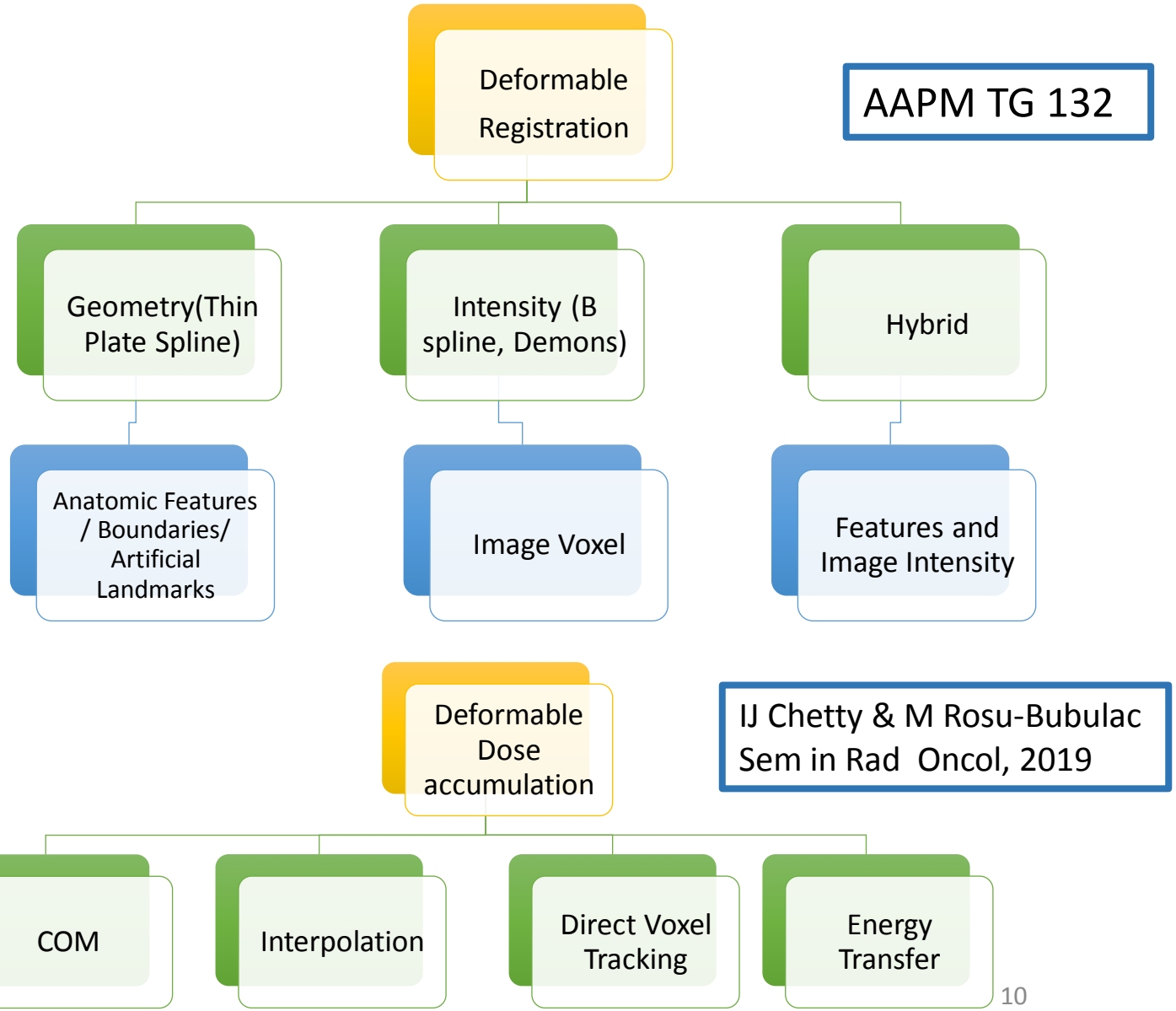
Algorithms aim for simple deformations, contour propagation



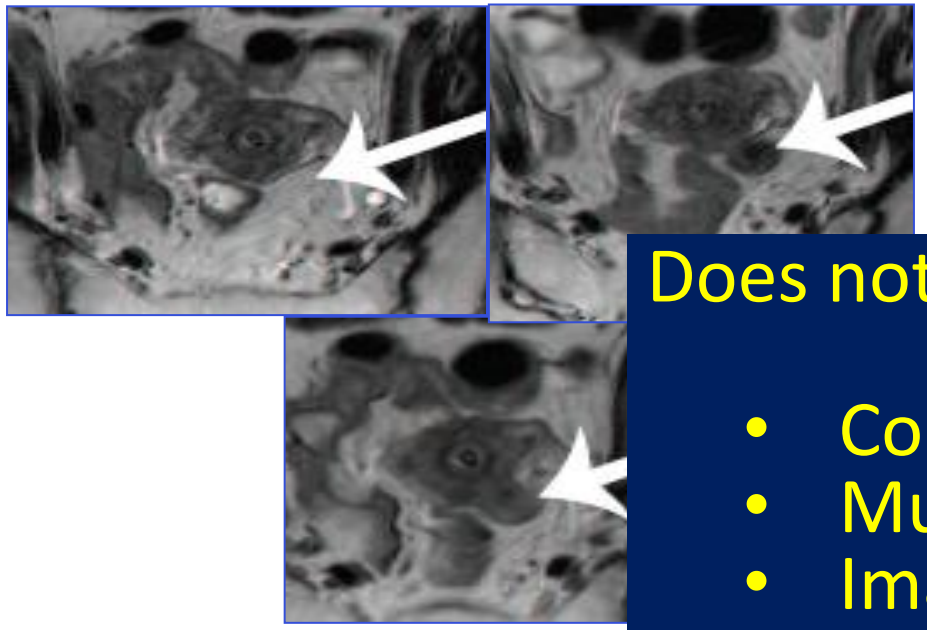
Picture courtesy: ICRU 89

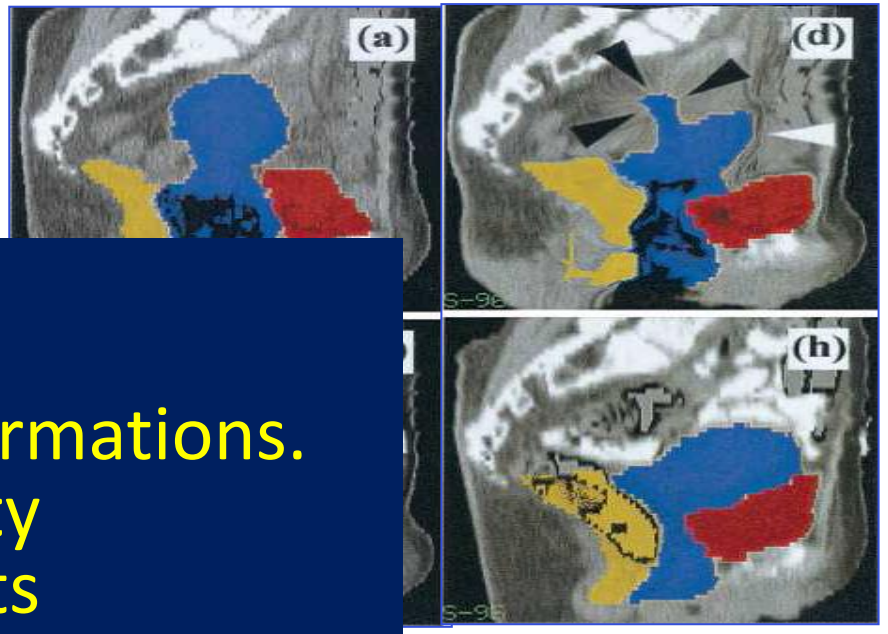
DIR products - Which algorithm ?

- **Velocity Medical Solutions**
  - Multi-modality demons
  - Multi-resolution modified b-spline
  - Structure guided
- **MIM Software Inc.**
  - Intensity-based free-form.
  - Hybrid
- **Ray Search**
  - Morfeus
  - Anaconda
- **Mirada**
  - Optical Flow
- ***DIR ART (MATLAB, need CERR)***
- ***3D slicer***
- ***DIR open source ITK***
  - *Implemented in C++*



Issues with Intensity based Algorithms





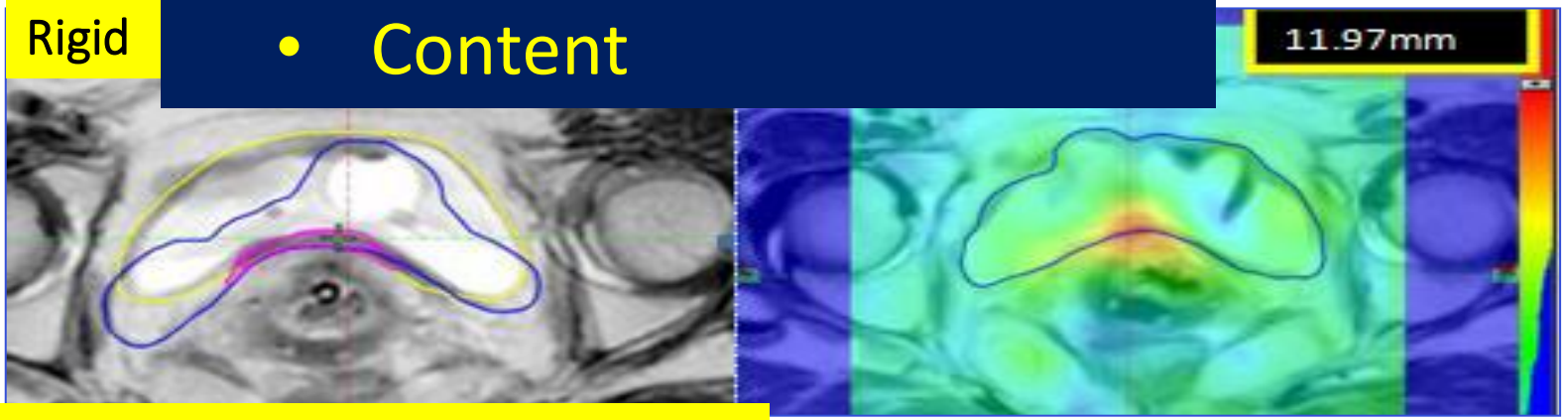
KO Noe, PhD Dissertation, Aarhus University, [illegible]

IJROBP 2001

Does not work well

- Complex deformations.
- Multi-Modality
- Image Artifacts
- Low Contrast
- Content

Rigid



Applicator cap is mistaken as bladder wall

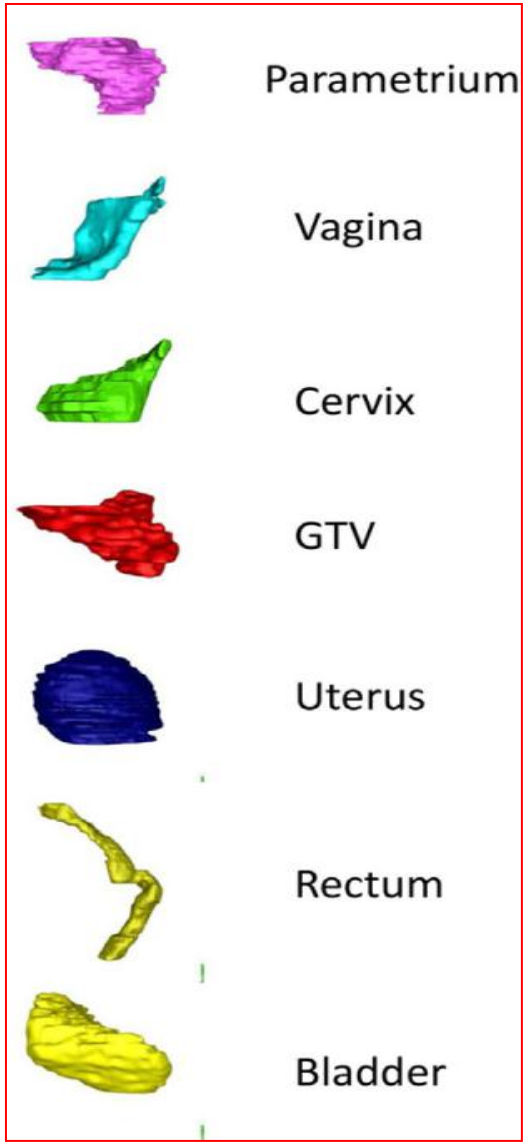
J Swamidas et al, Radiother Oncol 2015

(Thirion 1998,, Wang 2005, Kim H et al, JCB, 2014)

Issues with feature based algorithms

Lacks in modeling discontinuities at the interface of sliding organs (bladder, cervix-uterus, rectum-sigmoid…)

Use of a single set of regularization parameters to register all structures simultaneously.

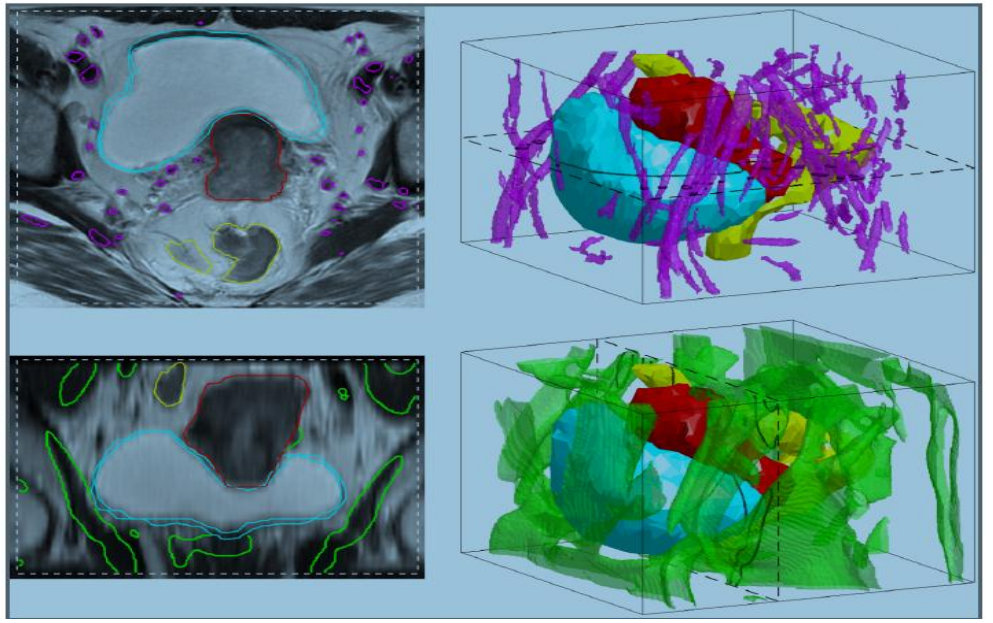


Flexibility can be prioritized between organs, not sufficient to model the very complexity of the deformations.

Bondar L et al. Med Phys.2010, Osario et al, Med Phys 2015

Structure wise registration with vector field integration (SW+VF)

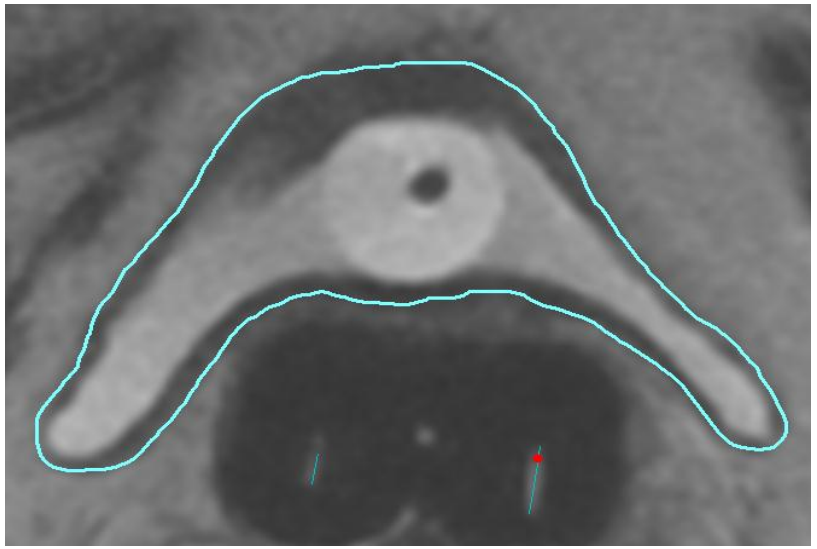
- Designed for Cervix-Uterus, Bladder and Rectum-Sigmoid.
- Uses independent registration of each structure, allowing to **naturally model <u>sliding</u> deformations.**
- Two types of features were segmented: tube-like features such as vessels and ligaments, and sheet-like features such as muscles.
- Achieved the best results - 3.5 mm for the anatomical correctness.

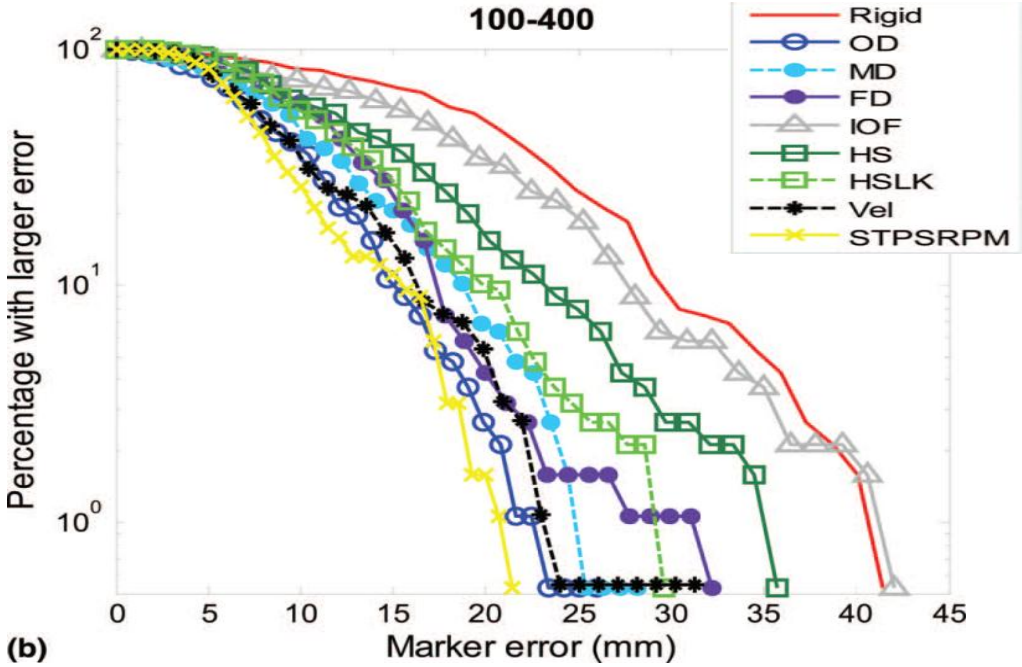


Osorio et al, Med Phys 2015

- Dosimetric validation
- Clinical Applicability

Which DIR algorithm for bladder?





Residual Distance Error

- Synthetic Bladder
  - 0.7 mm
- Porcine Bladder and patients
  - 3.7 mm

- The efficiency and accuracy of TPS-RPM-LTP indicate that it is a practical and promising tool for bladder dose summation.

- Present evaluation do NOT demonstrate that the current algorithm is sufficiently accurate for dose accumulation!

Wognum et al 2014 , Chen H et al PMB 2016

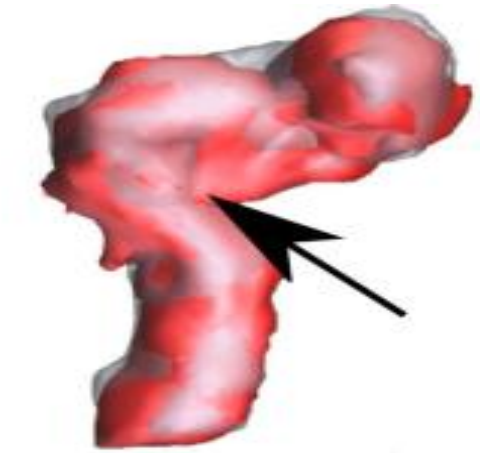
DIR for Rectum and Sigmoid

- **Rectum mask** (Tetrahedra) – include **shape** information - Bent tube or cylinder with variable content.

- **Physiological Characteristics** (Stretching of the muscles which elongates with the rectal filling).

- **Focus on the wall** – not the content.

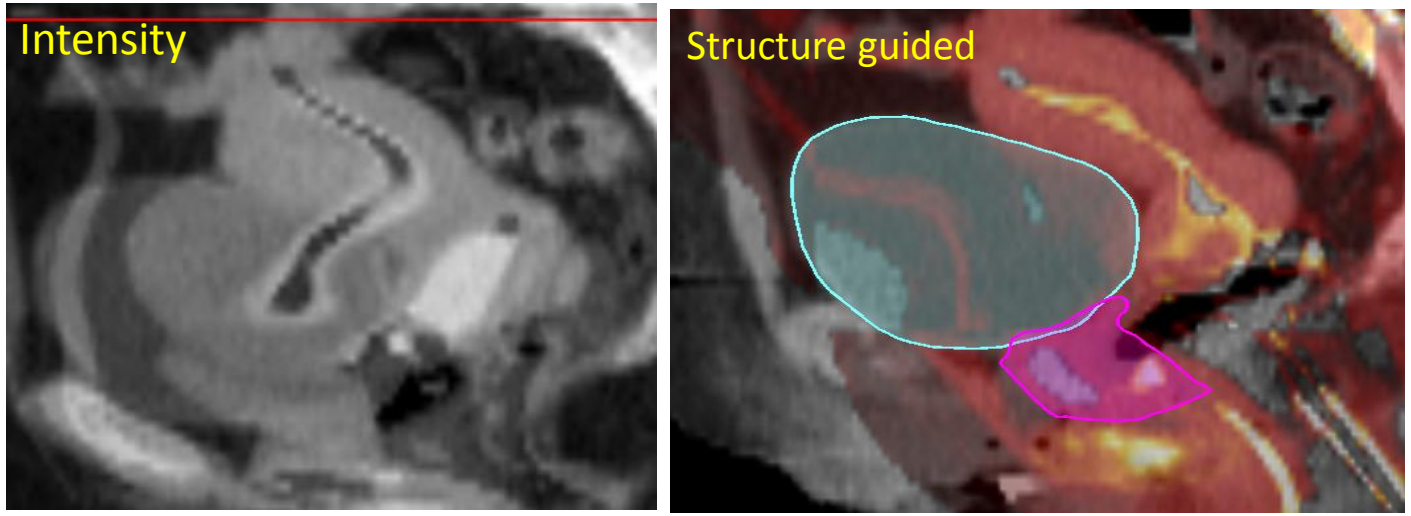
- **Most Algorithms were tested for BT not EBRT + BT.**



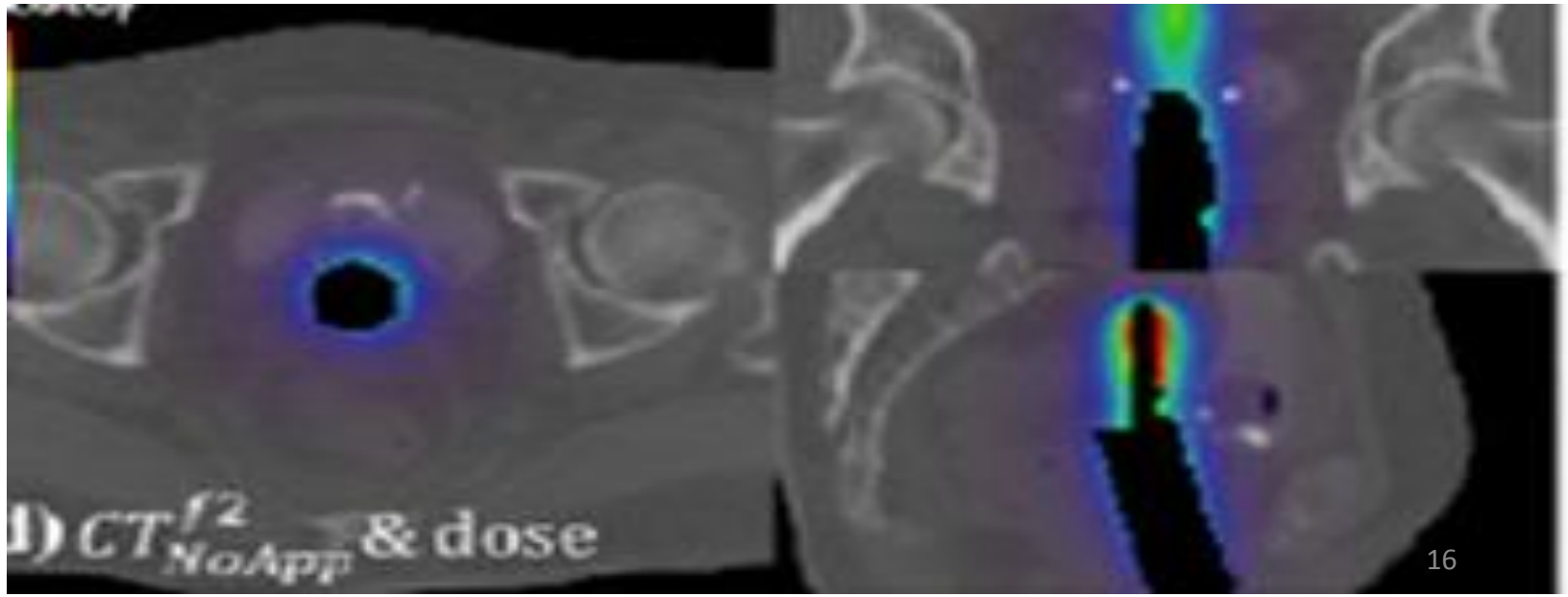
- Tubular
- Twist
- Non linear elastic FEM.
- Self Surface interaction.

Vila RB, et al. Med Phys 2012, KO Noe, Van Heerden et al

DIR in the presence of applicator and vaginal pack



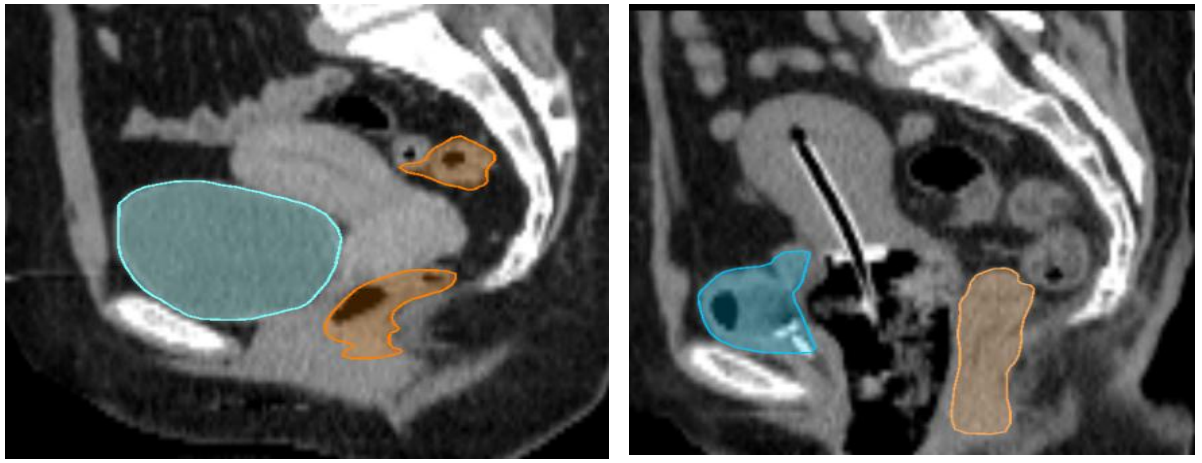
- In multi fractionated BT – may be Yes!!
- In EBRT +BT – How do we get point-point correspondence?



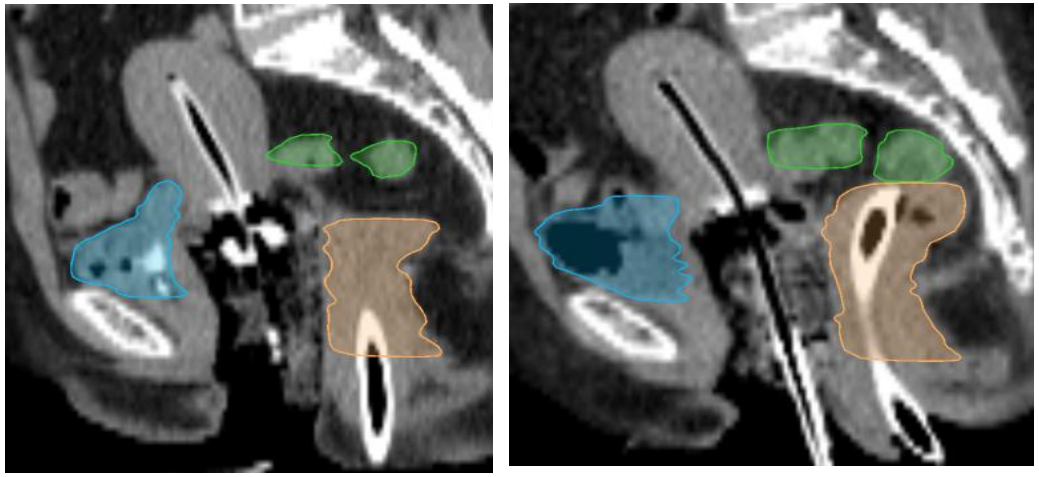
Teo et al,Radiother Oncol 2015
Zhen et al, PMB 2015

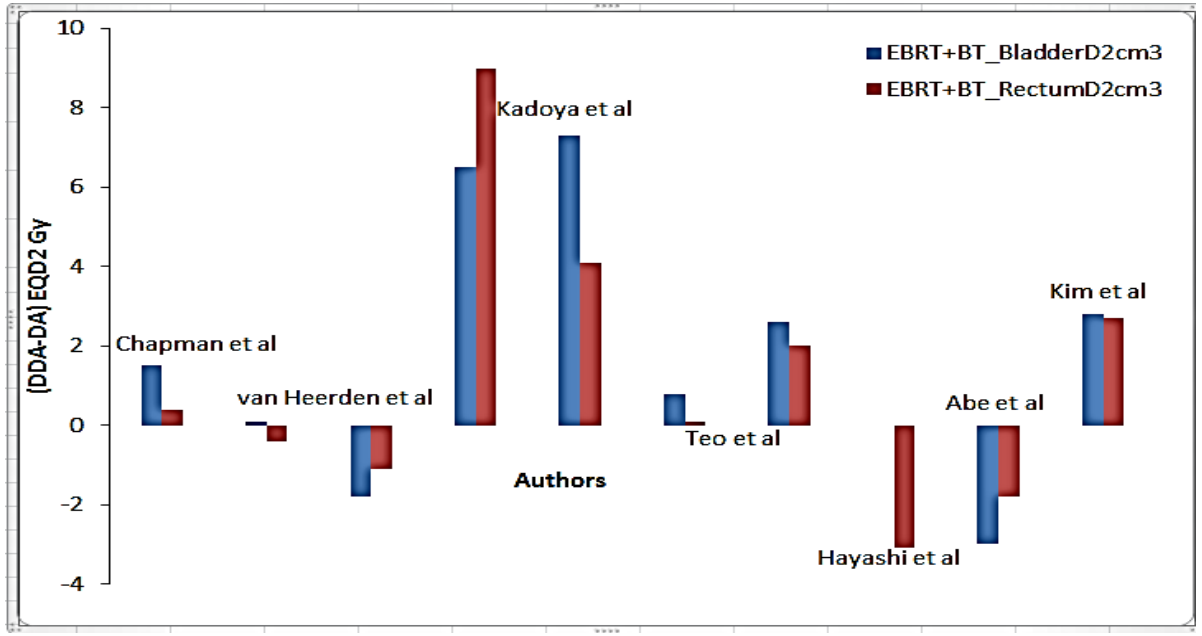
Deformable Dose Accumulation – Literature review

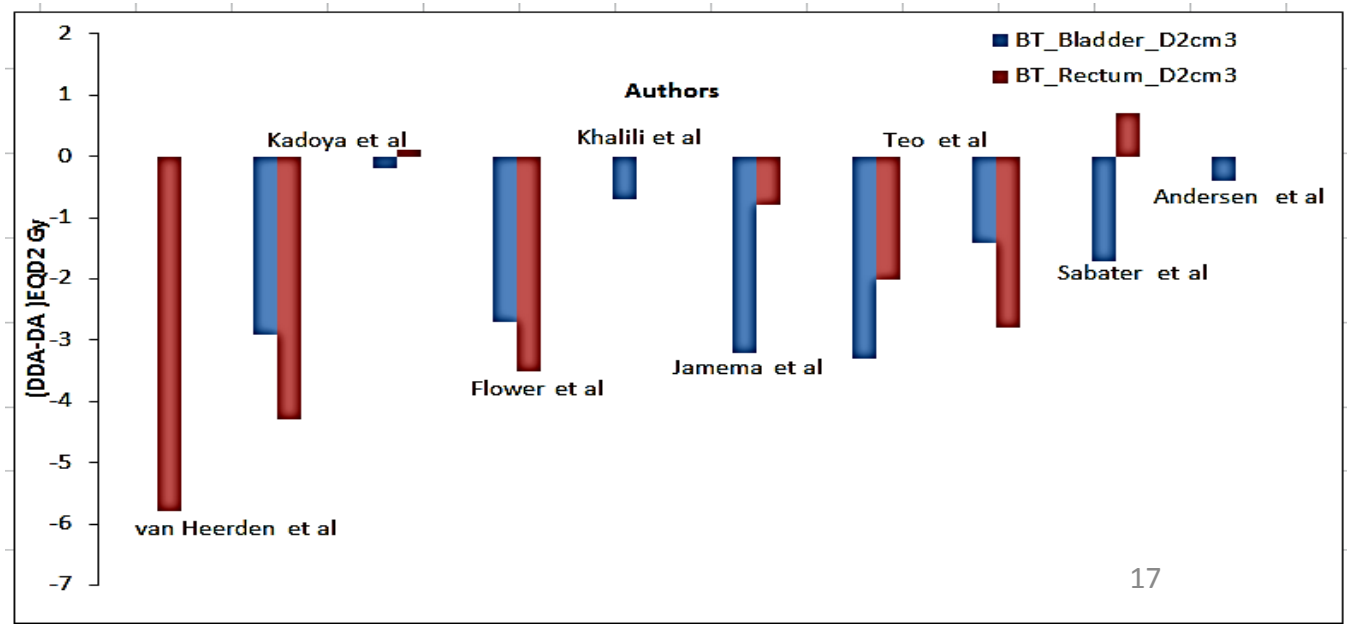
EBRT + BT



BT1 +BT2

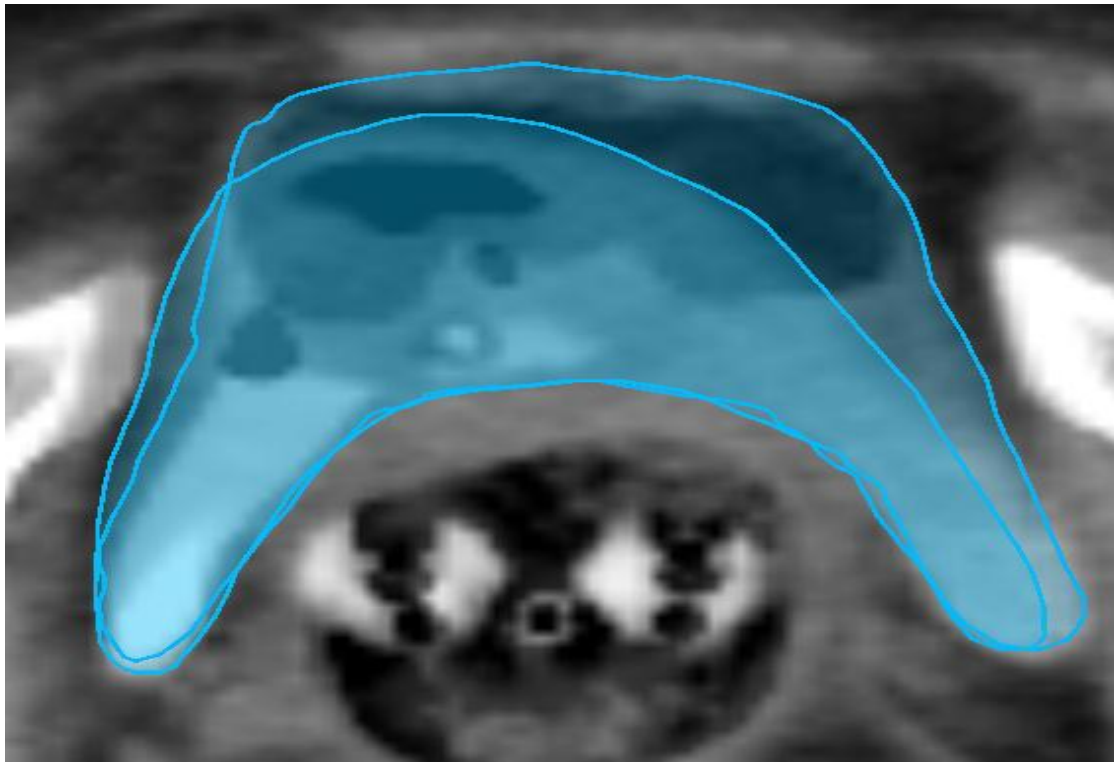




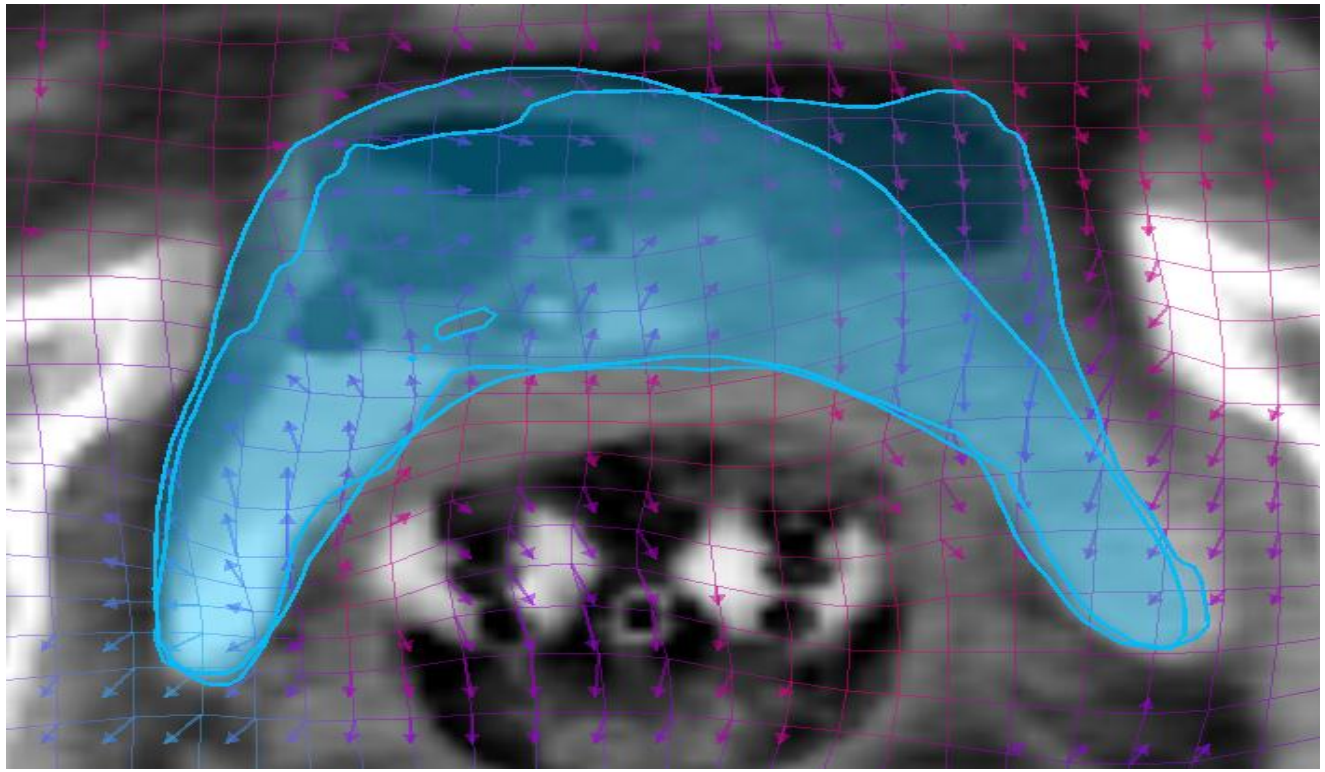


Brachytherapy - Bladder wall

Rigid



Deformable(b spline)



In Brachytherapy, the accuracy required at the walls is high, as the dose distribution is governed by inverse square law that leads to high dose gradient.

Validation

- **Hollow organs – Rectum, Bladder**
- **Non Hollow organs - Target**
- **Dice Similarity Coefficient**
  - Not suitable for Hollow organs
  - Focusses on the content not the wall.
  - In rectum and bladder, walls are clinically relevent.
  - Not suitable for BT- Dose gradient is high.
- **Surface Distance Error**
  - Suitable for Hollow organs, not for target.
  - Provides information about the distance between the structure surfaces.
  - Does not measure voxel-to-voxel agreements.

(VanHeerden et al 2017,Paganelli and Meschini et al Med Phys 2018)

Clinical Practice - Role of Registration

& tips to minimize the uncertainty of dose summation of EBRT and BT

EBRT

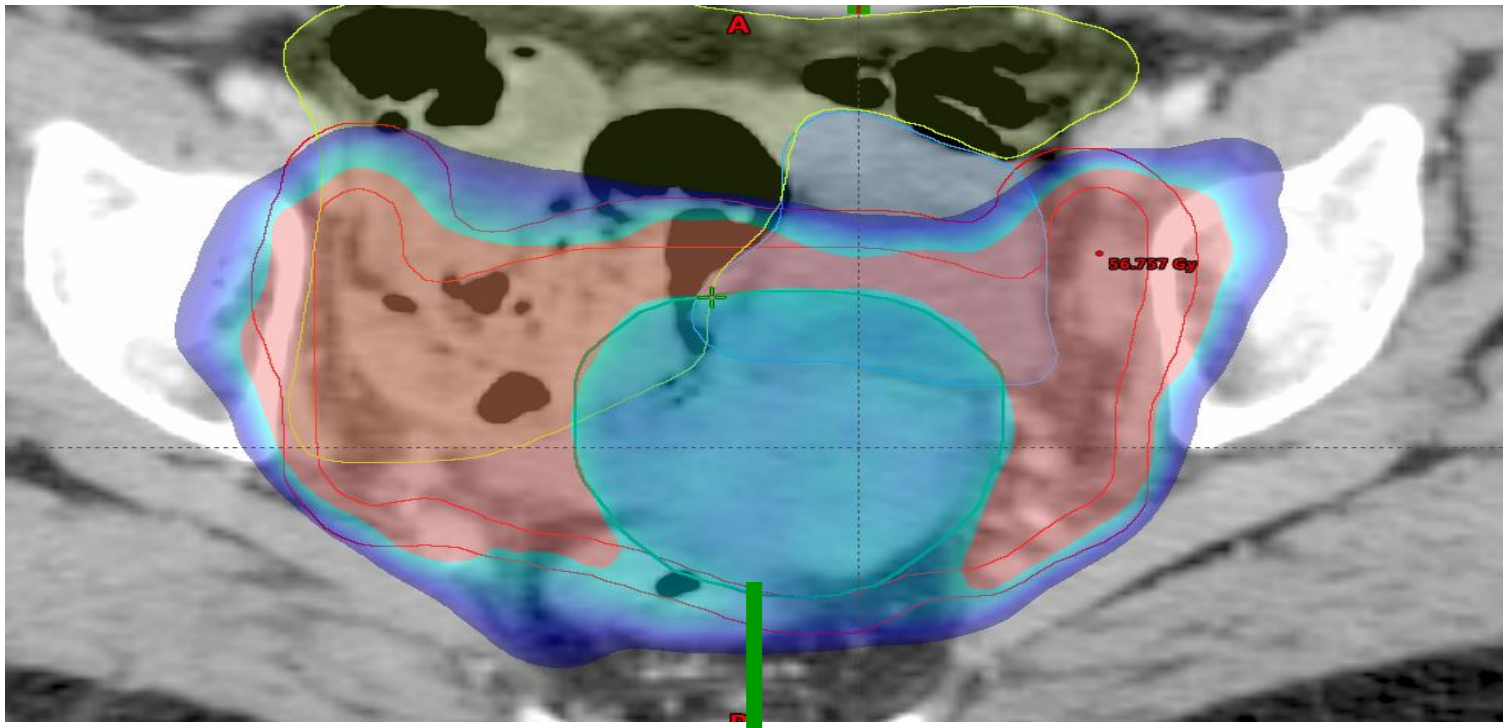
- GTV Contour mapping
  - dMRI to pCT (**Rigid**)
  - Bladder filling & Flat couch (manual)
- Maintain Uniform Dose in BT region
- Not always possible to maintain uniform dose in BT region during EBRT
  - SIB
  - MLB
  - Parametrial boost

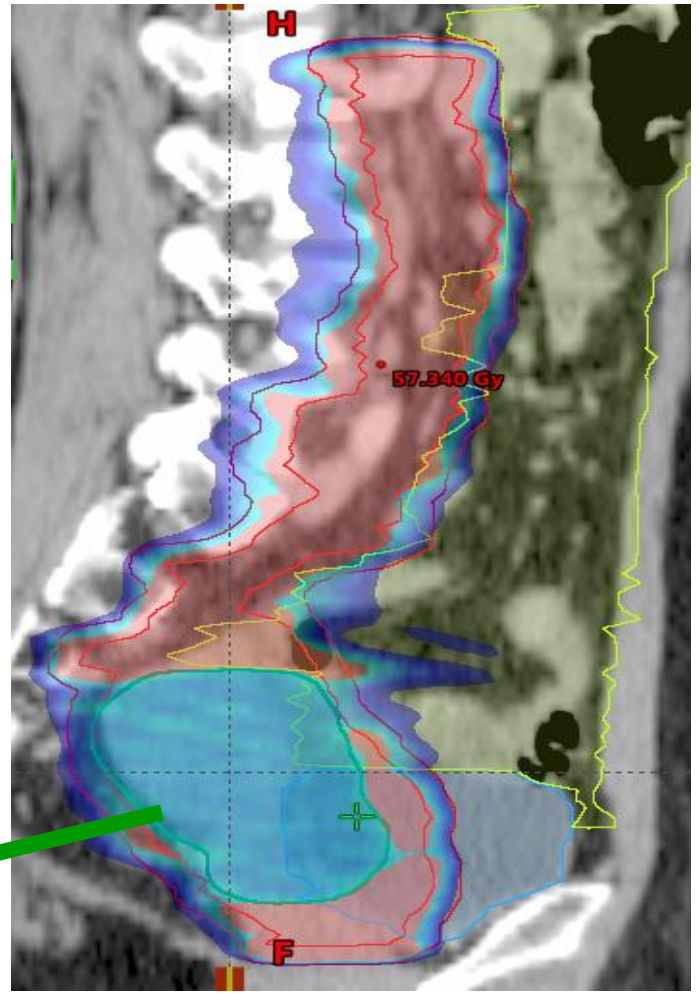
BT

Only Rigid as of now

- CTV_{HR} Contour mapping
  - BT1 MRI to BT2 CT
  - Applicator based **Rigid**
- Applicator reconstruction
  - CT to MRI
  - Applicator based **Rigid**

Uniform Dose in BT region during EBRT & to avoid hot spots





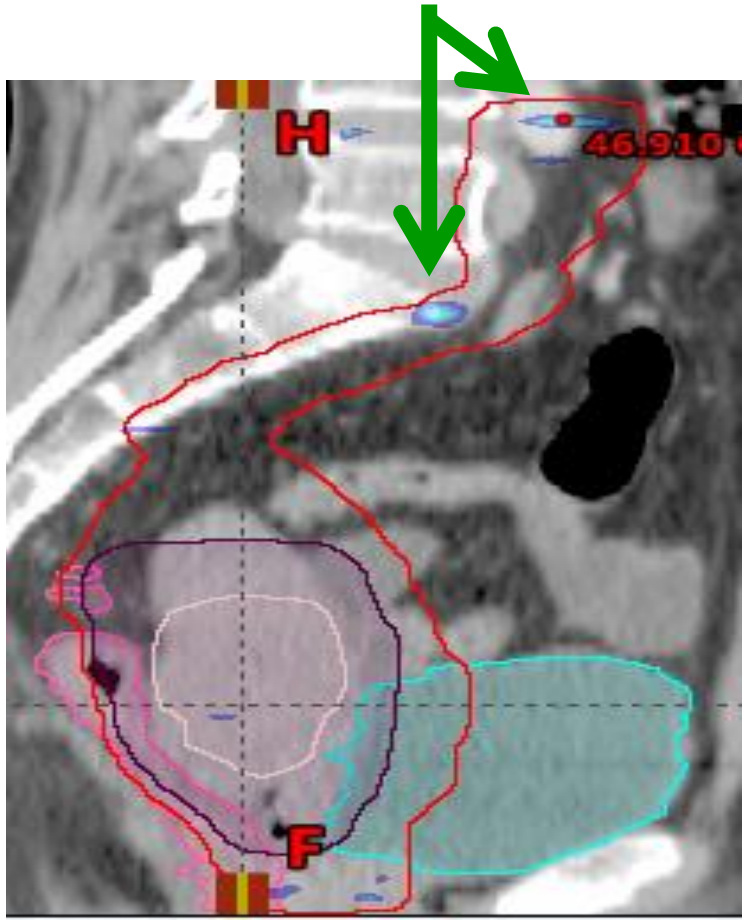
BT region Dmax < 46.35 Gy

External beam radiochemotherapy and MRI based adaptive BRAchytherapy in locally advanced CErvical cancer

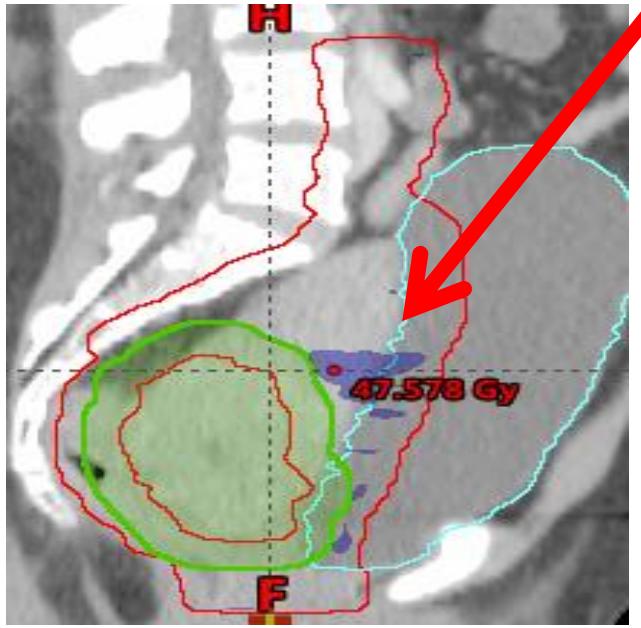
EMBRACE II protocol

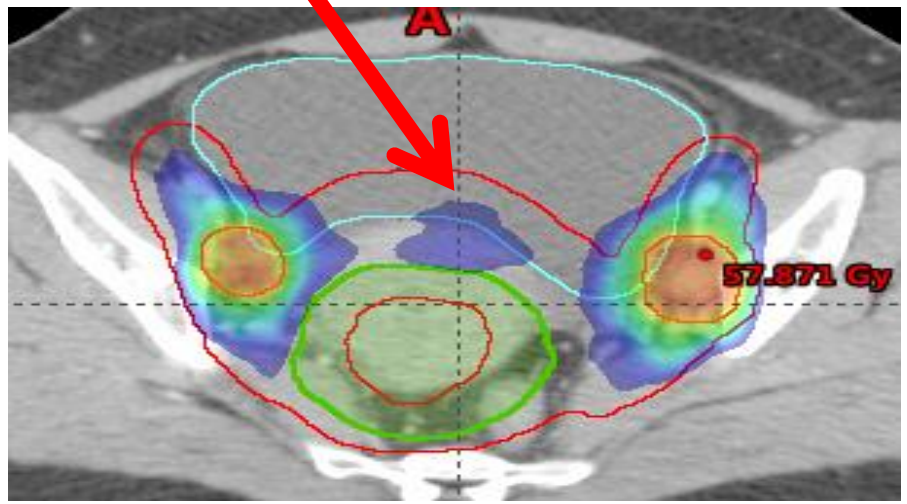
Attention: Organ walls for spatial Location of hotspots

Hot spots not in OARs

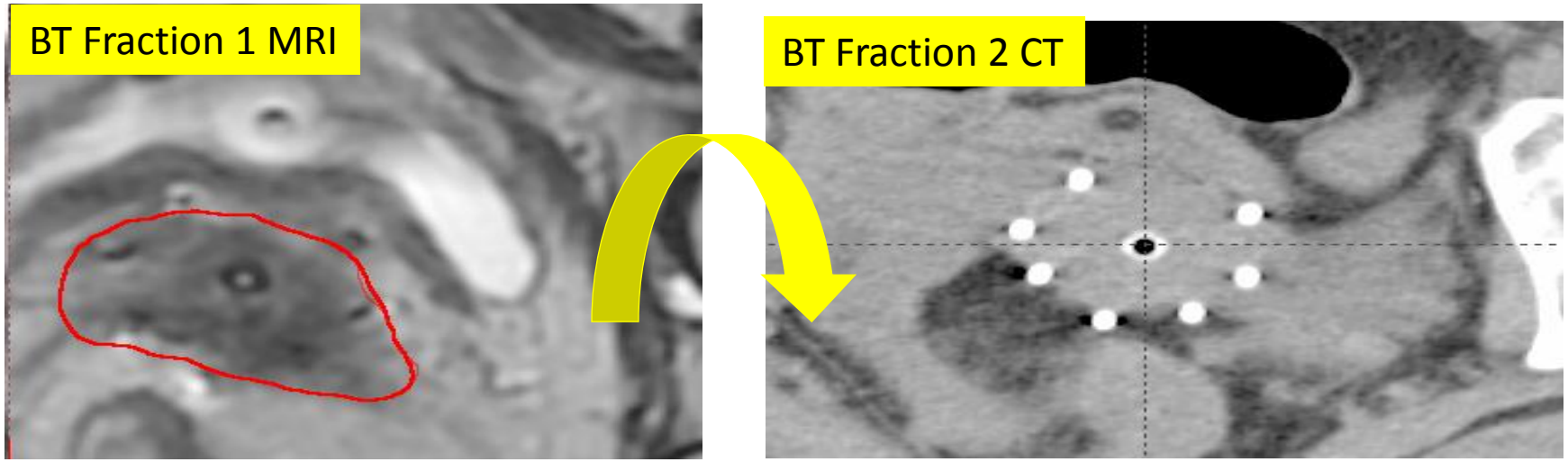


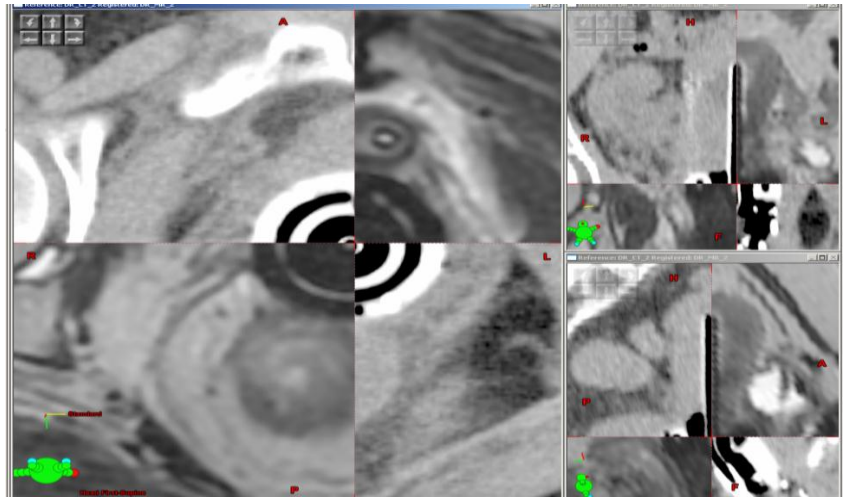
Hot spots in Bladder wall

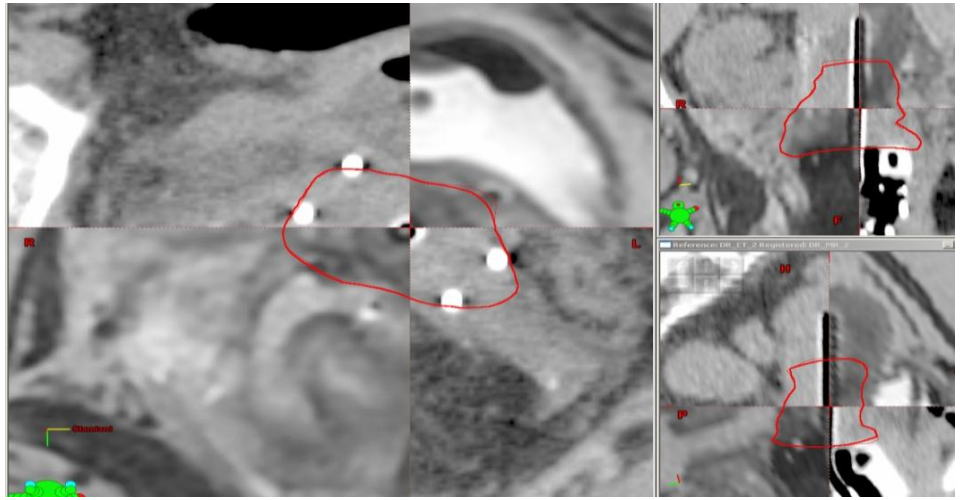




Brachytherapy CTV_{HR} Transfer - Applicator based Rigid Registration (nicole ref)

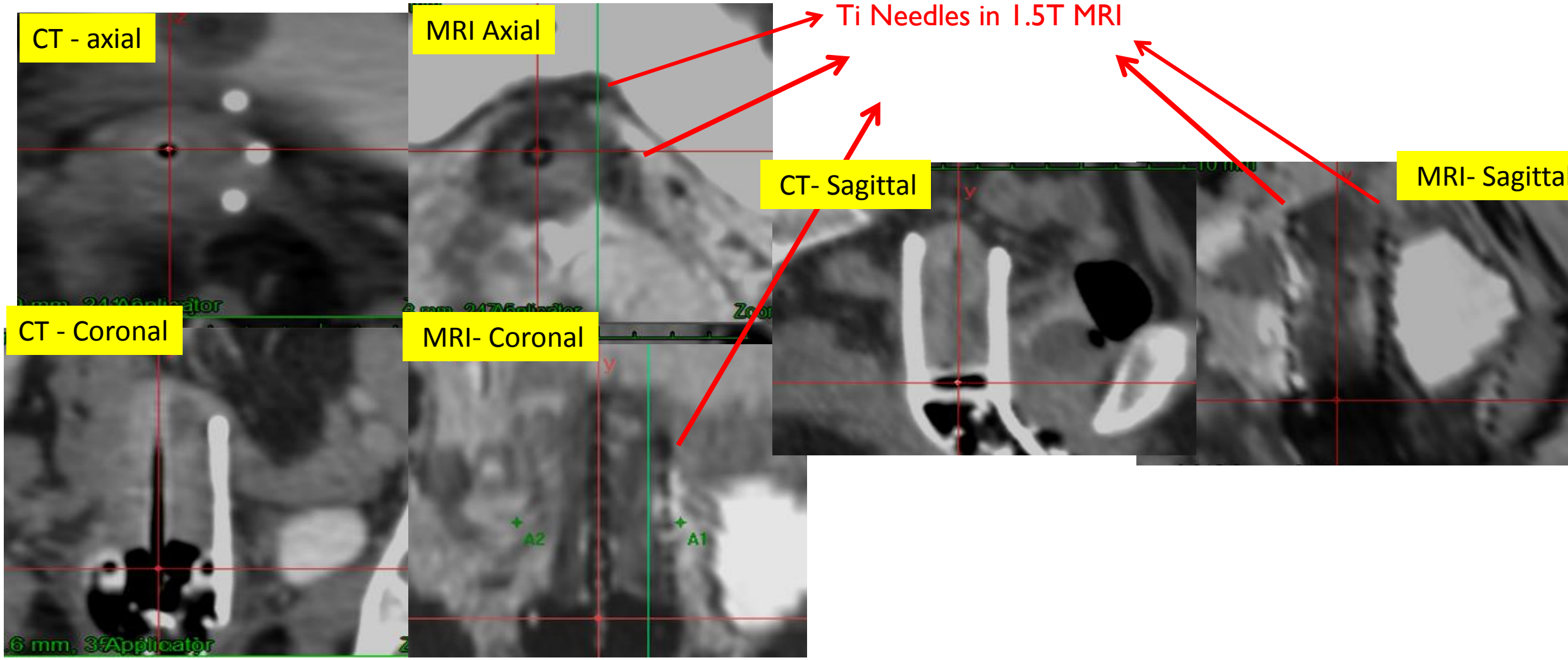






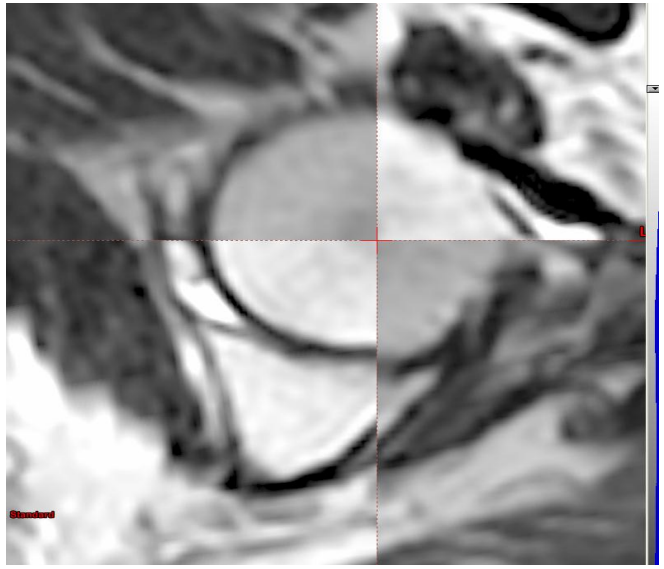
Nesvacil N, Radiother Oncol 2013

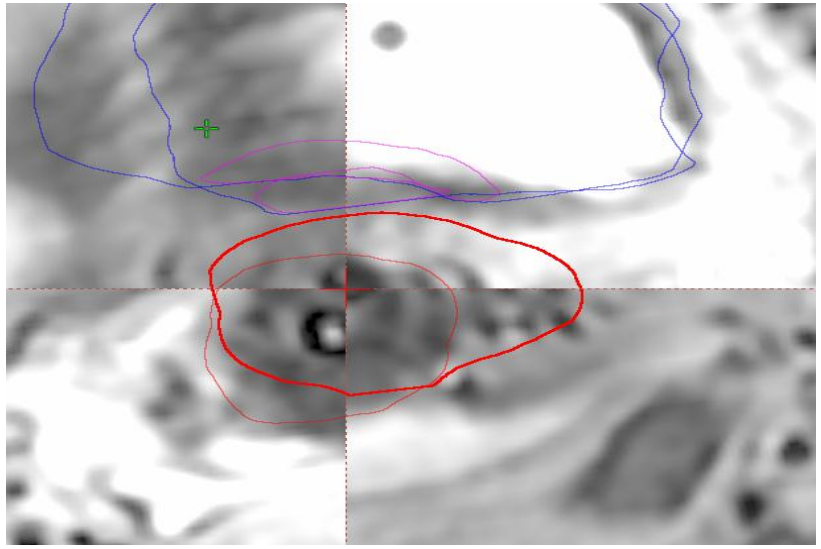
Needle Reconstruction – Rigid Registration



Applicator based Rigid registration in Brachytherapy

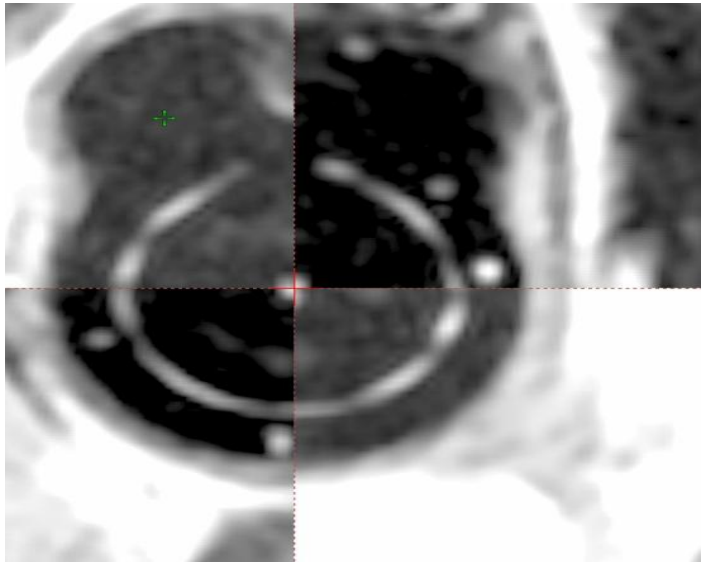
Good matching of bones

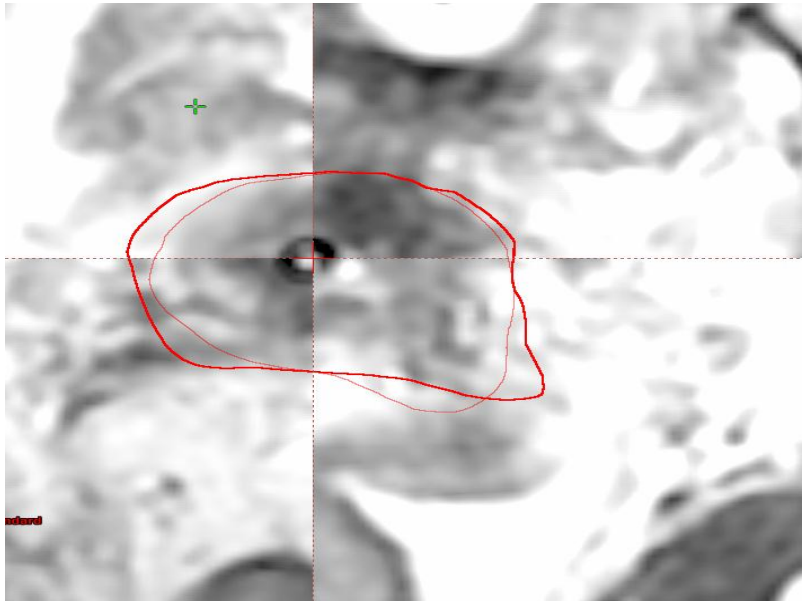




Mismatch of applicator and target

Applicator based Rigid Registration





Good alignment of target as the anatomy moves with the applicator in brachytherapy.

Conclusion

- Deformable dose accumulation of EBRT and BT is associated with wide range of uncertainties, current generation of algorithms are not yet robust enough to handle complexities.

- Direct addition of doses provides a reasonable estimate of the actual doses received by the target, bladder and rectum except in MLB, SIB, also sigmoid and bowel?

- For contour mapping and applicator reconstruction in BT, rigid registration based on applicator geometry provides good accuracy.

- "Adding EBRT and BT without deformation is a good approximation, as DIR algorithms may cause additional uncertainties" – ICRU 89, holds good.

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