Adaptive Proton Therapy Dose Assessment Using Cone Beam Computed Tomography

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PURPOSE/OBJECTIVE(S)

- The purpose of this study is to evaluate the workflow used by Varian's Velocity software to generate adaptive CT (aCT) images from cone beam computed tomography (CBCT) for proton therapy.
- Our goal is to validate this method and determine if it can be used reliably in the clinic to trigger the earliest possible action for adaptive re-planning due to an anatomical change in the patient. This will allow for the safest and most optimal treatment for each patient.

MATERIAL & METHODS

- This is a retrospective study on patients that underwent pencil beam scanning (PBS) proton therapy in which there were anatomical changes observed during a verification CT (Ct_{ver}) that lead to an adaptive plan.
- The aCT is generated in each case by using Velocity 4.1, which considers the anatomical deformation for HU re-assignment as well as the online matching used during the patient's treatment each day to account for patient setup errors between the planning CT and the corresponding CBCT.
- Velocity is also used to accumulate dose from each aCT to the planning CT to evaluate the changes over the course of treatment. The dose from the planning CT is projected onto the generated aCTs. It is then averaged over all aCTs and projected onto the planning CT while the original dose is subtracted away for comparison and evaluation.
- The target volume and surrounding critical structures are used to evaluate the deformation using indices such as the deformation volume change (ΔV_{Def}), Jacobian determinant, and subtractive dose volume histograms (DVH).

RESULTS

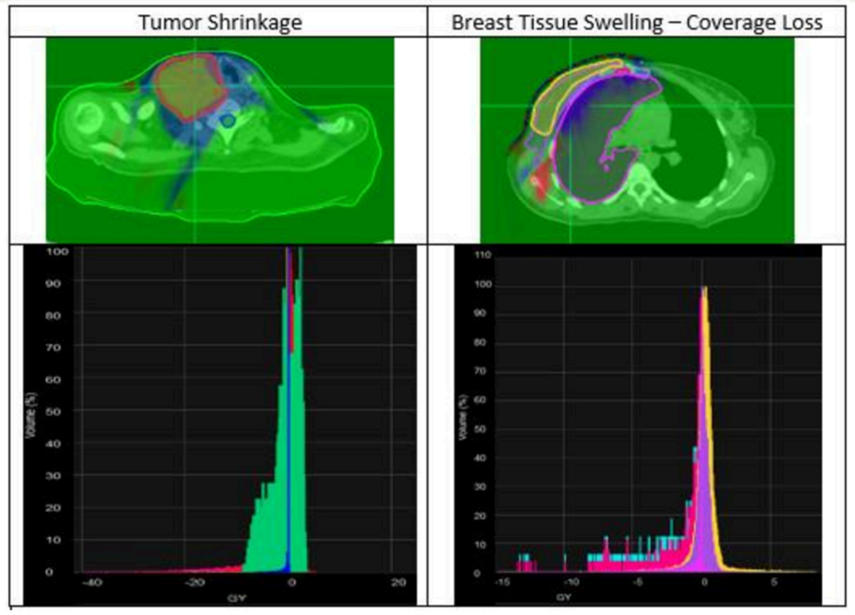
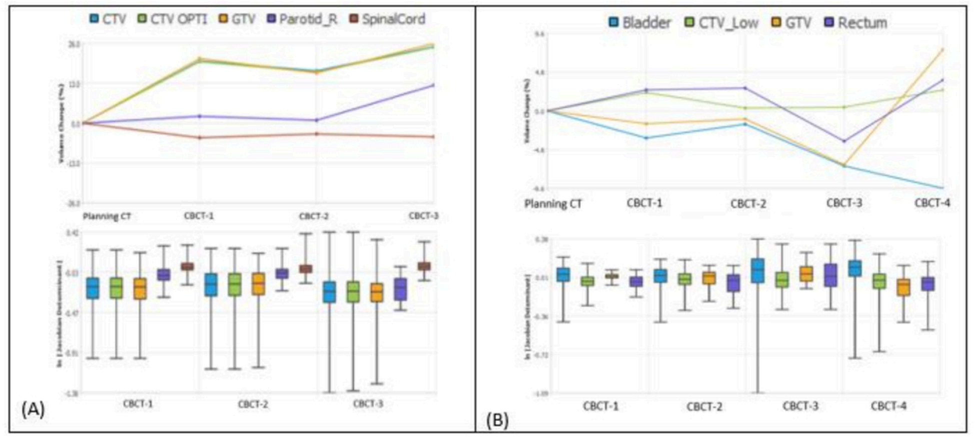


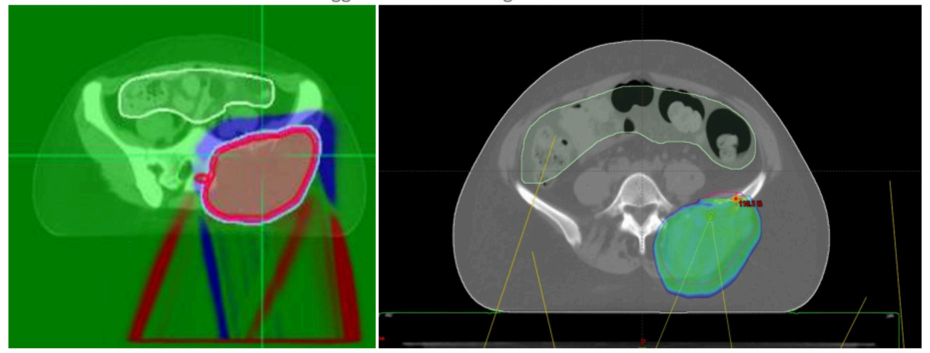
Figure 1. Two treatment sites dose accumulation results

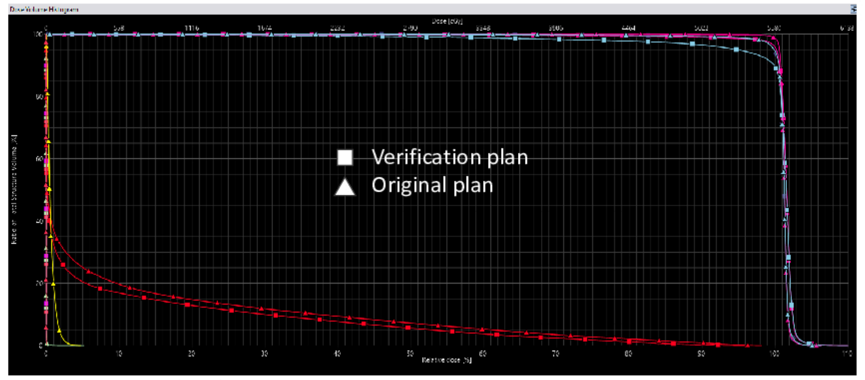
Figure 1 depicts the results of dose accumulation after deformation for two different treatment sites that have two different types of anatomical changes. The top images show the results of the accumulated aCT dose being subtracted from the original plan dose. The top left image shows the result of tumor shrinkage in the head and neck area. Top right shows tissues swelling in the breast region. The blue/red regions indicate areas where dose is lower (blue) or in excess (red). The plots beneath show the subtractive DVH. The subtractive DVH is a histogram that illustrates the difference between the original plan DVH and the average dose from the aCTs for every structure selected. In a case with no dosimetric differences, we would observe a straight line at 0Gy, In this case, the skewed curves indicate a dose variation in those structures, indicated by the negative dose difference. Skewed curves are one criteria to trigger further investigation.

Figure 2. Deformation indices for equally spaced CBCTs for two patients

Figure 2 shows some deformation indices for consecutive CBCTs for two different patients. (A) shows results for a head/neck patient and (B) shows results for a rectum case. The top plots show the volume changes for each structure during deformation. A positive percentage change indicates the volume needed to be enlarged during deformation to match the planning CT. The bottom plots show to log transformed Jacobian determinants spread. A large spread indicates highly variable volume changes within a given structure.







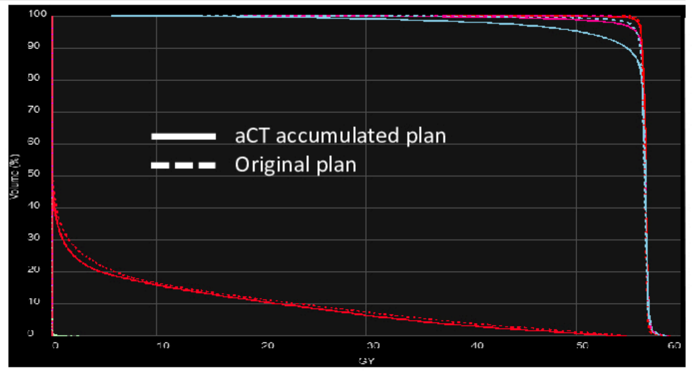


Figure 3. Accumulated dose subtraction and corresponding verification scan

Figure 3 shows the dose subtraction map (above - left) and the corresponding CT_{ver}(above - right) of a patient who gained a significant amount of weight during treatment. The blue areas in the subtraction map indicate cold spots, or areas where dose coverage is lost. The red areas indicate hot spots, or areas where dose coverage has increased. The streaks or lines indicate differences in the patient setup as opposed to significant anatomy changes. The cold region at the anterior portion of the target volume here corresponds directly to the loss of coverage observed on the patient's next verification scan. The two DVH curves shown (right) represent the accumulated aCT dose (right – bottom) as well as the dose from the verification plan (right – top). The curves match very well, indicating that the aCT dose accumulation shows similar trend and results to the CT_{ver}. This loss of coverage lead to an adaptive plan being generated to improve the quality of the plan.

CONCLUSIONS

- We can detect anatomical changes in the target structures and OARs for proton therapy even before a patient's scheduled CT_{ver}.
- The workflow is able to provide a visual representation of coverage loss or dose hotspot increases by automatically generating the dose subtraction map.
- We have determined a set of criteria for further investigation: a ΔV_{Def} greater than 5% in a critical structure (target or OAR), a large spread in the Jacobian determinant, and/or a skewed subtractive DVH.
- Using this workflow, we observed similar results to those seen during different patient's verification scans. Therefore,, applying this workflow will be able to detect anatomical changes and trigger adaptive planning earlier in treatment than before without any unnecessary added dose to the patient.
- This workflow provides indicators to trigger adaptive proton re-planning. This allows for safer and more effective patient treatment.
- This adaptive workflow does have limitations. Currently, Velocity does struggle to perform an accurate deformation in certain cases. We have found that cases that are treating the nasal cavity area do not deform well to account for changes in the nasal cavity and sinus filling between fractions. This is a limitation of the Velocity algorithm itself.

REFERENCES / ACKNOWLEDGEMENTS

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