Automated multi-objective treatment plan generation: experience in Erasmus MC

Ben Heijmen
Disclosures

This work is in part funded by research grants from Elekta AB, Stockholm, Sweden and Accuray Inc, Sunnyvale, USA.

Elekta AB is preparing commercialization of the Erasmus-iCycle approach of automated multi-objective planning.
Automated multi-objective treatment plan generation

Automated plan generation
Computer generates for each new patient 1 plan that is Pareto optimal and clinically favourable

Multi-objective plan generation
Each plan has clinically favourable balance between treatment objectives (according to the institution’s protocol, clinician’s preferences, ..).

head and neck patient, balance between
- PTV and parotid gland
- parotid gland and oral cavity
- etc.
Automated multi-objective treatment plan generation

Outline:

1. Erasmus-iCycle/Monaco for fully automated multi-criterial plan generation
2. Clinical validation: how good are automatically generated plans?
3. Future of automated planning in Erasmus MC
4. Summary/Conclusions
Sebastiaan Breedveld, PhD
Peter Voet, PhD

Erasmus-iCycle pioneers
automated multi-criterial treatment planning with Erasmus-iCycle/Monaco


Monaco: Elekta AB, Stockholm, Sweden
# Prostate wishlist

## Constraints

<table>
<thead>
<tr>
<th>Volume</th>
<th>Type</th>
<th>Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>PTV</td>
<td>max</td>
<td>104% of prescribed dose</td>
</tr>
<tr>
<td>PTV shell 50 mm</td>
<td>max</td>
<td>60% of prescribed dose</td>
</tr>
<tr>
<td>Unspecified tissue</td>
<td>max</td>
<td>104% of prescribed dose</td>
</tr>
<tr>
<td>Right + Left hip</td>
<td>max</td>
<td>40 Gy</td>
</tr>
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</table>

## Objectives

<table>
<thead>
<tr>
<th>Priority</th>
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<th>Goal</th>
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<tr>
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<td>PTV</td>
<td>↓LTCP</td>
<td>0.5</td>
</tr>
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<td>2</td>
<td>Rectum</td>
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<td>40% of prescribed dose</td>
</tr>
<tr>
<td>3</td>
<td>Rectum</td>
<td>↓gEUD (parameter 8)</td>
<td>25% of prescribed dose</td>
</tr>
<tr>
<td>4</td>
<td>Rectum</td>
<td>↓mean</td>
<td>33% of prescribed dose</td>
</tr>
<tr>
<td>5</td>
<td>External ring</td>
<td>↓max</td>
<td>40% of prescribed dose</td>
</tr>
<tr>
<td>6</td>
<td>PTV shell 5 mm</td>
<td>↓max</td>
<td>93% of prescribed dose</td>
</tr>
<tr>
<td>7</td>
<td>Anus</td>
<td>↓mean</td>
<td>10% of prescribed dose</td>
</tr>
<tr>
<td>8</td>
<td>PTV shell 15 mm</td>
<td>↓max</td>
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Shells are used for steering on conformality
OAR sparing versus conformality

0-46 plan:

difference between 2 plans
up to 8 Gy ...
.... 20 % NTCP
OAR sparing versus conformality

8 Gy difference in Oesophagus mean dose
For each treatment site the wishlist is a priori established

iterative procedure of Erasmus-iCycle plan generations/evaluations, followed by wishlist updates

- generation of initial wishlist based on review of recently delivered plans
- Erasmus-iCycle plan generation for limited set of patients based on current wishlist
- update wishlist based on review of generated plans
- final wishlist

Institutions can generate their own wishlists
Advantages of automated planning based on a wishlist:

- Optimization based on a wishlist is transparent and intuitive.
- The wishlist approach is flexible:
  - Apart from experience captured in previously generated plans, other sources of knowledge (e.g. literature or wishes of clinicians to do better than current practice) can be used for generation of wishlists.
  - The quality of automatically generated plans does not (only) depend on the quality of previously generated plans in a database, no direct use of previously generated plans.
  - After a change in treatment protocol, re-starting automated planning does not require extensive manual planning to first get a database of high quality plans (wish-list generation: 5-10 plans)
  - The same wishlist can be used for all modalities (VMAT, Cyberknife, protons, ..). For each modality a (different) optimal plan will be generated.
  - Institutions can easily exchange wish-lists to compare plan quality (a wish-list is only a text file)
main features of Erasmus-iCycle/Monaco:

- developed for **fully automated** IMRT/VMAT plan generation (currently also Cyberknife and protons).

- Erasmus-iCycle has **multi-objective** plan generation
  - Pareto navigation is implicit, based on objective priorities
  - based on lexicographic optimization with **wishlist**
  - per patient, a single plan is generated which is Pareto-optimal, clinically favourable and clinically deliverable.
  - the most important objectives automatically get highest priority
  - 1 wishlist per patient group

- OAR doses automatically get as low as feasible, also lower than prescribed. High priority objectives have preference.

- beam profile and beam angle optimization
main features of Erasmus-iCycle/Monaco:

- Erasmus-iCycle generates plan which is mimicked in Monaco to generate a clinically deliverable plan.
- due to automation
  - no trial-and-error tweaking of TPS parameters for individual patients
  - result is operator independent
  - huge reduction in workload
- Erasmus-iCycle/Monaco can be used for unbiased comparisons of treatment techniques (non-coplanar beam arrangement, more beams, protons, Cyberknife, …, ) using the same wishlist.
- Erasmus-iCycle/Monaco is very hard to beat by human planners.
Automated multi-objective treatment plan generation

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How good is automated planning compared to ‘manual’ planning? Head and Neck cancer

In 97% of cases autoplan selected by treating physician

Physics Contribution

Toward Fully Automated Multicriterial Plan Generation: A Prospective Clinical Study

Peter W.J. Voet, RTT, Maarten L.P. Dirkx, PhD, Sebastiaan Breedveld, MSc, Dennie Fransen, RTT, Peter C. Levendag, MD, PhD, and Ben J.M. Heijmen, PhD

Department of Radiation Oncology, Erasmus Medical Center—Daniel den Hoed Cancer Center, Groene Hilledijk 301, Rotterdam 3075EA, The Netherlands

Received Jan 24, 2012, and in revised form Mar 27, 2012. Accepted for publication Apr 10, 2012

How good is automated planning compared to ‘manual’ planning?

Prostate cancer, Rotterdam experience

- quality autoVMAT similar to manVMAT by an expert planner in absence of time constraints (optimistic non-clinical condition)
- autoVMAT: vast reduction in workload

Physics Contribution

**Fully Automated Volumetric Modulated Arc Therapy Plan Generation for Prostate Cancer Patients**

Peter W.J. Voet, RTT, Maarten L.P. Dirxk, PhD, Sebastiaan Breedveld, PhD, Abrahim Al-Mamgani, MD, PhD, Luca Incrocci, MD, PhD, and Ben J.M. Heijmen, PhD

Department of Radiation Oncology, Erasmus MC—Daniel den Hoed Cancer Center, Rotterdam, The Netherlands

Received Sep 19, 2013, and in revised form Dec 10, 2013. Accepted for publication Dec 28, 2013.
How good is automated planning compared to ‘manual’ planning?

Prostate cancer, International validation study:

Florence
Leeds
Mannheim
Vienna

manuscript in preparation, oral presentation ESTRO 2016, Torino
Study protocol:

For each center:

- Include plans of 30 recently treated patients (manual VMAT planning)
- 10 patients used for wishlist generation according to center’s local treatment approach
- For other 20 patients: generate AUTOVMAT plan
- Tasks physician for these 20 patients:
  - compare 20x2 plans: which is better CLINICAL or AUTO?
- All plan evaluations/comparisons in Monaco, in the center.
- In 38% of cases, the AUTO plan was better with a high clinical impact.
- Only in 9% of cases the CLIN plan was better with a high impact; 2 cases because of small bowel which was not in the wishlist, 1 case because of instability in Monaco.
- In 72% of cases, AUTO plan quality was higher than or similar to CLIN plan quality.
Solid = auto

rectum

bladder

PTV
How good is automated planning compared to ‘manual’ planning?

advanced stage lung cancer

Study design

41 CT-scans of previously treated patients

Compare:

VMAT plan, automatically generated with Erasmus-iCycle/Monaco

with

1. Clinical IMRT plan, manually generated with Monaco
2. Manually generated VMAT plan

Courtesy Giuseppe della Gala, manuscript in preparation, oral presentation ESTRO 2016, Torino
Automated planning for advanced lung cancer

![Graphs showing comparison between Clinical and AutoVMAT plans for various metrics such as MLD (Gy), Lungs V5 x0.1, Lungs V20 x0.1, PTV D99 x0.5, PTV V95 (%), Esophagus mean dose (Gy), Heart mean dose (Gy), and Conformity Index (HI x10) with Homogeneity Index (HI) with p-values.]

Courtesy Giuseppe della Gala
Automated planning for advanced lung cancer

- 85% of autoplans clinically acceptable
- Fixing of remaining 15%: 10 min.
- Clinicians: all acceptable autoplans superior to clinical plans
- PTV underdosage: 11/41 clinical plans; dose escalation with auto planning:

<table>
<thead>
<tr>
<th></th>
<th>clinical</th>
<th>auto</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 pts</td>
<td>45 Gy</td>
<td>55 Gy</td>
</tr>
<tr>
<td>1 pt</td>
<td>55 Gy</td>
<td>60 Gy</td>
</tr>
<tr>
<td>2 pts</td>
<td>60 Gy</td>
<td>66 Gy</td>
</tr>
<tr>
<td>1 pt</td>
<td>60.5 Gy</td>
<td>66 Gy</td>
</tr>
</tbody>
</table>

- Manual VMAT planning: ~4 hours

Courtesy Giuseppe della Gala
How good is automated planning compared to ‘manual’ planning?

cervical cancer

Study design

44 CT-scans of previously treated cervical cancer patients

Compare:

autoVMAT

with

- manVMAT expert planner, no time pressure
- autoIMRT: 20 beams
- CLINICAL: 9 field IMRT

Courtesy Abdul Sharfo, manuscript submitted
Results cervical cancer
Table 3. Measured treatment delivery times for autoVMAT and autoIMRT using the MLCi2 and Agility MLCs.

<table>
<thead>
<tr>
<th>Planning Technique</th>
<th>Patient</th>
<th>MLCi2 Treatment Delivery Time (min)</th>
<th>Agility Treatment Delivery Time (min)</th>
<th>Difference (min/%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>autoVMAT</td>
<td>Pt 1</td>
<td>4.5</td>
<td>2.9</td>
<td>1.6 / 35.6</td>
</tr>
<tr>
<td></td>
<td>Pt 2</td>
<td>3.8</td>
<td>2.7</td>
<td>1.1 / 28.9</td>
</tr>
<tr>
<td></td>
<td>Pt 3</td>
<td>4.1</td>
<td>3.2</td>
<td>0.9 / 22.0</td>
</tr>
<tr>
<td></td>
<td>Pt 4</td>
<td>4.4</td>
<td>3.1</td>
<td>1.3 / 29.5</td>
</tr>
<tr>
<td></td>
<td>Pt 5</td>
<td>3.9</td>
<td>2.6</td>
<td>1.3 / 33.3</td>
</tr>
<tr>
<td><strong>Mean</strong></td>
<td></td>
<td>4.1</td>
<td>2.9</td>
<td>1.2 / 29.9</td>
</tr>
</tbody>
</table>

| autoIMRT           | Pt 1    | 15.0                               | 9.8                                 | 5.2 / 34.7        |
|                    | Pt 2    | 17.6                               | 9.5                                 | 8.1 / 46.0        |
|                    | Pt 3    | 14.0                               | 7.9                                 | 6.1 / 43.6        |
|                    | Pt 4    | 17.5                               | 10.4                                | 7.1 / 40.6        |
|                    | Pt 5    | 14.1                               | 7.8                                 | 6.3 / 44.7        |
| **Mean**           |         | **15.6**                           | **9.1**                             | **6.6 / 41.9**    |

Courtesy Abdul Sharfo, manuscript submitted
Conclusions for cervical cancer

**With automated planning:**

- Higher plan quality compared to an expert planner in absence of time constraints (optimistic non-clinical condition).
- **ALWAYS**: vast reduction in workload
Automated planning currently applied for plan-library-based ‘plan-of-the-day’ ART: 2-3 VMAT plans per patient.
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LRPM: a fast lexicographic multi-objective optimiser for automated treatment planning

Rens van Haveren, Ben Heijmen, Wlodzimierz Ogryczak and Sebastiaan Breedveld

1Dep. of Radiation Oncology, Erasmus MC Cancer Institute, Rotterdam, The Netherlands
2Institute of Control & Computation Engineering, Warsaw University of Technology, Poland

Evaluation of Fast and Fuzzy Hierarchical Decision-Making for Automated Multi-Criterial Treatment Planning (AMTP) for Head-and-Neck Cancer

Sebastiaan Breedveld, Rens van Haveren, Wlodzimierz Ogryczak and Ben Heijmen

1Dep. of Radiation Oncology, Erasmus MC Cancer Institute, Rotterdam, The Netherlands
2Institute of Control & Computation Engineering, Warsaw University of Technology, Poland
Prostate SBRT at Cyberknife

Courtesy Linda Rossi
Dear Ms. Rossi,

The abstract review committee for ESTRO 35, to be held in Turin, Italy from 29 April-3 May 2016, has now finalised the abstract review and selection for this conference.

We are pleased to inform you that your abstract **Fully automated planning for non-coplanar CyberKnife prostate SBRT - comparison with automatic VMAT** with first (presenting author) L. Rossi 1, S. Breedveld 1, S. Aluwini 1, B. Heijmen 1 has been accepted for presentation as an oral communication in the Proffered Papers Physics 7: Treatment planning: optimization algorithms. This session will be held on 01/05/16 from 10:45 to 11:45. You will have 10 minutes for your presentation, discussion time included. Please do strictly respect the timing.
Dear Mr. Sharfo,

The abstract review committee for ESTRO 35, to be held in Turin, Italy from 29 April-3 May 2016, has now finalised the abstract review and selection for this conference.

We are pleased to inform you that your abstract **VMAT plus few optimized non-coplanar IMRT beams is equivalent to multi-beam non-coplanar liver SBRT** with first (presenting author) **A.W.M. Sharfo**, M.L.P. Dirx, S. Breedveld, A.M. Mendez Romero, B.J.M. Heijmen has been accepted for presentation as an oral communication in the Proffered Papers Physics 7: Treatment planning: optimization algorithms. This session will be held on 01/05/16 from 10:45 to 11:45. You will have 10 minutes for your presentation, discussion time included. Please do strictly respect the timing.

**ABSTRACT NUMBER**

Your abstract number is 535.1220. Should you need to contact the ESTRO Office with further details, please do not hesitate to do so.
Near real-time dose restoration in IMPT to compensate for tissue density variations

Thyrza Jagt†, Sebastiaan Breedveld, Steven van de Water, Ben Heijmen, Mischa Hoogeman
Dept. of Radiation Oncology, Erasmus MC Cancer Institute, Rotterdam, The Netherlands.
Model-based selection for proton therapy

protons

photons

Courtesy T. Aerts, S. Breedveld, M. Hoogeman
Automated multi-objective treatment plan generation

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Conclusions/Summary

- Compared to ‘manual’ planning, automated planning with Erasmus-iCycle/Monaco
  - has higher or non-inferior plan quality
  - plan quality is not operator dependent
  - plan quality is not dependent on allotted time in a busy clinic
  - has negligible workload

- Automated planning is in Rotterdam in **routine clinical use** for prostate cancer, head-and-neck cancer, and cervical cancer, being introduced for lung cancer, studied for liver SBRT, breast cancer, lymphoma, vestibular schwannoma and prostate SBRT (Cyberknife)

- From January 2015 till October 2015 ~ 600 patients were treated with an autoplan.

- Future developments: more patient groups, VMAT+NC, Cyberknife, protons, speed enhancement, (semi)-automated wishlist generation, fast on-line re-planning, MR-linac, …