ADAPTIVE RADIATION THERAPY IN RAYSTATION

During radiation therapy treatments, the patient’s anatomical state is not static. Many different factors contribute to a shifting picture, such as breathing, the presence of non-rigid, gas-filled or liquid-filled structures, weight changes, and changes in gross tumor volume or clinical target volume to name just a few.

Adaptive radiation therapy is a treatment approach that uses frequent imaging to compensate for anatomical differences that occur during the course of treatment. Images are taken daily, or almost daily. When significant changes are observed, replanning is considered.

Naturally, the treatment planning system will have a critical role in this approach. RaySearch has collaborated with leading cancer centers worldwide, such as Princess Margaret Hospital in Toronto, Canada, to pioneer adaptive planning. As a result, the RayStation® treatment planning system is specifically designed to make adaptive therapy faster and easier in clinical practice. It includes modules for dose tracking and adaptive replanning, as described below.

DOSE TRACKING

The dose tracking module in RayStation makes it possible to determine the dose actually delivered to the patient. There are many benefits to this, such as the ability to ensure more accurate margins. Traditionally, a generic margin is applied to account for changes in patient geometry and positioning during treatment. However, these margins may not be appropriate for all patients, limiting the possibility of dose escalation or, conversely, resulting in unwanted dose to nearby organs at risk (OAR).

Most clinics today use image-guided radiotherapy. During treatment, fraction images such as cone beam CTs are taken on a regular basis for patient positioning, and sometimes to identify anatomical changes during the course of the treatment. However, these images do not give the clinician sufficient data for a decision on the need for adaptive planning. Dose tracking is a key tool in achieving the ultimate goal of adaptive therapy: treating the disease to the prescribed dose without causing harm.

Figure 1: Dose escalation in bladder.

Data courtesy of INSERM, Rennes.
DOSE CALCULATION BASED ON CBCT
With RayStation, the cone beam CTs can be used for more than just positioning. Once the image sets are fused, the beam setups from the plan can be applied to the fraction image, and the actual delivered dose can be computed. Deformable image registration in RayStation allows structures on the planning data set to be propagated to the fraction data set for dose evaluation. It also allows the delivered dose to be deformed back to the planning CT and accumulated for a comparison with the planned dose up to that fraction.

Accumulated dose distributions and related analysis from the dose tracking module in RayStation can provide documentation and support for informed decisions regarding modification of the treatment plan. A further step could be for the clinician to anticipate geometry changes that are likely to take place, based on the pattern revealed by dose tracking, and factor these into the adaptive replanning.

ADAPTIVE REPLANNING
Adaptive replanning needs to be fast in order to fit into the clinical workflow - with respect to computation time and also the quality assurance process. In RayStation, it is possible to "warm start" the optimization on a new planning image, using the delivered accumulated dose, computed through dose tracking, as background dose. The fact that everything is performed within the same system, combined with RayStation’s high-speed optimization and dose calculation engines, makes it possible to do this in a matter of seconds. While most adaptive replanning is currently done in an “offline” mode, online adaptations are expected to become more common in the near future.

Figure 2: Regular imaging to track the dose for detection of dose escalation, significant OAR changes.

"Adaptive therapy demands a high-speed planning system, combined with high-quality imaging. It’s only feasible with a system such as RayStation, which is extremely fast and has excellent tools for the clinician.”

Giuseppe Sasso, MD, Clinical Director Radiation Oncology, Auckland City Hospital, New Zealand.
COMMON USE CASES
The following examples illustrate how RayStation can be used in common adaptive therapy and deformable registration scenarios.

Retreatment or treatment of a nearby body site
The starting point here was DICOM data from a previous treatment from any planning system, along with structures in the original planning CT data set. The dose from the previous treatment was then deformed to the new planning data set and used as background dose during optimization. Note that the actual plan (including beam setups) can be used but is not required. Dose distribution information is sufficient.

Significant physical change suggests a new plan is needed
In this case, a new CT was acquired during the treatment. Dose was computed on the repeat CT, given to structures propagated from the original planning image, then assessed. A new plan was then created based on the repeat CT, using the dose planned so far as background dose. This dose was based on the number of delivered fractions and was deformed to the repeat CT.

The adaptive planning function in RayStation does not require that the user re-enter the beam parameters or the inverse planning objectives. The sum of the doses is easily displayed so that an overall analysis can be made on the efficacy of the delivery.

Figure 2: Significant physical change suggests a new plan is needed.

Adaptation planning is sometimes simply unavoidable, especially in the case of protons that are sensitive to density and anatomical changes in the body. It would be impossible to plan this in an efficient and/or safe manner without advanced technologies such as deformable registration and adaptive therapy in RayStation.”

Niek Schreuder, Chief Medical Physicist, Provision Center for Proton Therapy, Knoxville, USA.
Regular imaging to track the dose for detection of dose escalation, significant OAR changes, etc.
Images are acquired daily or at another regular interval. Structures are propagated from the planning CT, and actual delivered dose is computed on the fraction image and deformed to the planning CT for dose accumulation and comparison with the planned dose. It is important to note that an adaptive plan is not always needed. However, useful information can be obtained and used to improve future fractions (e.g. better bladder filling, changes to patient positioning/rotation, etc.).

Expert data mapping from atlas data image.
If the user does not want to use original drawn ROI, or they are not available, an atlas can be imported, allowing RayStation to deformably register data sets to a particular patient and then map them across the deformation field¹.

Thoracic 4DCTs for multiple phase evaluation
Structures can be defined in one phase and propagated to the remaining phases through deformable image registration. The next step is assessment for gating and/or ITV extent.

By implementing adaptive radiation therapy we can further improve the precision in our treatments. This requires very sophisticated software tools and RayStation really stands out as the best treatment planning solution on the market for adaptive therapy. I see this as a starting point for a deep collaboration with RaySearch for both clinical and research applications.”

Karsten Eilertsen, MD, Head of Radiotherapy Physics, Oslo University Hospital, Norway.

TIME IS NOT AN ISSUE
In tests, average processing time for dose tracking of one fraction using scripting was 53 seconds on a machine running Windows 8.1 (64-bit) operating system with 32GB RAM, one Intel Xeon E5-2697 CPU (12 cores) and two AMD FirePro D700 GPUs. Both deformable image registration and dose computation use GPU acceleration. Typical time for visual inspection of patient outline, propagated structures and deformable image registration was around one minute².

REFERENCES
¹ RaySearch white paper: Deformable registration in RayStation