Planar radiographic imaging for prostate fiducial tracking

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Scope

Survey clinical methods of intrafraction prostate motion monitoring using kV and MV planar imaging of implanted markers
Rationale

• Clinical goals of high-precision RT, esp. hypofractionated
• Knowledge of intrafraction motion from beacon studies

Table 2. Patient-Specific Percentage of Over-3 mm Time Using NI Strategy With Different Setup Delays.

<table>
<thead>
<tr>
<th>Setup Delay (sec)</th>
<th>30</th>
<th>60</th>
<th>120</th>
<th>180</th>
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</thead>
<tbody>
<tr>
<td>Percentage of overthreshold time, mean (standard deviation), max, (%)</td>
<td>IMRT 6.9 (7.1), 33.1</td>
<td>8.2 (8.5), 44.0</td>
<td>9.3 (10.4), 66.3</td>
<td>19.0 (22.3), 70.0</td>
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<tr>
<td>VMAT 7.1 (7.2), 31.1</td>
<td>8.5 (8.7), 42.9</td>
<td>11.3 (12.0), 66.8</td>
<td>17.0 (19.3), 77.3</td>
<td></td>
</tr>
</tbody>
</table>

Abbreviations: IMRT, intensity-modulated radiation therapy; NI, no intervention; VMAT, volumetric-modulated arc therapy.

(Ma et al TCRT 2019; 18:1)
Outline

• Room-mounted systems
• Gantry-mounted systems
• Intrafraction acquisition modes
• Strategies for obtaining 3D information
• Quality assurance
Room-mounted imaging systems
Real-Time Tumor-Tracking (RTRT) system

Shimizu et al. Radiat Oncol 2014; 9:118
- 110-patient study prostate IMRT
- Mean # kV localizations: 7.5/fx
- Median couch corrections: 19/30fx

Shirato et al, UROBP 2000; 48:1187
CyberKnife Robotic SRS/SBRT

Prostate SBRT trials:
• King et al IJROBP 2009; 73:1043
• Friedland et al TCRT 2009; 8:387
ExacTrac X-ray

- Flat-panel detectors
- X-ray tubes
- 4D thermal camera (surface monitoring)

(Brainlab.com)
Study of ExacTrac X-ray 6D IGRT setup uncertainty for marker-based prostate IMRT treatment

- 43 patients, 1200 fx, 3500 corrections
- Visicoil or cylindrical markers
- Average 3 corrections/fx

(DRR) Setup kV radiograph

(Shi et al JACMP 2012; 13: 35)
Gantry-mounted imaging systems
Vero System

www.Brainlab.com

Kamino et al. JROBP 2006; 66:271
Elekta Infinity

Flat-panel detector

kV x-ray source

EPID

(varian.com)

Varian TrueBeam

Flat-panel detector

kV x-ray source

EPID

(elekta.com)
Considerations in localization with gantry-mounted planar images
Intrafraction acquisition modes
Intrafraction acquisition

Snapshot (Ad-hoc imaging):
- Interrupt beam, acquire/correct, resume

Fluoroscopic
- Continuous kV, ~3-30 Hz
- Imaging dose a consideration, hybrid mitigation methods

Triggered kV
- Trigger on time, MU, gantry angle, respiratory gating
- ≤0.5 Hz
Auto-detection of markers:
Circle = planned marker position + tolerance
Crosshairs = detected marker
• Green = within tolerance
• Yellow = marker not detected
• Red = outside tolerance

(Korpics et al JACMP 21:3:184)
Strategies for obtaining 3D information (1)

Kilovoltage intrafraction monitoring (KIM)
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KIM-guided gated RT in prostate:

1) kV fluoroscopy during MV treatment
2) Auto-detection of markers in 2D images
3) 2D-to-3D reconstruction from model of estim. motion correlations
4) Display of real-time positions

Example at right:

(a) Motion within tolerance
(b) Outside tolerance: needs couch shift

(Keall et al IJROBP 2016; 94:1015)
KIM-guided gating example

(a) With gating: Couch corrections at 60s and 170s

(b) Without gating (estimate)

(Keall et al IJROBP 2016; 94:1015)
Strategies for obtaining 3D information (2)

MV/kV Intratreatment monitoring of Prostate SBRT
MV/kV clinical process – VMAT

- Triggered kV + MV short-arc digital tomosynthesis @ 20° intervals
- Audio/visual alert if 2 mm tolerance is exceeded
- Manual beam interruption and correction of position if needed
- Modification of control-point sequence to increase fiducial visibility
Quality Assurance (1/3)

Gantry-mounted MV & kV systems
• AAPM TG-104, TG-142

Gantry- & room-mounted MV & kV systems
• AAPM MPPG 2.a

Robotic radiosurgery
• AAPM TG-135
KIM-specific (Ng et al Med Phys 2014; 41:111712)

1) Stationary localization accuracy
2) Dynamic localization
3) Treatment interruption
4) Latency measurement
5) Clinical conditions

Tests 1-4: Anthro phantom + markers, 3D motion platform, prostate motion trajectories

Test 5: Comparison to MV/kV triangulation from RT

1) Stationary localization accuracy
2) Dynamic localization
3) Clinical conditions

Test methods:

1) Anthro phantom + markers, scripted VMAT + MV/kV image control points (Developer Mode, TrueBeam)
2) Same as Test 1 + scripted couch motion w/ clinical prostate trajectory
3) Patient study (n=3), VMAT+MV/kV, comparison to manual localization