"Real-Time Whole-Brain Radiation Therapy: A Single-Institution Experience"
Anh H. Le, PhD, Strahinja Stojadinovic, PhD, Robert Timmerman, MD, Hak Choy, MD, Romona L. Duncan, BS, CMD, Steve B. Jiang, PhD, and Arnold Pompos, PhD
1. Utilizing the on-board imaging technology to improve the efficiency of palliative treatments.

2. Using scripting functions available in the treatment planning system to streamline and improve planning efficiency.

3. Taking a cross-disciplinary approach to improving work-flow to decrease the time the patient spends in clinic.

Hardware and Software Used

<table>
<thead>
<tr>
<th>Treatment Machine</th>
<th>Treatment Planning System</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agility</td>
<td>Pinnacle3</td>
</tr>
<tr>
<td>Elekta Oncology</td>
<td>Philips Medical Systems</td>
</tr>
<tr>
<td>Atlanta, GA</td>
<td>Andover, MA</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Second Verification</th>
<th>Record and Verify</th>
</tr>
</thead>
<tbody>
<tr>
<td>RadCalc</td>
<td>Mosaig</td>
</tr>
<tr>
<td>LifeLine Software</td>
<td>Elekta/IMPAC Medical Systems</td>
</tr>
<tr>
<td>Austin, Tx</td>
<td>Sunnyvale, CA</td>
</tr>
</tbody>
</table>
Introduction

- Radiation therapy (RT) functions as a multistep process with complex workflows and executed by a multidisciplinary team.
- Traditionally, each stage is given time in the current standard of care schema.
- Some special RT procedures, such as $^{60}$Co Gamma Knife radiosurgery and $^{192}$Ir high-dose-rate (HDR) brachytherapy, are typically administered in a real-time fashion in which planning, quality assurance (QA) and treatment are done in a single day.

Technological advances are driving the ever-changing environment and treatment practices in radiation oncology.

One avenue in that evolution is implementation of fast algorithms capable of processing data in real time.

The common themes of studies revolving around real-time dose calculation, planning, and motion monitoring is to make each step in Radiation Therapy more efficient without compromising accuracy and precision in treatment delivery.
Whole Brain Radiation Therapy

- WBRT was first recognized as a beneficial therapeutic method for treatment of multifocal cerebral metastasis in the early 1950s.
- The predominate technique for WBRT is two parallel-opposed lateral beams as a standard setup throughout the evolution of treatment machines.
- Technologic innovations provided the use of conformal field-in-field treatment planning which improved the historical Roentgen-ray therapy by ±20% dose variations of two-dimensional plans.
- The latest advances for WBRT uses linac or helical tomotherapy intensity modulation radiation therapy (IMRT) and volumetric modulated arc therapy (VMAT) techniques for avoiding dose heterogeneity and sparing critical structures.

Real-Time Whole Brain Radiation Therapy

- A Real-Time WBRT procedure was designed and implemented in our institution to enhance patient experience and expedite treatment delivery.
- Throughout the process it was observed that each physician drew slightly different blocks for the treatment fields, and each planner had a different method to achieve the field-in-field 3D whole brain plan.
- The scripted IMRT technique is mainly used as a “proof of principal” for paving the way for more complex treatments.
- Utilizing scripting to help standardize the practice of whole brain treatment planning and achieving consistent plan quality results.
Real-Time
Whole Brain Radiation Therapy

- A workflow for real-time WBRT was designed for a synchronized team of attending physicians, residents, physicists, dosimetrists, and therapists.

- After physician consultation, the patient simulation was scheduled for a 60-minute time slot on a linac equipped with on-board imaging (Cone Beam CT) capability.

- The workflow was then practiced using a phantom so that the process could be reviewed, improved, and familiar.

Real-Time WBRT Workflow

- For the success of the real-time WBRT procedure, a synchronized team is a key factor.

- Our current policy requires that all members of the team are immediately available at the console area.

- This ensures a swift execution of steps in the workflow and for timely response to unexpected situations.

- Occasionally technical difficulties during the procedure created outliers, and as each difficulty presented itself we discussed as a team an effective strategy to either prevent or work around should it arise again.
A real-time whole brain radiation therapy procedure workflow. The tasks are color-coded: blue for tasks performed by a physician, green for radiation therapist, yellow for dosimetrist, and red for physicist. Blue dashed line depicts the process that could be eliminated if the patient stayed on the couch during the treatment planning process. Tasks inside the thin dotted line were performed in parallel. Abbreviations: CBCT = cone-beam computed tomography; TPS = treatment planning system. (A color version of this figure is available at www.redjournal.org.)

- Each patient is positioned supine on a thin mattress on the treatment couch
- A mesh head mask immobilizer is then constructed inside the treatment vault.
- Once the mask is cooled BB’s are placed at the level of the lasers to mark isocenter for treatment planning
For the real-time WBRT protocol, the acquired CBCT images are used for planning instead of conventional fan-beam or helical CT Data.

By design, CBCT imaging is used to verify 3-dimensional patient positioning relative to a reference CT imported to the linac console.

In the real-time WBRT scenario, this requirement must be circumvented to be able to acquire the CBCT scan without the reference CT data.

A unique image protocol configuration file was created for the Agility linac to void the requisite of the reference CT images.

The treatment planning process starts when CT images are imported to the RT planning system.

Real-Time WBRT Treatment Planning Image

- A unique image protocol configuration file was created for the Agility linac to void the requisite of the reference CT images.
- The CBCT scans are then acquired using the machines on-board imaging, with a small field of view, a S20 filter, and an open window filter F0
- The resulting reconstructed CBCT from the Agility resulted in:
  - A scan length of 27.7cm
  - A scan diameter of 27cm
  - 88, 3mm thick slices

The acquired CBCT images are then exported to the treatment planning system.
Real-Time WBRT Importing

- Once the CBCT Scan is imported into the treatment planning system, the couch is removed.
- Isocenter is automatically placed at the intersection of the laser cross-hairs during setup.
- This point is extracted from the CBCT data and visually verified by the BBs placed on the patient.

Real-Time WBRT Contouring

- A pinnacle3 model-based atlas is used for auto-contouring on the CBCT images.
- Atlas based contouring is used to create:
  - Brain
  - Spinal Cord
  - Right and Left Eyes
Real-Time WBRT Contouring

- The auto-contouring script then creates:
  - Clinical Target Volume (CTV)
  - Planning Target Volume (PTV)
  - Normal Tissue tuning structure (NT)
- The CTV encompassed the whole brain, including C1 or C2 based on the physician's discretion.
- The CTV is then expanded by 6mm in all directions, except inferiorly, to create the PTV.
- The Contours are then reviewed and approved by the planning physician before the start of scripted planning.

Real-Time WBRT Treatment Planning

- The Auto-planning script:
  - Creates 2 parallel-opposed oblique beams
    - Gantry at 275° and 85°
    - Field-in-Field Multi-Leaf collimator
    - Utilized for IMRT optimization
    - Set to homogeneous dose calculation
  - Enters in the prescription of:
    - 30Gy in 10 Fractions
  - Imports an IMRT template for planning
- The treatment plan is designed by allowing a maximum of 8 control points with a goal of PTV dose homogeneity criterion within 95%-107% of the prescription dose.
- Due to the inaccuracy of reconstructed Hounsfield units in CBCT images, the dose distribution is calculated without heterogeneity corrections
Real-Time WBRT Treatment Planning - Objectives

Real-Time WBRT Treatment Planning – 3 View
Plan Approval, Printing, and Charting

Typical Clinical Workflow

Plan Approval
• Physician Approves treatment plan for printing.

Plan Printing
• Dosimetrist then prints the plan for the patient’s records.

Chart Completion
• Dosimetrist then transfers all data to the record and verify system for treatment.

Chart Check
• Physics completes secondary check of the chart.

Patient Treatment
• Therapists review the chart, take port films if necessary, and beam on.

This was **NOT** the most efficient workflow for Real-Time Whole Brain planning.

Plan Approval, Printing, and Charting

Real Time Planning Workflow

Plan Approval
• Physician Approves treatment plan for printing.

Chart Completion
• Dosimetrist then transfers all data to the record and verify system for treatment.

Port Films
• Therapist begins to read SSDs, take port films, and draw fields

Plan Printing
• Dosimetrist then prints the plan for the patient’s records

Chart Check
• Physics completes secondary check of the chart.

Patient Treatment
• Therapists review the chart, and beam on.
Scenario #1
WBRT dose clouds were calculated using heterogeneous dose calculations on the CT-based datasets. The dose distributions were recomputed using a homogenous dose calculation on the corresponding CBCT.

Scenario #2
For 10 previously treated patients a real-time WBRT plan was generated by scripted auto-planning. The 3D dose distributions were generated using both homogeneous and heterogeneous calculation methods.

Scenario #3
The DICOM-RT files for all of the CBCT plans were then sent to Mobius3D* for plan check verification. The Agility log files were acquired for each and uploaded for treatment delivery verification.

Results
On Average the reference point dose for homogeneous plans was 1.9% higher relative to the corresponding heterogeneous plans.

<table>
<thead>
<tr>
<th>Case no.</th>
<th>CT-based plans point dose</th>
<th>CBCT-based plan</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Heterogeneous dose (cGy)</td>
<td>Homogeneous dose (cGy)</td>
</tr>
<tr>
<td>1</td>
<td>3002.9</td>
<td>3035.0</td>
</tr>
<tr>
<td>2</td>
<td>2001.0</td>
<td>2034.4</td>
</tr>
<tr>
<td>3</td>
<td>3086.9</td>
<td>3145.7</td>
</tr>
<tr>
<td>4</td>
<td>3731.0</td>
<td>3847.1</td>
</tr>
<tr>
<td>5</td>
<td>2684.4</td>
<td>2748.5</td>
</tr>
<tr>
<td>6</td>
<td>3603.2</td>
<td>3664.4</td>
</tr>
<tr>
<td>7</td>
<td>1997.3</td>
<td>2029.6</td>
</tr>
<tr>
<td>8</td>
<td>3000.5</td>
<td>3034.0</td>
</tr>
<tr>
<td>9</td>
<td>2991.6</td>
<td>3056.4</td>
</tr>
<tr>
<td>10</td>
<td>2551.9</td>
<td>2612.4</td>
</tr>
</tbody>
</table>

Mean ± σ 1.9% ± 0.3% -2.1% ± 1.1% 98.3% ± 0.5% 98.3% ± 0.5%

Commissioning results: Point dose for CT-based homogenous versus heterogeneous plans, RadCalc secondary MU calculation, and Mobius3D and MobiusFX 3D Gamma for CBCT-based homogeneous plans.

*Each plan has the same number of MU calculated in heterogeneous and homogeneous dose mode.
Real-Time WBRT
Heterogeneous vs Homogeneous Dose Calculations

- 98.3% Passing Rate Agreement
- -2.1% Average
- -1.2% Average

Mobius3D/Fx
3D Gamma dose comparison analysis with 3%, 3mm global dose difference and isodose point distance criteria, respectively.

RadCalc MU
The independent RadCalc MU computations were within -2.1% on average, relative to the treatment planning calculations.

Ion Chamber Point
The measured PinPoint ion chamber point dose was within -1.2% compared with the treatment planning calculated point dose.

Clinical Implementation

The Real-Time WBRT procedure was implemented into the clinic in July 2014, and ran through July 2017.

The majority of the patients treated utilizing the new procedure were treated for later stages of brain metastasis and non-small cell lung cancer as the prophylactic cranial irradiation treatment.

Over time, the portal image verification step showed little need for correction on day 1, and as a result it was moved to the second day of treatment.

The time was recorded for each step of the process, and the total time of treatment was reviewed.
**Clinical Implementation Time Spent**

### Average time allocation for procedures throughout the real-time whole-brain radiation therapy course.

The numbers in colored boxes of the stacked bar chart represent the time in minutes for each process with and without portal imaging. Abbreviations: CBCT = cone-beam computed tomography; IMRT = intensity modulated radiation therapy.

<table>
<thead>
<tr>
<th>Workflow step</th>
<th>x ± σ (min), n = 34</th>
<th>x ± σ (min), n = 66</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patient Preparation</td>
<td>4.3 ± 2.2</td>
<td>5.8 ± 2.2</td>
</tr>
<tr>
<td>Mask &amp; isocenter placement</td>
<td>5.0 ± 2.2</td>
<td>4.6 ± 1.3</td>
</tr>
<tr>
<td>CBCT</td>
<td>2.7 ± 2.5</td>
<td>2.6 ± 2.2</td>
</tr>
<tr>
<td>Contouring</td>
<td>6.0 ± 1.3</td>
<td>5.8 ± 1.8</td>
</tr>
<tr>
<td>IMRT planning</td>
<td>2.3 ± 1.4</td>
<td>3.3 ± 2.2</td>
</tr>
<tr>
<td>Plan evaluation &amp; approval</td>
<td>5.6 ± 7.7</td>
<td>2.7 ± 2.9</td>
</tr>
<tr>
<td>Documentation / Mosaiq plan import &amp; portal imaging</td>
<td>12.0 ± 6.2</td>
<td>–</td>
</tr>
<tr>
<td>Final plan approval [and port films check]</td>
<td>–</td>
<td>8.5 ± 3.6</td>
</tr>
<tr>
<td>Beam delivery</td>
<td>3.9 ± 1.9</td>
<td>4.7 ± 2.2</td>
</tr>
<tr>
<td>Exiting</td>
<td>2.5 ± 0.4</td>
<td>2.9 ± 1.2</td>
</tr>
<tr>
<td>Total (patient enters and exits)</td>
<td>3.6 ± 1.9</td>
<td>3.8 ± 1.5</td>
</tr>
<tr>
<td>Total (CBCT to last beam delivered)</td>
<td>4.79 ± 11.3</td>
<td>4.46 ± 8.1</td>
</tr>
<tr>
<td><em>Port film verification was not performed on the latter 66 patients</em></td>
<td></td>
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</tr>
</tbody>
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Clinical Implementation
Time Spent

Time spread for procedures throughout real-time whole-brain radiation therapy course without portal film imaging (n=66) shown by the median, quartiles, range and outliers using a box and whisker chart. The X in colored boxes represents the mean; the median divides the box into the interquartile range; the box represents 50% of the data set, distributed between the first and third quartiles; the dots are the outliers. Abbreviations: CBCT = Cone-beam computed tomography; IMRT = intensity modulated radiation therapy. (A color version of this figure is available at www.redjournal.org)

Real-Time WBRT
Looking Towards the Future

- We hope to further enhance the process by implementing new solutions for improving the CBCT image quality that could potentially bring the automatic CBCT contouring capability to a new level currently possible for CT Images.

- A fully automated WBRT treatment planning would incorporate automated contouring, automatic plan optimization and fast dose calculation with CBCT data as the primary imaging modality.

- These assortments of automations could be especially helpful to reduce the potential of human errors as tasks are preformed in a relatively short timeframe.

- However, the shift from human process to automated process could potentially cause systematic errors that are harder to detect.
Real-Time WBRT Clinical Benefits

**Emergency Patients**
- Had an equal opportunity to receive advanced treatment options versus the traditional 2D clinical setup plans.

**Patients**
- Alleviated anxiety during the waiting time between planning CT and first fraction.

**Referring Physicians**
- RT is completed faster, and as such patients could get on with other therapies.

**RadOnc Professionals**
- A more uniform and automated process meant less chance for human errors.

There was no overall net gain in clinical time because the patients conventional CT simulation and the first treatment times are comparable to our reported average time for real-time WBRT.

The limitations of the real time approach include:

- Increased treatment room occupancy time
- Disturbance of the conventional clinical workflow
- Interference with the existing schedule
Real-Time WBRT
Conclusions

- A real-time WBRT workflow using integrated on-site imaging, planning, and delivery was commissioned, thoroughly tested, and deemed clinically feasible offering an attractive option for WBRT.
- Our study supported the idea that real-time RT is feasible within existing clinical environments.
- We are currently looking at moving the procedure beyond the traditional whole brain treatment to other sites and dose fractionation schemes.

Questions?
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