Proton Therapy Workflow
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Disclaimer:
I have no financial interest in any vendor of radiotherapy hardware, software, or otherwise
A brief history of photon therapy

**Then**
- Four field box
- Historical margins
- Lasers + X-ray
- Paperwork
- 1 plan
- Long-term follow-up

**Now**
- IMRT, VMAT, RapidArc
- Error analysis -> margins
- CBCT
- Treatment chain integration
- Adaptive therapy
- In-vivo dosimetry + long-term follow-up

Closed loop
Closed Loop: Check and Correct

Check Delivery

Check Anatomy

Treatment plan
The **Promises** and the **Peril**

The Promises:
- Lower upstream dose
- No downstream dose

The Peril:
- Finite Range !!!

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**Protons: Spread-out Bragg Peak**

**Protons: Pristine Bragg Peak**

**Beam Direction**

**Dose (%)**

**Depth (cm)**
Dose degradation in proton therapy

Proton therapy needs to:
- Detect potential severe dose degradation
- Allow effective treatment plan adaptation

Not all patients!
The workflow challenge
Patient intake
Patient referral

- **Standard indications**
  - Children
  - Intra-ocular
  - Base of skull

- **Other indications**
  - Head and neck
  - Prostate
  - Breast
  - Lung
  - Sarcoma
  - Pancreas
  - Liver
  - Etc

We want to / will treat everything...

...using adaptive (Intensity modulated) Proton Therapy!

<table>
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<tr>
<th>Indication</th>
<th>CMS</th>
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Clinical reality

Data part of a workflow survey of 12 US-based proton therapy centers

- Passive-scattering: 75%
- PBS-SFUD: 22%
- IMPT: 3%
Hospital-based or not?

- **Stand-alone**: 58%
- **Separate building**: 25%
- **Embedded**: 17%
### Facility layout

#### Gantries

- 1

#### Fixed beam

- 0

### Number of treatment rooms vs. (a.u.)

<table>
<thead>
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<th>Number of Treatment Rooms</th>
<th>Gantries</th>
<th>Fixed beam</th>
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</table>

Typically, Pediatric patients, and sometimes SBRT patients, will get priority for beam usage as these are challenging cases.

Although some systems allow prioritization of beam requests, in other cases the rooms will coordinate by means of intercom. Or one can simply wait, beam delivery time is typically acceptable, room switching is improving. (Only) large PBS fields in a slow scanning solution provide a real challenge.

No advanced scheduling system yet in clinical use, though (some) vendors are actively working on it and promising it to new customers.

Some

Some

None

Some

Some

Some

Some

Some

None

None

Only one center with more than two rooms claims no interplay effect.
Treatment planning
Treatment planning workflow
Fields per treatment course

- Pediatric
- Intra-cranial
- Gastro
- Prostate
- Head and neck
- Thoracic
- SBRT

# Fields
Treatment planning effort

Patients planned per FTE dosimetrist

<p>| | |</p>
<table>
<thead>
<tr>
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<tr>
<td>Photons</td>
<td>200 – 300</td>
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<tr>
<td>Protons</td>
<td>60 – 110</td>
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</table>

Do I need photon back up planning?
Treatment Planning

• Commercially available TPS
  – CMS XiO
  – Varian Eclipse
  – Raysearch Raystation
  – Philips Pinnacle
  – (Astroid)

Tools to look for to make life easier

• Auto-patching and auto-matching
• Dose accumulation and deformation
• Scripting / auto-planning
• Multi-criteria optimization (MCO)
• Re-painting strategies
Signatures

- Treatment plan
- Calibration
- Setup image
- Field

<table>
<thead>
<tr>
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<tr>
<td>Physician</td>
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<tr>
<td>Physicist</td>
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<td>Dosimetrist</td>
<td>67</td>
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<tr>
<td>Therapist</td>
<td>17</td>
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</table>

- 0%
- 25%
- 50%
- 75%
- 100%
Integration / connectivity

TPS → OIS → TDS → Patient

Integration / connectivity

TPS

OIS

TDS

Patient

Delineation

Treatment Planning

OIS

TDS

Setup verification

Velocity (3)

Elekta XiO (4)

Raystation (2)

Varian Eclipse (7)

In-House (1)

In-House (2)

Mimvista (4)

In-House (1)

In-House (2)

Velocity (3)

Mimvista (4)

In-House (1)

Next to using the TPS itself

Very few users for each package / combination
OIS and connectivity
Integration status

“Are you happy about the electronic integration between TPS, OIS and TDS?”

For a not yet too difficult treatment / workflow:

• “The integration between TPS and OIS is acceptable. The challenge is mainly in the communication between OIS and TDS.”

• “We do a lot of in-house manipulations to make our OIS work with protons.”

• “There is no integration whatsoever.”

• “No way this system can be integrated.”
Image-guidance
IGRT and ART, until now

• State of the art
  – Daily Orthogonal X-rays (plus some off-line imaging)

• Auxiliary positioning systems
  – Ultrasound
  – VisionRT
  – Fiducial markers
  – Electromagnetic Transponder Tracking

• Treatment adaptation
  – Off-line CT
  – Slow adaptation -> TPS vendors picking up the pace

• Remote positioning
  • E.g. Fava et al. Radiother Oncol.103, p.18, “In-gantry or remote patient positioning? Monte Carlo simulations for proton therapy centers of different sizes.”
Orthogonal X-ray alignment

Pro
• On-line setup protocol
• 6-DOF setup correction

Con
• Time-consuming
• Intra-operator variability
• Rotations are difficult
• No treatment adaptation

• Dose degradation remains unknown!

Aligning the tumor is not even half the solution!
Cone-beam CT at isocenter (photons, 2009)

Room entrance to first “beam-on”:
6 minutes +
VMAT / RapidArc
4 minutes =
10 minute fraction

Slide courtesy of J-J. Sonke, NKI
Fraction times in proton therapy (2014)
Frequency of setup verification

<table>
<thead>
<tr>
<th>Category</th>
<th>Every field (%)</th>
<th>Every fraction (%)</th>
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<td>H&amp;N</td>
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<td>Thoracic</td>
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<td>SBRT</td>
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Every field

Every fraction
3D in-room imaging

- Volumetric matching
- Visualize anatomy changes
  - Dose recalculation

Need for decision protocols and software to (semi-)automate these

Having on-line 3D imaging is not even half the solution!
Treatment adaptation
Repeat CT: Examples of clinical application

- Adaptive IMPT at MD Anderson
- Weekly repeat CT and recalculation
- 9/34 patients had to be replanned
- In two cases to ensure OAR sparing
- 3 days to start of new plan

Chang et al. IJROBP2014, p.809

IMPT vs IMRT
MLD reduction: 4.4 Gy

IMPT vs PSPT
MLD reduction: 4.3 Gy
Esophagus V65: 3% vs 10%

Esoph 60 Gy
Clinical reality: Adaptive proton therapy

On average: 75% never or once

On average: 85% never or once
Adaptive Therapy Vision (2013 PTCOG)

• **0 years**
  – Off-line, next 2-3 days

• **5 years**
  – On-line evaluation of plan adequacy and choice of plan of the day

• **10 years**
  – 10 second automated on-line plan re-optimization
Example: online adaptive PT

1. Create treatment plan library using *individualized* motion model and/or variable *plan robustness*

2. Daily plan selection on the basis of *in-room CT* scanning plus *dose-recalculation*

Fast on-line dose recalculation is at the moment proton therapy’s best bet for validating continued plan adequacy!
Clinical reality: Moving tumors

- Margins: 100%
- Breath-hold: 50%
- Gating: 8.3%
- Repainting: 8.3%
The other workflow

Not patient-specific but indication specific
The balance in proton therapy

Margins
- Range error
- Setup error
- Number and direction of beams
- Use of ITV
- Dual-Energy CT
- …

IGART
- Frequency of imaging
- Kind of imaging (X-ray, CBCT, in-room CT
- Plan of the day
- Prompt-gamma imaging
- …

What we need

4D error simulation platform for do-it-yourself analysis.
Rescanning variables

- Spot size
- Lateral spot overlap
- Distal spot overlap
- Volumetric or layer repainting
- Number of rescans
- Number of treatment fractions
- Number of beams in the plan
- Simultaneous gating or breath-hold
- Iso-layer or scaled-rescanning
- Spot-, line- or contour-scanning
- Uniform, phase-controlled, random, time-delay, …
- Layer changing time (vendor dependent)
- Re-image and re-plan approach
- …

Different answer for:
- Each indication?
- Each patient?
Quality Assurance
Dosimetric quality assurance

- Extent depends on:
  - Facility layout (e.g. # rooms)
  - Your beamline(s) (e.g. PSPT, universal nozzle, PBS)
  - Patient mix (gating, tracking, …)
  - Experience
  - Patient specific?

- No standard approaches (yet)
  - QA tools and QA program
  - Technically demanding (who can do it)

- Night-time and morning work

Imaging QA to 1st order similar to photon therapy
**QA time needed:**

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<th>Time</th>
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<td>Daily</td>
<td>10 – 30 minutes per room</td>
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<tr>
<td>Weekly</td>
<td>5 hours per week</td>
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<td>Monthly</td>
<td>5 – 25 hours per month</td>
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<td>Modality switch</td>
<td>Followed by daily QA</td>
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<td>Fields: Hardware (PSPT)</td>
<td>0.5 – 1.0 FTE</td>
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<tr>
<td>Fields: Dosimetric</td>
<td><strong>5 – 15 hours per week</strong></td>
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Overall QA time in % of yearly clinical operational hours:

- **Photons:** 10%
- **Protons:** 20%

60% of PSPT
100% of PBS
Facility start-up
Indications treated

![Bar chart showing the percentage of patients treated for different types of cancer over four years.](chart.png)

- **1st year**:
  - Prostate: 100%
  - Pediatric: 100%
  - Head and neck: 50%
  - Sarcomas: 40%
  - Gastro-intestinal: 50%
  - Lung: 50%
  - Pelvis: 50%
  - Breast: 50%

- **2nd year**:
  - Prostate: 75%
  - Pediatric: 25%
  - Head and neck: 50%
  - Sarcomas: 50%
  - Gastro-intestinal: 25%
  - Lung: 50%
  - Pelvis: 50%
  - Breast: 50%

- **3rd year**:
  - Prostate: 25%
  - Pediatric: 50%
  - Head and neck: 50%
  - Sarcomas: 50%
  - Gastro-intestinal: 25%
  - Lung: 50%
  - Pelvis: 50%
  - Breast: 50%

- **4th year**:
  - Prostate: 20%
  - Pediatric: 50%
  - Head and neck: 50%
  - Sarcomas: 50%
  - Gastro-intestinal: 25%
  - Lung: 50%
  - Pelvis: 50%
  - Breast: 50%
Staffing (for 500 patients per year)

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Closed Loop: Check and Correct

- **Check Delivery**
  - In-vivo dosimetry

- **Check Dose**
  - Dose recalculation

- **Check Anatomy**
  - Best possible imaging

- **Treatment plan**
  - Improved treatment plan design
The workflow challenge

General patient complexity

Need for IGART

Technology Status

Photons

Protons

Palliative

Curative

(a.u.)

(a.u.)

(a.u.)
Conclusions

Quality, integration and efficiency of proton therapy

- More and better tools
- More and better use
- More patient benefit

We are here
Thank you

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