Clinical Applications of Surface Imaging

Frameless (Maskless, Bite-blockless) Intracranial Radiosurgery

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Disclosure

- Work partially supported by VisionRT
Background:
Intracranial Stereotactic Radiosurgery

- Total prescribed doses: order of \(10 - 50\) Gy
- Planning targets are small: from 1 to 35 cm\(^3\).
- Positional and numerical accuracy in dose delivery are ±1mm and ±5\%, respectively.
- Accurate determination of the target volume and its location with stereotactic techniques.
- Conformal Dose distributions: sharp dose fall-off outside the target volume.
- Accurate knowledge of the total dose and fractionation scheme required for treatment of a particular disease.
Background:
SRS Frame and fiducial markers

Goals of frameless SRS/SRT

- Patient comfort
- Ease of treatment
- Similar or better accuracy of positioning
- Potential for hypofractionated treatments
**Advanced Techniques**

- IGRT techniques for accurate patient positioning / monitoring
  - Radiographic localization
  - Non-radiographic localization

- Better precision of hardware in treatment machine
  - High precision mechanics (Couch, Gantry, MLC etc.)
  - Full automatic 6DOF couch
  - Manual Head Adjuster for 3D rotation

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**Frameless (Maskless, Bite-blockless) SRS**

- Real-time setup and monitoring
  - VisionRT surface imaging

- Immobilization approaches

[Passive, Minimally Active]
**AlignRT System**

- **Stereo photography**
  - 3 cameras & visible light projector
  - Reference image = Contours from DICOMRT, Previous AlignRT image

- **Registration algorithm**
  - Minimize distance between reference image and real-time surface
  - Rotations & translations

**Initial System Testing**

- **Compare**
  - AlignRT monitoring
  - Zmed monitoring

- **Observe motion due to couch movements**
  - Use calibration SRS phantom with ZMed
  - Use Rando head phantom with AlignRT

Cervino et al. Phys Med Biol. 2010
Initial System Testing

Results: Translations

<table>
<thead>
<tr>
<th>Test no</th>
<th>Vertical motion (mm)</th>
<th>Long. motion (mm)</th>
<th>Lateral motion (mm)</th>
<th>Vert. difference (mm)</th>
<th>Long. difference (mm)</th>
<th>Lateral difference (mm)</th>
<th>Vector difference (mm)</th>
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<tbody>
<tr>
<td>1</td>
<td>−0.1</td>
<td>36</td>
<td>0.7</td>
<td>0.8</td>
<td>0.2</td>
<td>0.4</td>
<td>1.18</td>
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<td>2</td>
<td>−20.7</td>
<td>36</td>
<td>0.5</td>
<td>0.2</td>
<td>0.2</td>
<td>0.6</td>
<td>1.00</td>
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<tr>
<td>3</td>
<td>−20.5</td>
<td>36</td>
<td>19.1</td>
<td>0.1</td>
<td>0.2</td>
<td>1.0</td>
<td>1.14</td>
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<td>4</td>
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<td>36</td>
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<td>0.4</td>
<td>0.8</td>
<td>1.18</td>
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<tr>
<td>5</td>
<td>0.1</td>
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<td>−18.9</td>
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<td>0.4</td>
<td>0.63</td>
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<td>6</td>
<td>−0.1</td>
<td>−0.1</td>
<td>−19.5</td>
<td>0.0</td>
<td>0.1</td>
<td>0.4</td>
<td>0.71</td>
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<tr>
<td>7</td>
<td>−0.2</td>
<td>−0.3</td>
<td>0.6</td>
<td>0.2</td>
<td>0.1</td>
<td>0.3</td>
<td>0.77</td>
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<td>8</td>
<td>0.1</td>
<td>−0.4</td>
<td>20.9</td>
<td>0.2</td>
<td>0.1</td>
<td>0.4</td>
<td>0.84</td>
</tr>
<tr>
<td>9</td>
<td>−20.7</td>
<td>36.7</td>
<td>21.1</td>
<td>0.1</td>
<td>0.2</td>
<td>0.6</td>
<td>0.95</td>
</tr>
</tbody>
</table>

Difference in motions detected by Zmed and AlignRT
(Average = 0.93mm)

Cervino et al. Phys Med Biol. 2010

Initial System Testing

Results: Rotations

<table>
<thead>
<tr>
<th>Couch angle</th>
<th>90 deg.</th>
<th>45 deg.</th>
<th>315 deg.</th>
<th>270 deg.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vert. (mm)</td>
<td>0.4</td>
<td>0.2</td>
<td>0.2</td>
<td>0.4</td>
</tr>
<tr>
<td>Lat. (mm)</td>
<td>0.6</td>
<td>0.3</td>
<td>0.4</td>
<td>0.6</td>
</tr>
<tr>
<td>Lng. (mm)</td>
<td>0.8</td>
<td>0.8</td>
<td>0.3</td>
<td>0.1</td>
</tr>
<tr>
<td>Head yaw (°)</td>
<td>0.2</td>
<td>0.1</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>Head pitch (°)</td>
<td>0.1</td>
<td>0.0</td>
<td>0.3</td>
<td>0.7</td>
</tr>
<tr>
<td>Head roll (°)</td>
<td>1.0</td>
<td>0.3</td>
<td>0.1</td>
<td>0.3</td>
</tr>
</tbody>
</table>

Cervino et al. Phys Med Biol. 2010
Other publications

- Detecting shifts with a torso phantom
  - Sub-millimeter accuracy (0.75 mm) for the 3 translational degrees of freedom and less than 0.1° for each rotation
  - Bert et al. Med Phys. 2005

- Detecting shifts with a head phantom
  - 1D motion detection was 0.1 mm±0.1 mm, dependent on the CT skin definition with ~0.4 mm variation
  - Li et al. Med Phys. 2011

UCSD FMB Procedure

1. CT Simulation
   - Patient Simulation
     - Create mask & head cushion

2. Planning
   - Plan and isocenter
     - Create body contour

3. FMB Image registration
   - Importing plan & body contour
     - Select ROI

4. Initial setup
   - Manual head adjuster
     - Start from bridge of nose

5. Capturing new-reference Image
   - CBCT image registration
     - Capture new reference surface

6. Treatment
   - Monitoring
     - Adjust if needed
**Equipment**

- Varian TrueBeam
- Varian Eclipse V10
- AlignRT V 5.0.517 with HD Camera
- Manual Head Adjuster
- Daily QA phantom
- Monthly QA phantom

**CT Simulation**

Not a real patient

<table>
<thead>
<tr>
<th>Tx Site / Technique</th>
<th>Mask Type</th>
<th>Immobilizers</th>
<th>Setup</th>
</tr>
</thead>
</table>
| Brain / FMB         | Open Mask with S-frame | - "B" Headrest  
- Custom head cushion  
- Pad on the table  
- Kneefix w/ 1 insert  
- Hands on abd. with ring | Patient to keep their chin down  
Align at Midline on the Brain  
Scan Protocol: SRS (Slice size: 1.25 mm) |
FMB Planning

- Body contour
- Resolution of target structure
- Smaller calculation grid size
- Origin @ bridge of nose (shift information to isocenter)
- PTV margin info @ setup note
- Documenting AP/LAT BEV (Body contour) with graticule
- Plan evaluation

Treatment: Initial Positioning

100 cm SSD for setup
Patient setup

Initial setup: moves from the bridge of nose with given shift numbers

Two therapists: one looks after rotations another after shifts
Patient setup

Target: < 0.5 mm, < 0.5 °

Capture new reference

- Co-registration to CBCT approved by a radiation oncologist
- New reference surface after CBCT-based shifts
- Expect small deviations
Treatment, Real time monitoring

- Beam-off if out of tolerance (depends on setup margin)

General Tolerance
- Any translational < 1mm
- Any rotations < 1°
- 3D MAG < 1.0 mm

Treatment, Couch rotation
Treatment, Couch rotation

Example Case
Example Case

![Diagram showing deviation over elapsed time with couch rotation at 45 degrees and 315 degrees, labeled as Arc 1 and Arc 2, respectively.]

Daily QA, Cal. Board

- Board with distinct pattern
- 100 cm SSD, Align with cross-hair
- Verification of camera calibration
Daily QA, Cal. Board

Calibration verification successful, RMS error 0.2mm.

Daily QA, Cal. Board – recalibration if needed
Daily QA, QA Phantom

- Level and set to lasers
- Precisely setup with AlignRT
- Test plan with deliberate shift 1 cm in each direction
- Verify with kV/kV, CBCT and MV

Daily QA, QA phantom

- Matching to fiducials has to show 10 mm shifts in each direction
- End-to-End test tolerance +/- 1.5 mm
- kV/kV + CBCT, move couch from CBCT, MV orthogonal pair
Daily QA, QA Phantom

- After couch moves Align RT report required shifts
- Have to match 10 mm shifts made
- This completes the loop including shifts seen by Align RT

Monthly QA, Hidden target

- Align RT phantom setup
- Monthly QA procedure
- Hidden target testing
**Monthly QA, Hidden target**

**Clinical Results**

- **44 patients**
  - 115 intracranial metastases

- **Median follow-up of 4.7 months**
  - 1 year actuarial local control rate was 84%
    - 95% confidence interval: 69-99%

Pan et al. Neurosurgery, 2012, 71 (4) : 844-852
### Clinical Results

Comparison of local control & survival for retrospective studies of brain metastases treated with radiosurgery

<table>
<thead>
<tr>
<th>Treatment System</th>
<th>Pts (n)</th>
<th>Actuarial 1y LC* (%)</th>
<th>Actuarial 1y Survival (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frame-based linac</td>
<td>80</td>
<td>89</td>
<td>33</td>
</tr>
<tr>
<td>Frame-based Gamma Knife</td>
<td>205</td>
<td>71</td>
<td>37††</td>
</tr>
<tr>
<td>Frameless linac</td>
<td>53</td>
<td>80</td>
<td>44</td>
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<tr>
<td>Frameless linac</td>
<td>65</td>
<td>76</td>
<td>40</td>
</tr>
<tr>
<td>Frameless, surface-imaging guided linac</td>
<td>44</td>
<td>84</td>
<td>37</td>
</tr>
</tbody>
</table>

*LC: local control; †: not reported; ††estimated from Kaplan-Meier curve

### Summary

- Frameless SRS treatments with surface imaging are able to achieve the required level of accuracy
- Accuracy and precision of the system could be improved and verified with updated hardware (HD camera, 6D couch etc.) and an optimized QA program
- UCSD has established FMB intracranial stereotactic radiosurgery as its sole SRS/SRT technique
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