Adaptive Radiation Therapy

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Acknowledgements

Di Yan – William Beaumont Hospital
Robert Jeraj – University of Wisconsin
Michael Sharpe – Princes Margaret Hospital
Kristy Brock – Princes Margaret Hospital
Katja Langen – MD Anderson Cancer Center
Randall ten Haken – University of Michigan
Spring Kong – University of Michigan
Marcel van Herk – NKI-AvL
Simon van Kranen – NKI-AvL
Jasper Nijkamp – NKI-AvL
Content

- Principles of radiotherapy
- Anatomical changes
- Image guided radiotherapy
- Image registration
- Adaptive radiotherapy
Image Guided Radiotherapy
Radiotherapy procedure

Tattoo, align and scan patient

Align patient on machine on tattoos and treat (many days)

Draw target and plan treatment on RTP
Patient Position Changes

The patient moves from day to day
Organ Motion

Organs move from day to day
How can we solve this problem?

1. Use large margins, irradiating too much healthy tissues
2. Use small margins, and risk missing the target
3. Or: use image guided radiotherapy
Image Guided Radiotherapy

- Image the tumor + organs-at-risk or their surrogates just prior or during treatment

- Assess changes in patient position relative to treatment plan

- Adapt treatment plan (couch shift) to account for changes, increasing treatment precision
Safety Margins

Verellen et al. Nature Reviews Cancer 2007
The image guided radiotherapy process

Pre-treatment Imaging -> Treatment Planning

Pre-treatment Imaging

In Room Imaging

Image Registration & Correction

Treatment Delivery
image guidance: not a new idea!

First isocentric Co-60 machine in Netherlands at NKI (1960)
Planar Imaging
Many In-room Imaging Systems
CT Acquisition

Conventional CT
- ‘Fan’ beam
- 1D detector
- 1 rotation = 1 slice

Cone-beam CT
- ‘Cone’ beam
- 2D detector
Elekta Synergy Research system at NKI

Frame Rate: 2.7 fps; Acquisition Time: 1 - 4 min; 1-2 mAs/Frame
NKI high speed reconstruction software (20 s)
Sample Image
Image Analysis: comparing with reference image

Reference Image (conventional CT)  Verification image (cone beam CT)  Color-fused image (unmatched)
Matching on region of interest

Reference image  Verification image  Reference image  Verification Image

Required couch shift: 
(-3.2, -1.5, -0.6) mm

Required couch shift: 
(+1.5, -3.2, -6.1) mm
Pre Correction
Post Correction
Margin reduction

![Graph showing PTV Margin vs Tumor Amplitude for mean Tumor, mean Bone, ITV Tumor, and ITV Bone.](image)
Uterus interfraction motion

- Cervix/uterus on CT
- Delineations on CBCT
Uterus motion model

Select 6 bladder fillings based on this model:

- -20 %
- 0 %
- 33 %
- 66 %
- 100 %
- 120 %
Plan Selection
Differential Motion and Shape Variability

No couch correction can solve this problem
Adaptive Radiotherapy
Adaptive Radiotherapy

The adaptive radiotherapy technique aims to customize each patient’s treatment plan to patient-specific variation by evaluating and characterizing the systematic and random variations through image feedback and including them in adaptive planning.

Adaptive radiotherapy will become a new treatment standard.
The Adaptive Replanning Process

- Pre-treatment Imaging
- Treatment Planning
- In Room Imaging
- Image Registration & Correction
- Treatment Delivery
- Adaptive Replanning
- Treatment Assessment
Adaptive Radiotherapy

Initial treatment plan

Adapt treatment plan

Scan first $N$ days

Weekly Monitor treatment

Group-specific ART strategy

Adaptive radiotherapy for prostate cancer using kilovoltage cone-beam computed tomography: first clinical results

Jasper Nijamp, M.Sc., Floris J. Pos, M.D., Ph.D., Tonnis T. Nuver, Ph.D., Rianne de Jong, R.T.T., Peter Remeijer, Ph.D., Jan-Jakob Sonke, Ph.D., and Joos V. LEBESQUE, M.D., Ph.D.
Geometric uncertainties

Series of 9 repeat CT scans during a 25 x 2 Gy treatment schedule

Setup errors corrected

CTV shape variation

Bladder
Rectum
CTV
PTV margin

Planning CTV

AVG treatment CTV

Systematic error ($\Sigma$)
PTV margin

Daily CTV’s
AVG treatment CTV
Random error ($\sigma$)
Systematic error

Initial map

Adaptive map
Deformable Registration
Multimodality Images
Image Registration
Image Registration

Finding *geometrical correspondences* between imaging data sets (2D/3D/4D) that differ in time, space, modality and/or subject
An image is a N-dimensional mathematical function mapping coordinates to intensity values.
Principle of Image Registration

Fixed Image

Floating Image

Interpolator

Transformer
General Framework for Image Registration

- **Fixed image**
- **Floating image**
- **Metric**
- **Interpolator**
- **Transformer**
- **Optimizer**

Flow:
- From **Fixed image** to **Metric**
- From **Metric** to **Optimizer**
- From **Optimizer** to **Transformer**
- From **Transformer** to **Interpolator**
- From **Interpolator** to **Mapped Image**
- From **Mapped Image** to **Adjusted Parameters**
- From **Adjusted Parameters** to **Optimization**
- From **Optimization** to **Metric**

Keywords:
- Geometric Transformation
- Similarity
- Mapped Image
- Adjusted Parameters
- Geometric Transformation
Deformable Registration Example
Adapting to shape changes

- planning CT
- daily CBCT scans
- CT CBCT overlay
CBCT-CT DR – visual verification by movie loop

online couch correction  vs  deformably registered
Adapting to shape changes
Dose accumulation during treatment

Planned

Accumulated

Adapted Accumulated
Dose accumulation during treatment

Planned

Accumulated

Adapted Accumulated
Dose accumulation during treatment

Planned

Accumulated

Adapted Accumulated
Dose accumulation during treatment

Accumulated dose for target during treatment

\[ \Delta \text{Dose (Gy)} \]

fraction

- CTVsd - D99%
- GTVpet - D99%
- without ART
- with ART

\[ \gg \text{difference with P0} \]
Dose accumulation during treatment

Accumulated dose for OARs during treatment

$\Delta$ Dose (Gy) vs. fraction

- PAROTID_GL_R - Dmean
- PAROTID_GL_L - Dmean
- SPINAL_CORD - D1%
- BRAINSTEM - D1%
- without ART
- with ART
Timing of Rescanning
Relative Volume

Relative volume parotid glands

-23% @ wk 6
Biological Imaging
Classified patients with residual disease after radiotherapy show a worse overall survival.

hazard ratio = 3.00
(95 % CI: 1.45 to 6.24; p=0.003)

From Imaging to Target Delineations

CT scan

Delineated volumes

GTV

Boost region
The Adaptive Replanning Process

Pre-treatment Imaging → Treatment Planning

In Room Imaging → Image Registration & Correction

Adaptive Replanning → Treatment Assessment

Treatment Delivery

Biological Response Monitoring
Limitations / Pitfalls

- In room image quality / Field of View
- Single repeat CT scan introduces new systematic errors
- Commercially available tools for “sophisticated “ ART are mostly lacking
- Work flow
Controleer de gegevens van het bestaand proefobject (Product).
Om de FADF goed te bekijken:
Klik op Status:

Vergeet de locatie van het bestaande schema in de status en de verdelingen en dagelijkse werkuren voor de aangezette door tracking shift.
Klik op de knop Documentation:

Het volgende schema komt voor:

Automatisch worden de Door Tracking shifts aangepast voor alle doorgevoerd shifts.
Klik OK.

Met de gekozen schema komt voor:
(Deze tekst is opgezet in de balk op de kop Window en selecteer Dokument settings.)
In de Docutype, selecteer de verbinding.
Alleen als het koptoon aanwezig is, mogen we met een expenser.
Onder Tolerance staan de betreffende tabellen.
Eind contour bestelling/instellingen door item/take: "XRAY." Pas dit aan indien nodig.

Tolerance tabellen:

Tolerance tabel 1: XRAY bij instellingen meten ITA.
Tolerance tabel 2: XRAY bij instellingen meten per staat.
Tolerance tabel 3: XRAY bij instellingen waardoor de grijze box en de tien hokjes vat staan.

Klik op het Field Setup, omdat de schemas vermeld.

Nota bij het bovenste hokje bij de Field Setup, omdat de eerste 3 regels maken de "B" en de lettering tekenen, de instellingen in de bestelling/instellingen tekenen af.

Zet een enkel kruis bij Display Field Setup, wordt het een enkel hokje met een selectie gedrukt, moet de gebruiker deze instellingen bewerken.
Summary

• IGRT and ART increase the precision of radiotherapy and thus have the potential to increase the therapeutic window

• Both complex geometric errors and treatment response can be mitigated

• Efficient workflows are required to enable frequent adaptive interventions