Online-Adaptive Robotic Radiotherapy

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High-Precision and Adaptive Radiotherapy

Conventional
Imaging
Target definition
Treatment planning

Treatment delivery
1. Fraction
2. Fraction
3. Fraction
4. Fraction
5. Fraction
6. ...

New
Imaging optimized for target definition
High-precision target definition

MRI, PET-CT, CT ...

1. Treatment planning delivery
2. Treatment planning delivery
## Image-Guided Radiation Therapy

<table>
<thead>
<tr>
<th>Challenges</th>
<th>IGRT</th>
<th>Offline Adaptive RT</th>
<th>Online Adaptive RT</th>
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<tbody>
<tr>
<td>Daily target position</td>
<td>Yes</td>
<td></td>
<td></td>
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<tr>
<td>Systematic target shape</td>
<td>No</td>
<td>Yes</td>
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<tr>
<td>Systematic OAR shape</td>
<td>No</td>
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</tbody>
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Lei Dong
Rationale of Online Adaptive RT

**Tumor perspective:** Large inter-fraction variability in target position and shape that cannot be corrected by a couch shift or rotation.

**OARs perspective:** Due to position and shape variations of the organs at risk the treatment plan may be far from optimal for the patient’s anatomy during dose delivery.
CyberKnife’s Stereo View

Can you see the tumor?

Yes, I can see the implanted markers.
In-Room Volumetric Imaging: Requirements

Diagnostic CT image quality
- Better than current CBCT solutions
- Competition with MRLINAC

Keep benefits of CyberKnife system
- Non-coplanar beam directions
- Tracking

Fast and versatile procedure
- ~30 seconds to move the patient from imaging to treatment location
- Imaging with patient in treatment position

Easy integration, using as much as possible using existing technology

Support of 3rd party image processing software (e.g. MIM)
CyberKnife with integrated CT-on-rails: System description and first clinical application for pancreas SBRT


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CT-Offset and Tracking

Robotic treatment couch has no absolute coordinate system

Match daily CT scan to planning CT scan based on the tracking features

Calculate the relative shift of the target

Shift the dose with respect to the tracking features

Use of In-Room CT in Erasmus MC

Clinical Studies
- Check location surgical clips and fiducials for ABPI
- Inter and intra-fraction OAR motion around gall duct
- Inter-fraction motion OAR around pancreas
- Plan of the day for abdominal lymph nodes

Clinical Routine
- Troubleshooting with fiducials
  - Suspicion of fiducial migration
  - Only 1 fiducial present
Motion in SBRT for Locally Advanced Pancreatic Carcinoma
15-20% 
Resectable

40-50%
Unresectable, metastasis

30-40%
Unresectable, no progression

Chemotherapy: 8 cycles Folfirinox

SBRT: 5 x 8 Gy prescribed to 80%
Daily Dose Variations in Organs at Risk

Results

Considerable trade-off target coverage/OAR sparing in SBRT for pancreatic cancer

Median increase was statistically significant for V35Gy in all critical structures

Duodenum

Stomach

Principal Component Analysis (PCA)

Population-based motion model of the OAR

Reference organs

Common patterns of OAR variations

35 LAPC1 patients
133 CT scans

Modes of Motion: Bowel, Stomach, Duodenom
Patient Selection Tool to Identify Who May Be at Risk

Figure 1: OAR classification criteria based on the clustering of the simulation predictions according to the clinical observations.

Figure 2: Comparison of the geometrical assessment and model-based predictions against the ground truth derived from clinical observations.
Online-Adaptive SBRT for Lymph Nodes
Online-Adaptive SBRT of Abdominal Lymph Nodes

Treatment of oligometastatic disease

Total dose of 45 Gy in 5 daily consecutive fractions

Dose prescribed at the 90% isodose line

PTV = GTV plus 3 mm
Adaptive Lymph nodes

**Easy Case:** GTV quite clear, bowel contour not perfect

**Difficult Case:** GTV and bowel difficult to see
Plan Library for Pelvic Lymph Nodes

A Standard Plan

B Different Anatomy Plan

C Hot Plan by prescribing to 80%
Online Adaptive Workflow

**Preparation**

1. Acquisition of fraction CT scan and import in MIM software
2. Fraction CT registered to Planning CT based on spine
3. Rigid propagation of dose distribution and target structures
4. Deformable propagation of OARs
5. Visual inspection of propagated contours by RTTs

**Plan Selection**

1. If all OAR constraints are met then select plan with the highest PTV dose
2. Otherwise select the plan with the lowest dose to the OARs
3. If it is too difficult to decide then take plan A
Results of the first 12 patients

Primary tumor
- 6 Colorectal
- 3 Prostate
- 3 Other

Localization
- 8 Abdomen
- 4 Pelvis

Medium minimum distance GTV-Bowel: 8.6 mm

Re-planning was performed for 3 patients:
- Due to a constraint violation for both duodenum and stomach
- A mismatch with the tumor, found at the moment of the first daily CT scan

10% more dose to the tumor was given in 24% of the fractions, but can go up to 40%

Plan B (different anatomy) was not selected
Conclusions

CT scanner was integrated successfully with CyberKnife system.
Integration with tracking system has been tested and is now being prepared for clinical use.
Library-of-plans based Plan of the Day strategies were introduced using MIM software.

Big step to clinically implement adaptive workflow with RTTs in charge. Limitations what RTTs (and physics) are allowed to do.

Need a physician to be present at the treatment?
Automation and quantitative decisions needed for RTTs based on automatically segmented contours.
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