Automated Treatment Planning
Using a Database of Prior Patient Treatment Plans

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OncoSpace: An eScience program for the advancement of care in radiation oncology

- Objectives:
  - To develop an analytical database and infrastructure to store clinical information for personalized medicine and future analysis

- Project 1: Integration of Data Collection with Clinical Workflow
- Project 2: Database Design: Security and Distributed Web-Access
- Project 3: Tools for Query, Analysis, Navigation and Decision Support
- Project 4: Data Mining, Decision Support and Biostatistic Research,
Dose distributions are stored for each radiotherapy session. Each radiotherapy session is associated with a single patient representation. The transformation table stores the transformation between multiple patient representations enabling dose accumulation.

Regions of interest are stored as run-length encoded masks associated with each Patient Representation. Shape and shape relationship descriptors are stored for fast query of patient shape similarities.

Dose Volume Histograms are stored for each region of interest for fast query. DVH stored for both treatment summary and individual treatment sessions.

Personal Health Information is stored in a single table to facilitate anonymization.

Tumor information is stored including staging and image based RECIST assessment.

Chemotherapy, medications, and surgeries Patient History Toxidity and Outcomes.

Lab values

Oncospace Website

Grade 2 & 3

Influence of Shape

- Shape Characteristics
  - Volume
  - Positional relationships between structures
  - Separation of surfaces

- Shape Change in Time

- Influence
  - Plan quality (IMRT)
  - Ability to achieve Tx goal
  - Motion management
  - Toxicity

- Simplification of information without loss of relevance?
Use of ROI Shapes in Oncospace

Overlap Volume Histogram

DB of prior patients

OVH for similar patients to predict expected DVH

Decisions:
- Plan Quality Assess
- Automated IMRT
- Expected Toxicities
- Dosimetric Trade-offs

That was descriptive only

Actual computation is with a Euclidean Distance Transform Algorithm which is more efficient than the process described.

From a point to an organ
Which dose?
- Maximum dose?
- Dose to e.g. 50%
- DVH

Overlap Volume
Histogram describes distance from a (sub)volume to the PTV

50% volume
at 1.5 cm from PTV

An example of OVH

For parallel organs, OAR2 (red) is more easily spared.
For serial organs, OAR1 (blue) is more easily spared.

Comparison between 1L and 5L: 1L is an outlier
Re-plan results of patient 1

Original plan

Re-plan

Treatment Plan Quality Control (outlier detection): parotids

Clinical goal: Parotid: V(30Gy)<50% of volume

\[ DVH = T[OVH_L \cdot OVH_M \cdot OVH_H] \]

\[ DGy = T[d_L cm, d_M cm, d_H cm] \]

Detection rule: For covering the same percentage volume of the OAR, the larger the expanded distance is, the easier to spare the OAR.

Treatment Plan Quality Control (outlier detection): parotids
• Select the lowest achieved dose = prediction of what is achievable
• Lookup dose at 50% DVH for selected patients
• Select all patients for which the 50% was closer to the PTV
• Read OVHs of all prior patients
• Lookup distance PTV to 50% of the organ
• 26 re-plan patients, 17 are outliers, 9 non-outlier indicated by the OVH.
• V(30Gy) of 8 parotids among the 17 outlier parotids are reduced to below 50%!
• All 26 re-plans are reviewed by physician.

Predict dose minimal dose to e.g. 50% of organ
• Lookup distance PTV to 50% of the organ
• Read OVHs of all prior patients
• Select all patients for which the 50% was closer to the PTV
• Lookup dose at 50% DVH for selected patients
• Select the lowest achieved dose = prediction of what is achievable

OVH-based Prediction
• Comparing OVH
• Predicting DVH
• IMRT optimization
Use of SQL DB reduces search to an SQL query.

H&N Retrospective Planning Demonstration

- 15 random pts from a DB of 91 H&N pts for OVH-assisted planning demonstration
  IMRT-SIB: 58.1 Gy, 63 Gy and 70 Gy
- Dose objectives of 13 OARs queried from the DB as initial planning goals in a leave-one-out manner
- Dosimetry of 3 sets of plans were compared:
  - CP - Clinical plans
  - OP1 - OVH-assisted plans after 1 optimization
  - OP2 - Final OVH-assisted plans

15 pts: PTV comparisons among CP, OP1 and OP2

<table>
<thead>
<tr>
<th></th>
<th>CP</th>
<th>OP1</th>
<th>OP2</th>
<th>Wilcoxon p test</th>
</tr>
</thead>
<tbody>
<tr>
<td>PTV1</td>
<td>94.1</td>
<td>94.5</td>
<td>94.3</td>
<td>0.16 0.31 0.85</td>
</tr>
<tr>
<td>PTV2</td>
<td>97.1</td>
<td>97.9</td>
<td>98</td>
<td>0.34 0.24 0.6</td>
</tr>
<tr>
<td>PTV9</td>
<td>98.9</td>
<td>99</td>
<td>99.5</td>
<td>0.31 0.21 0.8</td>
</tr>
<tr>
<td>D95(D95)</td>
<td>16</td>
<td>13.9</td>
<td>13.7</td>
<td>0.24 0.34 0.85</td>
</tr>
</tbody>
</table>

PTV coverage and homogeneity were slightly better in both OPs; conformity was similar.
15 pts: OAR Sparing among CP, OP1 and OP2

<table>
<thead>
<tr>
<th>OAR</th>
<th>End point</th>
<th>CP</th>
<th>OP1</th>
<th>OP2</th>
<th>Wilcoxon p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>central nervous system</td>
<td>D(50Gy)</td>
<td>61.25</td>
<td>54.58</td>
<td>41.75</td>
<td>0.798</td>
</tr>
<tr>
<td>brainstem</td>
<td>D(50Gy)</td>
<td>54.58</td>
<td>54.58</td>
<td>54.58</td>
<td>0.798</td>
</tr>
<tr>
<td>inner ear (right)</td>
<td>D(50Gy)</td>
<td>57.18</td>
<td>63.74</td>
<td>63.74</td>
<td>0.798</td>
</tr>
<tr>
<td>contra-lateral parotid</td>
<td>D(50Gy)</td>
<td>57.18</td>
<td>63.74</td>
<td>63.74</td>
<td>0.798</td>
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<td>D(50Gy)</td>
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</tr>
</tbody>
</table>

Significantly lower in both OPs: cord4mm (~6 Gy), brainstem (~7.4 Gy) and contra-lateral parotid (~7%).

Re-plan results of patient 1

Patient 1 brain (Gy) | Brainstem (Gy) | Cord4mm (Gy) | L inner ear (Gy) |
--- | --- | --- | --- |
original 63.35 | 54.58 | 41.75 | 57.18 |
re-plan 56.33 | 54.58 | 37.89 | 43.72 |

Patient 1 R inner ear (Gy) | mandible (Gy) | larynx for edema | esophagus (Gy) |
--- | --- | --- | --- |
original 40.57 | 66.58 | 61% | 63.74 |
re-plan 38.38 | 63.78 | 59% | 61 |

Plan comparison: efficiency (15 plans)

Average number of optimization rounds per OP is 1.9; that number for a CP is 27.6; 3 OPs finished in a single round.
Prospective clinical trial study

Purpose: Explore the feasibility of the automated OVH planning tool in clinic.

Pt accrual: 40 Pts accrued from 7/10 – 12/10
(26 oropharynx; 9 larynx; 5 nasopharynx)

Protocol: Definitive IMRT to 70 Gy in 35 Fractions to GTV and 63 Gy and 58.1 Gy to high and low risk CTVs. Three PTVs for each pt: PTV58.1, PTV63 and PTV70

Volume distribution of 40 pts

PTV70: mean (173.4cc); median (130.78 cc); SD (153 cc).
PTV63: mean (363.5 cc); median (309.4 cc); SD (210.6 cc).
PTV58.1: mean (914.14 cc); median (922.72cc); SD (253.17cc)

Study work flow
2 plans generated for each Patient

CP: Clinical Plan manually created by dosimetrists (unaware of the study).
AP: Automated Plan plans are automatically generated by the proposed TPS.
Clinical planning is guided by Dr. Sanguineti and in-house dosimetric guidelines.
1 week of post-approval of CP, both AP and CP are blindly reviewed by Dr. Sanguineti. One of the plans is chosen as the better one.
Dosimetric Results: CP vs. AP

Primary OARs (optic nerve, chiasm, brainstem, brain, cord and mandible)
- AP: reduced by 1.14 Gy ($p=0.004$) overall

PTV coverage ($V_{95}$ in %)
- AP: increased by 0.26% ($p=0.02$) overall

Secondary OARs (parotid, brachial plexus, larynx, inner ear, oral mucosa, esophagus)
- AP: reduced by 1.16 Gy ($p=0.04$) overall

PTV homogeneity and conformity
- AP: significant better homogeneity in PTV63 ($p=0.002$)
  and PTV70 ($p < 0.0001$)
- AP: significant better conformity in PTV58.1 ($p=0.009$).

AP: fully automated plans
CP: clinical plans manually created by dosimetrists in their regular way.

Planning efficiency

AP: 2 optimization runs per plan (~23 minutes)
CP: ~40 (SD: 29) optimization runs per plan

Physician Preference

Dr. Sanguineti reviewed the isodose distributions and DVH curves without knowing the origins of the plans.

Based on his opinion,
- All APs (40/40) are clinically acceptable and can be used to treat patients
- 27/40 APs are clinically superior to the CPs
AP completed in 22.1 minutes

Both clinically acceptable; physician preferred CP due to less hot spots inside PTV70 although better organ sparing in AP

Dash curve: AP
Solid curve: CP

Pancreas example
Steven Petit

Mean kidney dose decrease 6 Gy!

Results: liver

- 25% constraint: 91% within 1 Gy  96% within 2 Gy
- 50% constraint: 86% within 1 Gy  100% within 2 Gy
- 65% constraint: 93% within 1 Gy  100% within 2 Gy

After replanning: decrease in mean dose = 10% [0 – 27%]
Results: Kidneys

- 25% constraint: 89% within 1 Gy, 100% within 2 Gy
- 50% constraint: 96% within 1 Gy, 96% within 2 Gy
- 75% constraint: 65% within 1 Gy, 87% within 2 Gy
- After replanning: decrease in mean dose = 17% (0 – 76%)

Does this really work? One modification

- Consider part of organ within beams-eye-view of the beams (+ margin)

Clinical Release
Joseph Moore

- Tool is easily adapted to any site
- Release for Pancreas first
- Standardization of ROI Names
- Standardization of technique to some extent
- Query DB for predicted dose level for each objective function
- Completed new plans push to DB
Summary

• Automated TPS without user intervention
  • OVH: retrieve geometrically “similar” pts
  • DB of prior plans: control plan quality of future plans

• Quality of new plans is independent of experience of planners; consistent with quality of prior plans in DB

• Clinical trade-offs made by physician are captured in the database

• Easily implemented to other disease sites (pancreas and prostate)

• Easily implemented to VMAT modality (used current DB for VMAT)

• Easily applied with any commercial TPS

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