Setup registration, image fusion and uncertainties

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Techniques for rigid registration in RT

- **Identity (DICOM)**
  automatic registration based on DICOM coordinate system
  - PET-CT, PET-MRI
  - **BT**: multiplanar MRI

- **Mutual information**
  automatic registration (CT, MRI-CT)
  - in EBRT: bony anatomy, external contour
  - in **BT**: head: bony anatomy, pelvis: BT applicator (≠ bony anatomy)
  - delineated structures

- **Landmark-based**
  manual definition of landmarks for registration
  - external markers, implanted markers, clips

- **Applicator-based (BT)**
  - manual: landmark definition based on applicator points
  - automatic: image volumes with reconstructed applicators (3D models) in place
DICOM Identity-based registration of multiplanar MRI: applicator reconstruction, needle depth verification

- mark needle tip in transversal MRI
- verify with fused sagittal MRI

Improved reconstruction precision for large MRI slice thickness
Available in TPS and/or DICOM viewers

Uncertainty dominated by patient movement during acquisition (long scan times, anaesthesia)
Impact of fusion uncertainties when using one image set for applicator reconstruction and another image set for delineation

- Fusion between T1 and T2 during reconstruction
- Impact on DVH parameters:
  - HR CTV: 7% (underestimation)
  - Bladder: 10% (overestimation)
  - Rectum: 13% (underestimation)

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Treatment scheme for adaptive radiotherapy at AKH

**External Beam RadioTherapy**

- **1st APPLICATION**
  - MRI based treatment planning
  - CT, X-Ray
  - EBRT 1.8Gy
  - 1st fraction
  - 2nd fraction

- **2nd APPLICATION**
  - Brachytherapy
  - 3rd fraction
  - 4th fraction

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**Brachytherapy**
Image registration for adaptive BT workflows
Inter-/intra-fraction variations

Cervix Cancer BT

Target
fixed to applicator

Rectum:
change of position or filling with gas

Bladder:
change of filling (use of bladder filling protocol)

Sigmoid:
might change its location
Impact on dose: fixed plan + variable anatomy

Plan 1
- Insertion 1 – Fraction 1
  - MRI Tuesday afternoon
  - Plan 1

Plan 2
- Insertion 2 – Fraction 3
  - MRI Tuesday afternoon

- Insertion 1 – Fraction 2
  - MRI Wednesday morning
  - ≠

- Insertion 2 – Fraction 4
  - MRI Wednesday morning
  - ≠

<------ intra-application variation ------>

Stefan Lang
Lang et al. 2013, Radiother Oncol

Up to 30% random dosimetric uncertainty for OARs if anatomical variations are ignored.

Nesvacil et al. Radiother Oncol 2013
Applicator-based registration: evaluation of inter-/intra-fraction variations

Fast registration of MRI F1 and F2 via applicator coordinate system to
– check implant stability (relative position of applicators/needles and target)
– check organ variation
– decide to
  » treat
  » adapt organ filling
  » recontour and re-evaluate DVH
  » (rarely replan before treatment of F2)
Applicator-based registration (tandem-ring)
manual: landmark definition based on applicator points
automatic: image volumes with reconstructed applicators (3D models) in place

Applicator depiction on MRI insufficient for automatic mutual information MRI-MRI or MRI-CT registration
   -> use applicator reconstruction for definition of reference coordinate system

Example of manual method: Align coordinate system according to applicator model and digitize 3 well defined points

3 points for registration (DICOM coordinates)
Example: day 1 – day 2 comparison

- Routine quick-check of inter- and even intra-fraction variations (almost online verification possible, requires *automatic* registration solution)

- Only DVH re-calculation, no voxel-based dose summation for organs (worst case assumption (ICRU89))

- Uncertainty dominated by applicator visibility and reconstruction uncertainty
Adaptive IGBT with limited access to MRI
MRI for 1st fraction + CT for succeeding BT fractions

- "gold standard": MRI-only based treatment planning for all cervix cancer BT fractions (routinely performed at AKH Wien)
- for centers with limited infrastructure: access to MRI limited but CT based BT planning may be possible
  + CT: good applicator visibility
  - CT: lower soft tissue contrast – target delineation!

- Solution?
  - MRI based planning for 1st BT fraction
  - CT based planning of following BT fractions, reusing MRI target contour
Combined MRI-/CT- guided BT for cervical cancer

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1\textsuperscript{st} application: MRI

Applicator, target (HR CTV), OAR (rectum, bladder, sigmoid)
Dose planning and optimization on target+organ contours
2\textsuperscript{nd} application: CT

3D applicator reconstruction
2\textsuperscript{nd} application: CT

3D applicator reconstruction
Target transfer

Targets from first application MRI
2\textsuperscript{nd} application: CT

Rigid image registration based on 3D applicator model
2\textsuperscript{nd} application: CT

\textbf{Automatic target transfer} from MRI to CT with applicator as reference system
2\textsuperscript{nd} application: CT

Contouring OAR on CT
2\textsuperscript{nd} application: CT

Contouring OAR on CT

Target contour from 1\textsuperscript{st} application MRI

OAR contours from 2\textsuperscript{nd} application CT
2nd application: CT

Dose planning and optimization based on copied target and individual OAR contours. All dose constraints for targets and OAR have to be achieved.
MRI-based vs. combined MR-/CT- planning

- Verification of the workflow by a retrospective study (Nesvacil et al. 2013, Radiother Oncol 107:75-81)

- 20 patients treated at AKH with fully MRI based BT were replanned using MRI for the 1st and CT for the 2nd application
  - HR CTV Volumes: 10-20 cm³ (3), 20-40 cm³ (12), 40-60 cm³ (2), 60-90 cm³ (3)
  - Applicator type: intracavitary (ic) tandem ring (9), ic+interstitial (11)

- The new plans for the 2nd application (loading pattern and dwell times) were reevaluated on the original MRI contours for the 2nd application

- Clinically acceptable plan quality was reached for most of the cases with the MRI/CT combination technique
Results: $D_{90}$ HR CTV, $D_{2cm^3}$ sigmoid

Planning aim $D_{2cm^3}$ sigmoid<$80$Gy $\text{EQD2}(\alpha/\beta=3\text{Gy})$

In total was reached in all but one cases (intrafraction organ motion, contouring uncertainties)

Planning aim $D_{90}$ CTV$_{HR}>7\text{Gy}$ per fraction was reached in all but one cases (applicator position was different on MRI and CT)
Summary: Combined MRI/CT planning

- allows use of MRI-based target concept and dose prescription protocols for adaptive CT planning -> better agreement with MRI-only planning *(Nesvacil et al. R&O 2013)*
- fast if automatic applicator model-based registration implemented in TPS

Automatic method not implemented in currently available commercial TPS

Uncertainty dominated by applicator reconstruction, slice thickness, applicator rotation relative to target, time/target shrinkage between fractions
Solutions for 3D image guided adaptive planning

Is access to MRI with applicator in place available?

Yes, for each fraction/application
MRI for each HDR fraction
MRI for each application, CT before each fraction for OAR verification

Yes, but only for first application
MRI for first application, CT for subsequent fractions (re-using MRI target from first fraction): software-based target transfer to avoid interobserver contouring uncertainties

No, not at all
e.g. volumetric US scan after applicator insertion for target definition, and CT scan for OAR delineation (registration via applicator) – research in progress
Transrectal ultrasound for target definition in CT-based cervix cancer IGABT (no access to MRI @BT)

pre-implant scan, TRUS guidance of implantation

volumetric post-implant scan

TRUS target delineation

applicator tracking (ACMIT, Elekta)

main uncertainty: tracking, QA

TRUS-CT registration via applicator

Gyn Pre-planning: Intracavitary / Interstitial Insertion

Based on pre-brachytherapy MRI: With applicator in place

Cervix cancer: large anatomical changes between EBRT and BT planning scans due to applicator insertion

- BT implant preplanning with high geometrical reproducibility
- MRI target from pre-planning could be transferred to CT for planning at time of BT via applicator-based registration