De Oosterpoort, Groningen
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Focus Session: Physics & Health

Programme:

- Christian Hammer (UMCG): Introduction of Proton Therapy in the Netherlands – The concept of the model-based approach
- Emiel van der Graaf (KVI): Advanced X-ray CT and proton imaging for proton therapy
- Dennis Schaart (TUD): Online treatment verification in proton therapy: how to visualize a particle beam in vivo?
- Mischa Hoogeman (Erasmus MC / HollandPTC): Treatment planning in proton therapy

Session leaders: Sytze Brandenburg (RUG)

Abstracts:

Christian Hammer (UMCG): Introduction of Proton Therapy in the Netherlands – The concept of the model-based approach

Background:

The main advantage of proton therapy (PT) over other types of external beam radiotherapy (EBRT) is that charged particles allow the dose to be deposited over a narrow range and with a minimal exit dose. The question is how to translate these superior beam properties into clinical benefits. The randomized controlled trial (RCT) is still regarded as the gold standard for evidence based medicine. However, RCT's are mostly not suitable or feasible for testing new technologies, so alternative evidence-based methods are needed and available.

The model-based approach:

With the model-based approach, the 3-dimensional dose distributions in a variety of organs-at-risk are translated in toxicity risk profiles using Normal Tissue Complication Probability (NTCP) models, i.e., prediction models that describe the relationship between dose and the risk of toxicities. By comparing treatment plans made for photons and protons, delta-dose and delta-toxicity profiles can be created. These delta-toxicity profiles can then be used to determine which patients are expected to benefit the most from protons and can thus be used for decision-making. Four steps are needed for this approach, including: 1. Development of a normal tissue complication probability model (NTCP-model); 2. Individual dose comparisons protons versus photons; 3. An estimation of the delta toxicity profile; 4: External validation of the NTCP-model with PT follow-up data.

Conclusions:

The model-based approach is an evidence based alternative for RCT's for new radiation technologies that are primarily aiming at reduction of side effects. This approach will be used in the Netherlands for the selection of patients for PT and has been accepted by the health authorities.

Emiel van der Graaf (KVI): Advanced X-ray CT and proton imaging for proton therapy

The agreement between the actual and planned dose distributions in proton therapy critically depends on accurate knowledge of the proton stopping in the irradiated tissues. The standard clinical practice is to convert Single Energy Computed Tomography (SECT) information on photon attenuation into proton stopping information. In this conversion a generic (non patient specific) calibration curve is used

that directly relates CT numbers (quantifying photon attenuation) to proton stopping powers (proton energy loss per distance). The current uncertainty in the proton range caused by the uncertainties of the stopping powers deduced from CT-images amounts up to about 3 %, i.e. 3 – 6 mm, depending on the complexity of the tumour surroundings. This uncertainty imposes constraints on the treatment planning process (e.g. limitation of possible fields due to critical organs, sub-optimal reduction of dose in healthy tissue).

A more advanced X-ray imaging technique like Dual Energy CT (DECT) produces images at two (effective) X-ray energies. These images in combination with a physical model of the photon-tissue interaction allow extraction of tissue electron density and effective atomic number. These parameters can be used to estimate proton stopping powers that are patient specific. DECT scanners are increasingly used in the clinical practice and it is likely that in the near future proton therapy planning will be DECT-based.

Multi-energy CT (spectral CT), proton radiography and proton CT are emerging imaging techniques that may potentially contribute to decrease range uncertainties but are further away from clinical application. The use of protons for imaging is especially attractive as proton stopping powers are obtained directly without the need to convert photon attenuation to proton stopping information. This makes proton imaging less prone to artefacts e.g. by metal implants, than photon imaging.

Dennis Schaart (TUD): Online treatment verification in proton therapy: how to visualize a particle beam in vivo?

The physics of interaction of charged particles, such as protons, appear to be better suited for radiotherapy than those of photons. Especially with state of the art pencil-beam scanning systems, a field of very high dose can be "painted" inside the target volume, in principle reducing the dose to healthy tissues in comparison to external beam photon therapy. However, the characteristic dose profile, with a sharp dose falloff behind the so-called Bragg peak, also makes this form of treatment sensitive to deviations from the treatment plan. Examples of such deviations are patient setup errors, inter-fraction anatomical changes, intra-fraction organ motion, and range uncertainty. These phenomena may, if not adequately dealt with, result in severe overdosing to healthy tissues and/or underdosing in the tumor. In external beam photon therapy, anatomical image guidance has developed to a point where highly conformal dose distributions are applied routinely in the clinic. Indeed, online imaging modalities such as cone-beam CT and in-room CT are also becoming available in proton therapy facilities. In principle this enables the development of highly accurate treatment approaches. However, these anatomical imaging modalities do not provide direct information about the actual trajectories of the therapeutic particles within the body of the patient. Fortunately, imaging of the secondary gamma radiation created in proton-nuclear reactions along the beam trajectory within the patient can provide a means for performing online, in-vivo verification of the delivered dose. These reactions produce prompt gamma rays as well as positron emitters, which in turn give rise to the emission of annihilation photon pairs. This presentation discusses how these effects can be used for online treatment in proton therapy. Attention is also paid to the challenges that still lay ahead in turning the proposed methods into reliable clinical tools.

Mischa Hoogeman (Erasmus MC / HollandPTC): Treatment planning in proton therapy

A highly promising approach for treatment of cancer patients with radiation is Intensity Modulated Proton Therapy (IMPT), which is a new and most advanced form of proton therapy. The use of protons to irradiate the tumor has some distinct advantages over using photons. When a high-energy proton beam enters the patient's body it deposits only a small dose along its path. The absorbed dose increases gradually with greater depth and rises to a greatly localized dose peak in the tumor. This peak is known as the Bragg peak. In this context, IMPT has a unique potential to spare healthy tissues. However, the highly localized dose deposition makes proton therapy and IMPT in particular, very sensitive to often observed daily variations in patient setup and uncertainties in the conversion from CT number to relative stopping power. This will, if not adequately dealt with, cause severe overdose to healthy tissues and/or underdose to the tumor.

The current practice in proton therapy is to generate a personalized treatment plan based on a single snapshot of the patient's anatomy (planning CT scan) containing the machine control settings for the delivery of a curative dose to the target while sparing surrounding healthy tissues. Those settings are calculated following a mathematical optimization, balancing the treatment goals as specified by the physician regarding target prescription dose and tolerable doses to healthy tissues. In addition, the treatment plan is made robust against unavoidable uncertainties in dose delivery by including error scenarios in the optimization.

This presentation gives an introduction to treatment planning for proton therapy. In particular, the problem of robust optimization will be addressed and how it impacts the dose received by the target under dose delivery uncertainties and how it impacts the dose to the healthy tissues.