Clinical Testing of Automated Planning Modules

Presenter: Binbin Wu, Ph.D.
Assistant Attending Physics
Department of Medical Physics
MSKCC, New York, NY
Disclosures

• Partial of the research was supported by Philips Radiation Oncology Systems.

• Co-inventor of a patent associated with the knowledge-based planning (KBP) approach utilizing overlap-volume histogram (OVH), which was licensed to Varian Medical Systems in 2015.

Challenges

KBP requires a **sufficient, large number of high quality plans** for predictive model build-up.

- Prior data collection (>100 plans for prostate library)
  - Target-organ anatomical variations
- Dosimetric & anatomical feature extraction
- Model review for removing dosimetric outliers
- Model testing

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*Sample size requirements for knowledge-based treatment planning. Med Phys 2016; 43: 1212–21*

Aims

Aim 1: Cross-institutional plan library sharing in KBP

- **Significance**: allow centers to utilize an *established* library from another center to generate their KBP plans, instead of building their own library and developing their own model
- **Hypothesis**: target coverage and organ sparing achieved at the established library would be obtainable to other centers
- **Focus**: IMRT/VMAT for oropharyngeal cancer

Aim 2: KBP and Pinnacle\textsuperscript{3} Auto-Planning Engine (APE) performance comparison under cross-institutional implementations.

*Cross-institutional KBP implementation and its performance comparison to Auto-Planning Engine (APE),* *Radiother Oncol* 2017; 123: 57-62
Study design
Center 1: Radboud University Medical Center (RUMC), Netherlands
Center 2: Johns Hopkins University (JHU), Baltimore, MD,

Aim 1: Cross-institutional library sharing: utilizing an established library (179 H&N pt’s plans) from JHU for KBP on RUMC’s 35 pts

Aim 2: KBP and APE performance comparison: RUMC’s APE plans are compared to the library-shared KBP plans

Fully automated SIB-IMRT treatment planning is feasible for Head-and-Neck cancer: a prospective clinical study, IJROBP 2012; 84: e647–653.

Automatic planning of head and neck treatment plans. JACMP 2016; 17:272-282.
Aim 1: Cross-institutional library sharing

**Challenges:** protocol discrepancy among centers

- Beam configuration: IMRT Vs. VMAT Vs. TomoTherapy
- Prescription: RUMC’s 2-dose level Vs JHU’s 3-dose level
  - e.g., (50.3 Gy and 68 Gy) Vs. (58.1 Gy, 63 Gy and 70 Gy)
- Target–organ anatomical variations
- Planning guideline: sparing goals are different
  - RUMC: (Cord: $D_{0.1 \text{ cc}} \leq 50$ Gy) Vs. JHU: (Cord4mm: $D_{0.1 \text{ cc}} \leq 44$ Gy)
As reported as the following references, plans generated by

- 7-beam/9 beam IMRT/2-arc VMAT/TomoTherapy

are comparable.

<table>
<thead>
<tr>
<th>Beam configuration discrepancy</th>
<th>RUMC</th>
<th>JHU (library)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IMRT angles</td>
<td>7</td>
<td>9</td>
</tr>
<tr>
<td>Maximal segments per plan</td>
<td>60</td>
<td>120</td>
</tr>
<tr>
<td>Minimal area per segment (cm²)</td>
<td>10</td>
<td>4</td>
</tr>
<tr>
<td>Machine</td>
<td>Synergy</td>
<td>Infinity</td>
</tr>
</tbody>
</table>


SmartArc-based VMAT for oropharyngeal cancer: a dosimetric comparison with both IMRT and helical tomotherapy. IJROBP 2011; 80: 1248-1255

Using overlap volume histogram and IMRT plan data to guide and automate VMAT planning: A head-and-neck case study, Med Phys 2013, 40:021714
Prescription discrepancy

• RUMC: 50.3 Gy and 68 Gy

• JHU (library): 58.1 Gy, 63 Gy and 70G

• Assumption: organ doses depend only on low-level PTV
  – RUMC’s 35 pts: $D_{95}$ of PTV50.3 = 44.9 Gy
  – JHU’s 179 pts: $D_{95}$ of PTV58.1 = 57.3 Gy

• Dose scaling factor: $\frac{57.3}{44.9} = 1.27$
  – Predicted organ’s dose from JHU library is scaled down by 1.27, and then applied to RUMC pts for KBP.
Target–organ anatomical variations

PTV-cord distance $r_{0.1\text{cc}}$ for predicting cord’s $D_{0.1\text{cc}}$

RUMC: PTV-cord distance from 35 pts

$\text{JHU (library)}$: PTV-cord distance from 179 pts

$r_{0.1\text{cc}}$ in cm

$r_{0.1\text{cc}}$: Shortest distance from the PTV surface to the cord for covering 0.1 cc of the cord.
Target–organ anatomical variations

PTV-parotid distance $r_{50}$ for predicting parotid’s $D_{50}$

RUMC: PTV-parotid distance from 35 pts

JHU (library): PTV-parotid distance from 179 pts

$r_{50}$: Shortest distance from the PTV surface to the parotid for covering 50% volume of the parotid.
## Planning guideline discrepancy

<table>
<thead>
<tr>
<th>RUMC</th>
<th>JHU (library)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cord:</strong> $D_{0.1 \text{cc}} \leq 50 \text{ Gy}$</td>
<td><strong>Cord4mm:</strong> $D_{0.1 \text{ cc}} \leq 44 \text{ Gy}$</td>
</tr>
<tr>
<td><strong>Brainstem:</strong> $D_{0.1 \text{cc}} \leq 54 \text{ Gy}$</td>
<td><strong>Brainstem:</strong> $D_{0.1 \text{ cc}} \leq 54 \text{ Gy}$</td>
</tr>
<tr>
<td><strong>Brain:</strong> N/A</td>
<td><strong>Brain:</strong> $D_{1 \text{ cc}} \leq 60 \text{ Gy}$</td>
</tr>
<tr>
<td><strong>Mandible:</strong> N/A</td>
<td><strong>Mandible:</strong> $D_{0.1 \text{ cc}} \leq 73.5 \text{ Gy}$</td>
</tr>
<tr>
<td><strong>Parotids:</strong> $D_{\text{mean}} \leq 20 \text{ Gy}$</td>
<td><strong>Parotids:</strong> $V (30 \text{ Gy}) \leq 50%$</td>
</tr>
<tr>
<td><strong>Larynx:</strong> $D_{\text{mean}} \leq 30 \text{ Gy}$</td>
<td><strong>Larynx:</strong> $V (50 \text{ Gy}) \leq 25%$</td>
</tr>
<tr>
<td><strong>Oral cavity:</strong> $D_{\text{mean}} \leq 20 \text{ Gy}$</td>
<td><strong>Oral cavity:</strong> $V_{\text{cc}} (66.5 \text{ Gy}) \leq 64 \text{ cc}$</td>
</tr>
<tr>
<td><strong>Esophagus:</strong> N/A</td>
<td><strong>Esophagus:</strong> $D_{1 \text{ cc}} \leq 45 \text{ Gy}$</td>
</tr>
<tr>
<td><strong>Brachial plexuses:</strong> N/A</td>
<td><strong>Brachial plexuses:</strong> $D_{0.1 \text{ cc}} \leq 60 \text{ Gy}$</td>
</tr>
<tr>
<td><strong>Inner ears:</strong> N/A</td>
<td><strong>Inner ears:</strong> $D_{\text{mean}} \leq 50 \text{ Gy}$</td>
</tr>
<tr>
<td><strong>Submandibular:</strong> $D_{\text{mean}} \leq 40 \text{ Gy}$</td>
<td><strong>Submandibular:</strong> N/A</td>
</tr>
</tbody>
</table>

RUMC KBP: Brain, mandible, esophagus, brachial plexuses and inner ears are disregarded; fixed goals are applied to submandibular.
Pinnacle³ Auto-Planning Engine (APE) Optimization algorithm iteratively adjusts users’ pre-set DVH objectives to meet or exceed sparing goals.
RUMC’s physician opinion for 25 pt’s plans:
• All APE and KBP plans are clinically-acceptable

Cord sparing $D_{0.1\,cc}$ in KBP is significantly better: 5.1 Gy lower.
Final thoughts

• DVH objectives estimated from KBP model are patient geometric specific.
  – Performance depends on quality of play library

• APE employs a user’s pre-set of generic coverage/sparing goals, which are protocol-specific.
  – Performance depends on the pre-set goals and robustness of the “iterative algorithm”

• Hybrid solution integrating KBP and APE
  – KBP provides individualized optimization goals to APE’s optimizer
  – APE’s iterative algorithm is used to further refine them