Introduction
Adaptive radiotherapy is the practice of adapting to changes in patient anatomy over the course of radiotherapy treatments. The decision to perform adaptive radiotherapy varies from institution to institution. One approach is to adapt plans in response to progressive and expected changes that occur during the course of treatment. Another approach is to respond to random changes that arise unexpectedly. At Beatson West of Scotland Cancer Centre in Glasgow, Scotland, clinicians perform adaptive planning in both of these situations. By utilizing the features currently available within the Varian software family, including RapidPlan™ knowledge-based planning, they are able to quickly and efficiently adapt plans when needed.

Beatson clinicians approach adaptive planning in essentially three ways: plan of the day, scheduled mid-point adaptive, and ad hoc adaptive.

Plan of the day. Beatson clinicians employ a plan-of-the-day approach for gynecological and bladder cases, in which multiple plans are generated for the patient, based on bladder filling, using RapidPlan as the starting point. Starting with RapidPlan makes it practical and efficient to generate multiple plans for a patient. The best-match plan is chosen each day for delivery, based on the daily cone-beam CT (CBCT).

Scheduled mid-point adaptive plan. Beatson clinicians schedule mid-point CT scans for adaptive planning primarily for head-and-neck patients. “Even before the patient starts treatment, we book the mid-point CT to see if the anatomical changes we expect to occur in these patients necessitate an adaptive plan,” says Suzanne Smith, clinical scientific lead, Beatson West of Scotland Cancer Centre.

Ad hoc adaptive plan. The most challenging cases for adaptive planning are ad hoc patient referrals. In these cases, the need for adaptive planning arises unexpectedly and for a variety of reasons. Each patient requires an individual approach. Lung cases comprise the majority of ad hoc adaptive plans at Beatson.

Adaptive planning tools
For adaptive planning, Beatson clinicians utilize an integrated software toolset of RapidPlan knowledge-based planning, Velocity™ software for oncology imaging informatics, and the Eclipse™ treatment planning system.

RapidPlan was designed to break through the productivity barriers and streamline the process by enabling clinicians to use DVH estimation models as a baseline for developing high quality treatment plans. This can reduce or even eliminate the need for multiple, time-consuming iterations. A number of studies have shown that knowledge-based treatment planning both increases planning efficiency and results in higher quality, more consistent plans.1,2

Velocity brings all imaging scans and treatment information together into a consolidated view for faster, more informed decisions. Using Velocity tools to fuse and analyze imaging datasets, clinicians can quickly determine whether adaptive planning is required and assess whether adaptive plans meet the clinical objectives. “We have quite a lot of information about the gynecological patients in particular. We thought they would be a very good place to start to investigate how Velocity may play a part with RapidPlan to move forward to a new level of adaption,” says Smith.
ADAPTIVE PLANNING USE CASES

Use case 1: Ad hoc adaptive planning for lung SABR
A patient with a single-lesion T1 adenocarcinoma lung tumor was referred for stereotactic ablative radiotherapy (SABR). RapidPlan was used to generate a two-arc RapidArc® radiotherapy technology treatment plan for 55 Gy in five fractions, with dose constraints that follow the UK SABR Consortium Guidelines. The average intensity projection (AIP) was used for dose calculation. The patient was immobilized in a beam directional thermoplastic shell (BDS) with arms down. A daily CBCT was taken for soft-tissue matching.

The RapidPlan model
The RapidPlan model used was developed at Beatson from 99 patients treated over the years. The plans used for the model span different energies (6 MV and 10 MV FFF), numbers of arcs (dual and partial), and algorithm versions (PRO, PO, and AAA). The resulting lung model has proved valid for different tumor locations, for single and multiple lesions, and for other fractionation schemes that are close to 55 Gy in five fractions.

The issue
Using the RapidPlan model as a starting point, the dosimetrist calculated a plan with very good coverage for this patient. Figure 1 shows the hundred percent isodose line, which covers the gross tumor volume (GTV) in all dimensions.

The timeline for planning lung SABR cases typically spans 14 days from the time of the 4DCT planning scan to the time that the finalized plan is reviewed and approved. However, in this case, the time that elapsed between the 4DCT simulation and fraction one of treatment exceeded 14 days. On day one of treatment, the senior therapy radiographer performed a set-up CBCT. According to standard procedure, if the scan aligns to the treatment plan, treatment begins immediately and continues on alternate days until the course of treatment is complete. In this case, however, the therapy radiographer was not satisfied with the position of the lesion in relation to the original plan. Instead of beginning the treatment as planned, a new 4DCT was ordered. Figure 2 displays the original plan overlaid on the new scan, showing that the GTV coverage was no longer adequate and a replan was required.

The adaptive plan
In less than an hour, the new scan was done and the adaptive plan was generated. The original and new 4DCTs were fused in Eclipse. The registered structures were copied to the new 4DCT which saved time for contouring and provided a starting point for adapting the volumes that had changed. The adapted plan was recalculated and re-optimized in RapidPlan in approximately 15 minutes. As shown in Figure 3, the new plan covered the new GTV with good conformality.

In many cases, when the staff and the delivery system are available, Beatson is able to rescan, replan, and treat on the same day, with minimal delay to the patient.

“The coordination and communication among therapy radiographers, oncologists, dosimetrists and physics staff is more important than the time it actually takes for the technology to do the calculations. Adaptive planning works very well, but it does take teamwork,” says Smith.
Use case 2: Scheduled mid-point adaptive plan for head and neck
A patient presented with T2 tonsil cancer. RapidPlan was used to generate a two-arc RapidArc treatment plan for 65 Gy in 30 fractions, with two planning target volume (PTV) dose levels. The patient was immobilized in a BDS with arms down. Online kV-kV imaging was used for matching. A full verification CT scan was taken at the mid-point of treatment for adaptive planning if required.

The RapidPlan model
The head-and-neck (H & N) model is one of Beatson’s most complex. “We put a lot of work into removing outliers and optimizing the model. It contains 91 plans and was built using PO and AAA 13.6.23,” says Smith. The model consists of plans using a dose prescription of 65 Gy in 30 fractions and a low risk PTV prescription of 54 Gy in 30 fractions. Beatson uses 6 MV energy for H & N patients. All have been treated using a Millennium™ 120-leaf MLC.

The issue
For H & N cases, daily kV-kV online matching is used for patient set-up. A verification CBCT scan is taken at a mid-point during the course of the treatment. “The mid-point verification scan for patients who are also undergoing chemotherapy reveals any changes due to weight loss, which can cause positioning errors,” says Smith.

In this case, the therapy radiographers observed that the patient had lost weight. The mid-point CBCT confirmed their observations of the patient and the kV-kV positioning issues.

For the initial plan, shown in Figure 4, the 45-Gy color wash line spares the spinal cord in the transverse, coronal, and sagittal sections. However, at the mid-point scan, as shown in Figure 5, the color wash comes across the spinal cord in the sagittal section. “We found that a 1-centimeter shift in shoulder position was causing the neck to tilt and move the spinal cord closer to the PTV region,” explains Smith.

The adaptive plan
The original simulation scan was fused with the mid-point verification scan so that clinicians could review organs at risk (OAR) and the PTV coverage. The RapidPlan H & N model was used to recalculate a new plan in approximately 12 minutes. The adaptive plan, shown in Figure 6, shielded the spinal cord to the same degree as the original plan and provided confidence in OAR sparing.
The process for replanning was the same as described for the lung SABR case. The original CT and the new CT were fused, and the volumes were copied across for adapting. Full re-voluming, the most time-consuming part of treatment planning, was not required. The adaptive plan, including the new CT scan, was completed in two hours.

Use case 3: Daily analysis of gynecological cases using Velocity and RapidPlan
Planning gynecological treatments for a patient with an intact uterus can be a challenge because concurrent chemotherapy can cause significant variations in bladder filling from day to day. To protect the bladder under these variable conditions, clinicians at Beatson generate multiple plans with RapidPlan. Then, therapy radiographers acquire CBCTs every treatment day and decide which plan of the day to deliver.

The RapidPlan model
The gynecological RapidPlan model consists of 124 plans for patients who were prescribed 45 Gy in 25 fractions. Twenty-eight of plans included simultaneous integrated boost of doses that varied slightly depending on the patient and the location of the boost region. All were treated using 6 MV with a 120-leaf MLC. Plans for triple, dual, or partial arcs or a combination are included in the model. “We used two different algorithm types. We used PRO and AAA version 10, and then we moved on to PO and AAA version 13.6,” adds Smith.

Figure 6. H & N (Good coverage and cord sparing with RapidPlan replanning)

Figure 7 shows an example of a model-generated plan with 98% isodose coverage and good OAR sparing. “Without RapidPlan, we wouldn’t have the ability do multiple adaptive plans for these patients because of the workload involved.”

Figure 7. Gynecological case C (RapidPlan primary plan, 98% isodose coverage)

The issue
Beatson clinicians wanted to determine if they could use Velocity with RapidPlan as a QA tool to decide when a new plan is required and to help them be more adaptive.

Velocity deformably registers the original CT dataset to the daily CBCT, creating a synthetic CT. “By creating this synthetic CT, you have a new CT dataset that you can then use to look at the calculation in the entirety of the patient, and have confidence that your Hounsfield units are correct. QA tools within Velocity help to ensure that fusion worked correctly,” explains Smith.

Beatson is using Velocity and RapidPlan retrospectively to investigate the question: “Could running new RapidArc plans on the synthetic CT tell us if we should have replanned that patient, at what point within the patient’s journey we should replan them, and how often we should replan them,” says Smith. At present, Beatson has used the synthetic CT as a QA tool only. They haven’t yet used it clinically to calculate and deliver a new plan, but they are interested in the clinical potential.
The potential for Velocity and RapidPlan in adaptive planning
Figure 8 shows a primary RapidArc plan produced by RapidPlan (Top) next to the synthetic CT produced at fraction 10 (Bottom). Coverage has been reduced in relation to the original plan. There also appears to have been a slight shift anteriorly. The shape of the bladder is markedly different between the two CT scans.

Figure 9 compares the same slice at fraction 10 and fraction 11, indicating only small variations between the synthetic datasets. This is significant because the patient had chemotherapy at fraction 11. Bladder filling appears to have stabilized by this point.

Running the fraction-10 synthetic CT in RapidPlan reveals an opportunity to improve dose coverage compared to the original plan. However, running the fraction-24 synthetic CT in RapidPlan reveals almost no difference in dose coverage compared to the fraction-10 adaptive plan. (See Figure 10.)

“We find plan of the day very useful; however, we are thinking about doing multiple replans for these gynecology patients,” says Smith. “Using Velocity and synthetic CTs, we can predict with RapidPlan when it would be of use to do a replan and when it’s not of use to do a replan. We’re still in the developing stage with this, but so far it is promising.”
Conclusion

There are different options and approaches to implementing adaptive planning and arriving at the optimal outcome for each patient. Each clinical practice will need to take into consideration its processes and resources.

“Ongoing review and adaptation is the next step in radiotherapy,” says Smith. “The more you look at each patient and their journey and you look at what happens on a daily basis, the more you realize that adaption is very important.”

RapidPlan has helped the clinicians at Beatson to evolve adaptive workflow processes that enable a fast and efficient turnaround for patients. “RapidPlan enables us to produce quality plans quickly and with confidence, and to undertake more adaptive planning,” says Smith.


Figure 10. Gynecological case C (RapidPlan replan at fraction 10, replan verified on fractions 11 and 24 Velocity synthetic plan)