Image Guided Proton Therapy and Treatment Adaptation
Cancer in The Netherlands

- About 1 in 3 people get cancer in some stage of their life
- 86,800 new cancer patients per year in 2007
- Aging population: 123,000 new patients expected in 2020, rising by 1% - 2% per year until 2040
- About half of all treatments involve a form of radiotherapy
- About 52% of patients still live 10 years after diagnosis

PS: about 30% of all cancer deaths are due to smoking
HollandPTC R&D Program

Three main areas of research

1. Prove clinical value of proton therapy
2. High-precision proton therapy
3. Biology-driven proton therapy
Photon radiotherapy

Modern radiotherapy linacs allow irradiation from multiple angles using beams with varying shapes and intensity profiles, to maximize the tumor dose while minimizing the dose to healthy tissues.
The radiotherapy challenge

Killing all tumor cells without causing irreparable damage to healthy tissues

Different cell types have different radiosensitivity

Paradigm 1: Fractionation

Making use of the difference in repair capability of cancerous and healthy cells.

Different cell types have different repair capability.
Paradigm 2: Geometric accuracy

Aiming to deliver dose to tumor cells only

Intensity-modulated radiotherapy (IMRT) plan

Proton therapy plan
Pencil beam scanning
Protons: high-precision therapy...?

Rietzel et al. IJROBP 2005: 1535


Engelsman et al. Sem Rad Onc 2013:
Organ and tumor motion

Examples of inter-fraction (left) and intra-fraction (right) target motion
Image-guided radiotherapy

Radiotherapy Department, University Hospital Dresden

e^-linac
MV cone beam CT
kV X-ray position control, fluoroscopy

IR movement tracking
In-room CT on rails

Radiotherapy J. Distler, Bautzen
Image-guided particle therapy

The state of the art (2014)

Orthogonal planar X-ray imaging

Things start to improve (2014):

→ CBCT in gantry

→ in-room CT

OncoRay

Courtesy: W. Enghardt, Oncoray
Advanced in-room imaging to update 4D digital patient model

Online treatment adaptation to match present 4D digital patient model and updated treatment objectives

Real-time image-guided 4D dose delivery and verification

Image-guided online-adaptive proton therapy

Motion tracking

CT

Robot

PT

In-vivo QA

Real-time dose reconstruction

Time = 7 weeks

Time = 30 seconds
Secondary gamma radiation

Human body > 90% Oxygen, Carbon, Hydrogen and Nitrogen

Positron emitters:

Prompt gamma rays:
In-situ PET

P.C. Lopes et al, “First in-situ TOF-PET study using DPCs for proton range verification,” PMB 61, 6203-6230, 2016

2-minute PET acquisitions starting right after irradiation
Prompt gamma-ray imaging

Dr. Eelco Lens (TU Delft), ADAPTNOW project
How to use prompt gamma’s clinically?

Monte Carlo simulations of realistic patient cases

Patient #

Plan

Planning CT

Repeat CT 1

Repeat CT 2

…

Repeat CT #

Planned dose

MC

Planning CT

Simulated dose
Results – correlations dose vs. PG

\[ V_{95\%} \text{PTV}_{\text{high}} \text{ vs. median } |\Delta X_{50}| \]

- Varying correlation strength
- Varying linear relations

=> it’s a start!
Soft robotics for positioning

Kinematic Pillow: Precise and adaptable yet comfortable patient positioning

Current radiation therapy head mask

Artist impression of envisioned ‘kinematic pillow’ head support system.

From: Just herder et al (TU Delft)
Importance of Treatment Planning

- Conforming the physical dose spatial distribution.
- Handling anatomy changes, quantifying uncertainties.
- Robust optimization for proton treatments [2].

Underdosage probability in a non-robust plan [1]
Getting it together
Holland Proton Therapy Centre

Research-driven proton therapy

Clinically-driven research & development

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Thank You