2D- and 3D-matching for IGRT in prostate cancer

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Dose escalation in prostate cancer

Highly conformal 3D RT → less risk of rectal toxicity

Dose escalation → improved biochemical relapse free survival

Peeters et al, J Clin Oncol 2006;24:1990-1996
Zietman et al, JAMA 2005;294:1233-1239

Conformal RT techniques require greater precision in treatment set-up and delivery
Increased rectal toxicity


Image Guided Radiation Therapy

- Prostate gland is known to move
- Bony anatomy ≠ surrogate for daily prostate position
- Methods of prostate localization:
  1. Ultrasound (poor results, operator dependent)
  2. Fiducial gold markers + PI (MV or kV)
  3. CT (MVCT or CBCT)
Fiducial markers (FM)

• Daily online localization with FM → minimizing systematic and random target volume positioning errors
• Assumption: FM serve as an accurate surrogate for the prostate
  – No (random) migration
  – No prostate V change during RT
  – No prostate shape change during RT

Modelling prostate shrinkage for gold marker alignment

Background and Purpose:
• Currently, patient alignment tools based on FM use manual marker matching and rigid registration transformations to measure the needed translational shifts.
• To quantify the particular effect of prostate shrinkage, implanted FM were tracked during a course of RT to model prostate shrinkage

Budiarto et al, submitted Radiother Oncol
Modelling prostate shrinkage for gold marker alignment

Material and Methods:
- 8 patients with FM (7 also (neo)adjuvant androgen deprivation)
- Alignment to skin tattoos
- Orthogonal electronic portal images
- A semi-automated 2D/3D marker-based registration \(\rightarrow\) calculate couch shifts offline
- Registration consists of a rigid transformation + an isotropic scaling to model prostate shrinkage

Results:
- Inclusion of isotropic shrinkage in registration cancelled the corresponding increase in registration error
- Mean scaling factor was 0.90 ± 0.09.
- However, almost **no** difference in the translation offset between manual matching of EPIs to DRR and semi-automated 2D/3D registration
- Decrease in intermarker distance correlating with prostate shrinkage rather than with random marker migration.
Modelling prostate shrinkage for gold marker alignment

- Registration Error $[\text{mm}]$
- Treatment Fraction
- Scale Factor

(a) (b) (c)

Intermarker Distance Predicted Scale Change Compared to Registration Scale Change
Modelling prostate shrinkage for gold marker alignment

Conclusions:
• Inclusion of shrinkage in the registration process reduces registration errors
• Nevertheless, no clinically significant change in proposed table translations when compared to translations obtained with manual marker matching without scaling correction.

Margin reduction (CTV to PTV)
• Allows:
  – Less healthy tissue in PTV → toxicity ↓
  – Dose escalation
• Largest margin reduction: achieved by daily online correction based on FM; then only intrafraction motion should be taken into account.
Margin reduction

- **Formule**: (Van Herk et al.)
  \[2.5\sum + 0.7\sigma\]

- This calculates the respective PTV margins needed to deliver a 95% dose (D95) to the 95% clinical target volume (V95) for 90% of your patients
- \(\sum\) = preparation (systematic) error
- \(\sigma\) = the execution (random) error

Intrafraction motion

<table>
<thead>
<tr>
<th>Margins required when performing daily online correction</th>
<th>AP (mm)</th>
<th>SI (mm)</th>
<th>RL (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alonso-Arrizabalaga S et al</td>
<td>4.7</td>
<td>6.2</td>
<td>1.9</td>
</tr>
<tr>
<td>Litzenberg D et al</td>
<td>5.8</td>
<td>7.1</td>
<td>1.8</td>
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<td>Kotte A et al</td>
<td>2.1</td>
<td>1.9</td>
<td>1.0</td>
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<tr>
<td>McNair H et al</td>
<td>3.6</td>
<td>3.4</td>
<td>3.0</td>
</tr>
<tr>
<td>Beltran C et al</td>
<td>4.8</td>
<td>4.9</td>
<td>4.3</td>
</tr>
</tbody>
</table>
Daily 2D kV-kV matching in practice

- Eligible: all prostate cancer patients without contra-indication for FM implantation
- 4 FM transrectally implanted
- Planning CT reconstructed on 1 and 3mm
- Rigid registration of planning CT with MRI
- 5-field IMRT technique to 74Gy/2Gy on the prostate with a SIB of 55.5Gy/1.5Gy to the seminal vesicles
- FM delineated in the TPS as structures

Daily 2D kV-kV matching in practice

Two possibilities for matching on FM in the Varian OBI-system:

1. 2D-2D template based matching
2. Markermatch
2D-2D template based matching

- Offline review possible in database (no additional control images required)
- Excellent correlation between RTT and reviewer
Markermatch

CBCT (3D) IGRT

• Acquisition of 3D volumetric images with patient in treatment position
• Rotation of a kV X-ray source mounted on the accelerator gantry
• CBCT reconstructs entire image V from a single gantry rotation
• Matching with planning CT (bony anatomy, FM, soft-tissue)
Comparison of FM based matching and soft-tissue registration

• Aim:
  – To compare CBCT guidance using soft-tissue and kV PI guidance using FM
  – To assess if both methods are equivalent for determining isocenter corrections (validation with FM as a gold standard)

• CBCT and kV PI datasets obtained within same fraction before isocenter correction
• kV imaging used to correct pt position
• CBCT data stored for retrospective analysis
• Three measurement tools:
  1. kV PI localizing FM
  2. CBCT localizing FM
  3. CBCT localizing soft-tissue
Comparison of FM based matching and soft-tissue registration

Methods:
• Soft-tissue registration
• 3D markermatch
• Transfer to table parameters

Results:
• All measurements
• Without erroneous registrations
• Differences with kV-kV matching

I. Soft-tissue registration

• CT and CBCT are automatically registered using maximization of mutual information:
  1. Roughly aligned on whole image, after CT isocenter and CBCT center coincide
  2. Registration only within ROI encompassing the prostate (based on HU between 100 and 1500)
  3. Focus of soft-tissue registration further improved on the prostate itself (also based only on soft-tissue intensities) ~ 35s

Whole process: ~2 to 5 min
II. Marker based 3D-3D registration

1. Automatic marker detection in CT and CBCT (level windowing and thresholding)
2. All marker coordinates expressed in a coordinate frame to detect corresponding markers; RMS distances are calculated \( \rightarrow \) combination with shortest mean distance = marker correspondences
3. **Cave**: failure of automatic marker detection \( \rightarrow \) only markers detected in both CT and CBCT are taken into account (3 markers enough)
4. Translations are calculated based on translations needed to align the center of the markers
5. Rotation and scale are included

III. Transfer to table parameters

- 4 different coordinate frames
- Transformation of 3D marker match and soft-tissue registration results to table translations \( \rightarrow \) allows us to compare with the table shifts obtained from 2D-2D kV matching
Results

<table>
<thead>
<tr>
<th>Patient</th>
<th>lateral</th>
<th>vertical</th>
<th>longitudinal</th>
<th>error trans</th>
<th>error trans rot</th>
<th>CBCTs included</th>
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</thead>
<tbody>
<tr>
<td>-0.0540</td>
<td>-0.2969</td>
<td>0.0019</td>
<td>1.7829</td>
<td>0.5325</td>
<td>6 out of 6</td>
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<tr>
<td>-0.2051</td>
<td>-0.0924</td>
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<tr>
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<td>2.1907</td>
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</tr>
</tbody>
</table>

Table 1: Results of registration differences between markermatch and MIRIT registration. Longitudinal, vertical, and lateral denote the errors present in the patient at hand between the two registrations. Error trans gives the remaining errors on the landmarks when only translation is performed (markermatch), while Error trans rot gives the remaining errors when also calculation the required rotation (markermatch).
Results without erroneous registrations

Differences between MIRIT and marker registration in the 3 directions

Results without erroneous registrations

Influence of rotations on residual errors on marker positions
IV. Correlation between different measurement tools

<table>
<thead>
<tr>
<th></th>
<th>Pearson’s corr coefficient</th>
<th>Spearman Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RL</td>
<td>SI</td>
</tr>
<tr>
<td>CBCT localizing soft-tissue vs CBCT localizing FM</td>
<td>0.99</td>
<td>0.86</td>
</tr>
<tr>
<td>kV PI localizing FM vs CBCT localizing soft-tissue</td>
<td>0.86</td>
<td>0.74</td>
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<tr>
<td>kV PI localizing FM vs CBCT localizing FM</td>
<td>0.86</td>
<td>0.88</td>
</tr>
</tbody>
</table>

Bland – Altman analysis
V. Conclusions

• CBCT can successfully acquire (daily) volumetric images for IGRT
• Highly significant correlation between the different techniques
• Automatic soft-tissue registration allows 3D IGRT (no uncertainty in locating soft-tissue organs); however: still time consuming
• Further investigation needed
  – More data to confirm results
  – Speed up process for clinical implementation

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