Automated treatment planning for low-resource settings
Laurence Court, University of Texas MD Anderson Cancer Center

Percentage of patients with access to radiotherapy.

Conflicts of Interest

• Funded by NCI UH2 CA202665
• Equipment provided by:
  – Varian Medical Systems
  – Mobius Medical Systems

• Other, not related projects funded by CPRIT, Elekta

Project team

MD Anderson Cancer Center, Houston
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• Beth Beadle, MD/PhD - PI
• Ju Xu, PhD – algorithms and integration
• Peter Balter, PhD – radiation physics
• Jinhong Yang, PhD - atlas segmentation
• Rachel Mccarron – H&N algorithms
• Kelly Kikling, MS – GYN, breast algorithms
• Brian Anderson – positive node detection
• Ann Mroz, MSCR
• David Folowk, PhD

Santo Tomas University, Manila:
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  – Maureen Bojador, MS
  – Teresa Kim, MD

Stellenbosch University, Cape Town
  – Hannah Simonds, MD
  – Monique Du Toit – physics
  – Viwan Swancer, PhD

University of Botswana
  – Tshine Grover
  – Fensaga Matlou
  – Tebogo Kurumekele

Varian Medical Systems
Mobius Medical Systems
National Cancer Institute
  – Bhadravat Vikram
Radiation therapy staff shortages in LMICs

<table>
<thead>
<tr>
<th>Country</th>
<th>Number of Medical Physicists</th>
<th>Number of Rad. Technologists</th>
<th>Number needed by 2020</th>
</tr>
</thead>
<tbody>
<tr>
<td>Philippines</td>
<td>140</td>
<td>141</td>
<td>93</td>
</tr>
<tr>
<td>South Africa</td>
<td>56</td>
<td>93</td>
<td>82</td>
</tr>
<tr>
<td>All LMICs</td>
<td>9169</td>
<td>12,147</td>
<td>9,915</td>
</tr>
</tbody>
</table>


• Large deficit – including current physicists, need around 13,000 physicists in 2020
• Many international guidelines suggest that medical physicists need 2+ years residency, typically following graduate school.
• Staff retention is also a problem (anecdotal)
• Approximately 50% of physicist time is spent doing treatment planning
• So, if planning was automated, then the number of medical physicists needed could be reduced by 50%

We can build on the extensive history and advances in plan automation

• Treatment planning systems are complicated
• Many publications on plan automation
• Plan automation has been shown to significantly reduce hands-on time
  – E.g. Voet et al showed savings of at least 1 hour of hands-on time
• Vendors have implemented some of this
• Vendors have also improved our ability to control these features
• We need to implement for non-IMRT techniques also

Voet et al., Fully Automated Volume Modulated Arc Therapy Plan Generation for Prostate Cancer Patients, IJROBP 88(5), 1175-1179, 2014
Bugando Medical Center
Cancer Center, Tanzania

- Simulation:
  - 1 CT, 1 conventional simulator
- Treatment units:
  - 1 Elekta, 1 Varian, 1 Cobalt

Which cancers should we focus on?

Total incidence of cancer (2012)

<table>
<thead>
<tr>
<th>Medium HDI countries</th>
<th>Low HDI countries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lung</td>
<td>Breast</td>
</tr>
<tr>
<td>Liver</td>
<td>Cervix</td>
</tr>
<tr>
<td>Stomach</td>
<td>Liver</td>
</tr>
<tr>
<td>Breast</td>
<td>Oesophagus</td>
</tr>
<tr>
<td>Colorectum</td>
<td>Prostate</td>
</tr>
</tbody>
</table>

HDI = Human Development Index


Specific goals of the Radiotherapy Planning Assistant

- Automatically create plans for cervix, breast (chest wall), head and neck (including nose-pharynx, larynx, ...) cancers
- A person educated to the level of a high-school diploma can be fully trained (using video and online tutorials) to use the system in ½ a day.
- Once trained, treatment plans can be created in less than 30 minutes.
- Compatible with all treatment units / record-and-verify systems
- Automatic QA of all processes
- Begin clinical testing in 2018.
Big Picture of Auto Planner V1.0 Workflow

Workflow example: Cervical cancer
Identify marked isocenter
- Assume use of fiducials
- Two independent algorithms
- Additional sanity checks (e.g. position relative to specific bony structures)

Remove couch and segment the body
- Two independent algorithms
- Additional sanity checks (e.g. smooth changes between slices)

Determine the field aperture
- Two independent algorithms were developed
- The results of one can be used as an independent verification of the other
  - The 3D Method
    - Uses auto-segmentation of bony anatomy on CT
  - The 2D Method
    - Uses deformable image registration (DIR) of an atlas of standards plans to patient DRRs

Kelly Kisling, Automated Treatment Planning for Cervical Cancer in Low- and Middle-Income Countries, SU-F-T-423
Initial Results

- 39 patient treatment fields rated by a radiation oncologist
- **3D Method**
  - 96% passed
  - 62% as Per Protocol
  - 34% as Acceptable Variation
  - 4% failures were all same (jaw at incorrect vertebrae)
- **2D Method**
  - 79% passed – still working on improvements
  - 17% as Per Protocol
  - 63% as Acceptable Variation
- Now deployed this to clinical practice
Use of approach B to QA approach A

Approach A  Approach B  Unacceptable deviation  Acceptable deviation

Treating lymph node metastasis

- Lymph node metastasis – common, and predictable location
- May require a change in superior border
- Curative treatment requires a boost dose
- Many centers lack resources to identify these, so they are not treated
- Project to automatically identify LN metastases in collaboration with Surbhi Grover and team at the University of Botswana


Step 1: Identify region where positive nodes likely to be

- Volume based on probability map
- Deform to patient CT set, with lateral expansion (25mm)

Work by Brian Anderson

Location of PET positive lymph nodes in a cohort of patients with locally advanced cervical cancers
Step 2: identify multiple regions with:
- circular shape (2D)
- size characteristic of positive nodes (5-10mm radius)

Step 3: Further processing to remove false results based on
- Connectivity
- 3D shape - should be ellipsoidal – removes ‘traveling arteries’

So far:
- Tested on 30 patients, encouraging results.

Plan QA: Comparison with population ranges
- Some ranges are quite tight, so provide reasonable QA
- E.g. Total range of MU is 10%
- Range of jaw positions is ~2.5cm in lateral and AP directions, 6cm in SI direction

<table>
<thead>
<tr>
<th>Jaw positions – population statistics</th>
<th>Total MU – population statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td>x (deg)</td>
<td>y (cm)</td>
</tr>
<tr>
<td>St. dev.</td>
<td>1.9</td>
</tr>
<tr>
<td>min</td>
<td>15.7</td>
</tr>
<tr>
<td>max</td>
<td>18.2</td>
</tr>
</tbody>
</table>
Plan QA: Manual checks

- Initial tech review
- MD approval
- Physics, therapy review

Initial technical review

- Double check of vital plan check functions
- Only get to this point if passes all internal QA checks
- Technical items checked:
  - Marked isocenter
  - Patient orientation, laterality and site
  - Body contour
  - CT processing (couch removal)
  - Field apertures
  - Any significant artifacts or differences
  - Dose calculation complete
- Purpose designed document to lead the user through the checks
Marked isocenter

- Patient results
- Library examples

Checklist:
- Yes/No: Are all 3 fiducials visible on at least one of the slices shown?
- Yes/No: Do the central axis lines touch each fiducial on at least one slice?

Body contour

- Patient results
- Library examples

Checklist:
- Yes/No: On the CT slices, is the body correctly contoured (e.g. not including the couch)?
- Yes/No: Is the body contour smooth, like the library case?
- Yes/No: Is the orientation consistent with the library case?

Field apertures

- Patient results
- Library Case

Checklist:
- Yes/No: Is the patient orientation and body part consistent with the reference case?
- Yes/No: Are the blocks/MLCs in the acceptable region?
- Yes/No: Are there any significant differences between the patient and library images?
Dose calculation complete

Lessons learned

- Total 7 pages, 33 questions
- Initial tests: 3 physics undergraduates, 15 patient plans with intentional errors
- Time taken to check each plan: Average 4 min (range: 1 - 10 min)
- Techs can identify well defined issues, e.g. marked isocenter
- Testing is essential to optimize questions, and to give realistic expectations
  - e.g. what is an acceptable body contour
  - Is marked isocenter correctly identified
- Likely to be difficult for them to assess clinical tasks
  - e.g. field apertures
- Unlikely to catch issues not associated with a specific question
  - e.g. missing fields
- Credentialing of Planning Technologists will be necessary
- More work needed....

Head and neck treatments

- Range of complexities in treatments:
  - VMAT or IMRT
  - Opposed laterals / off- cord cone-downs
  - Complex conformal plans
- Starting with VMAT because easiest for us to integrate
  - Auto-contouring normal tissue
  - Auto-contouring low-risk CTV
  - Manual contouring of GTV
  - RapidPlan (Eclipse)
Normal tissue auto-contouring

Multi-atlas segmentation – deformable registration (accelerated “Demon”) followed by STAPLE algorithm to fuse contours

- Tested on 128 patients
- Scored by Radiation oncologist. 4+ is acceptable without edit
- Fails for non-standard head positions
- Otherwise all pass, except esophagus and cochlea
- Now deployed this to clinical practice

Valiation of Models

- Bagged Classification Tree Model
- Physician Rated Contours (Pass/Fail)
- 10 fold validation
- Minimize false negatives (maximize specificity)
- More testing needed……

<table>
<thead>
<tr>
<th>Structure</th>
<th>Sensitivity</th>
<th>Specificity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brain</td>
<td>0.97</td>
<td>0.93</td>
</tr>
<tr>
<td>Brainstem</td>
<td>0.88</td>
<td>0.96</td>
</tr>
<tr>
<td>Cochlea</td>
<td>0.79</td>
<td>0.89</td>
</tr>
<tr>
<td>Eye</td>
<td>0.80</td>
<td>0.92</td>
</tr>
<tr>
<td>Lung</td>
<td>0.63</td>
<td>0.89</td>
</tr>
<tr>
<td>Mandible</td>
<td>0.88</td>
<td>0.96</td>
</tr>
<tr>
<td>Parotid</td>
<td>0.84</td>
<td>0.95</td>
</tr>
<tr>
<td>Spinal Cord</td>
<td>0.99</td>
<td>0.95</td>
</tr>
</tbody>
</table>

RPA Deployment process

- Need to ensure that patients treated with RPA receive correct treatment
- Receive commissioning data + commission RPA (Eclipse)
- Radiotherapy Beam Audit Device + TLD output
- Remote planning audit of current planning system (comparison with standard beams)
- End-to-end tests (on-site)
Radiotherapy Beam Audit Device

- Use together with TLD output checks

Phantom built at IROC-Houston, with David Followill

End-to-end tests

- Will create tests based on IAEA-TECDOC-1583

Summary

- Automatic treatment planning may help reduce the planning burden, reducing staff shortages in LMICs
- Many approaches to ensure plan quality
  - Secondary independent algorithms
  - Additional 'sanity' checks
  - Population comparisons
  - Structured plan checks
- Limited testing starting in South Africa in September
- Then the Philippines
- Aiming to start use of the complete system in LMIC setting in 2018
- (and also work on 2D plans, not mentioned today...