Dose margin expansion for CyberKnife treatment plans: feasibility study

The CyberKnife uses an online prediction model to track moving targets. The system works well and can achieve a tracking accuracy of less than 1.5 mm if patients can breathe regularly. This makes it possible to use smaller PTV margins in planning. However, some patients cannot maintain a regular breathing pattern, which makes the target tracking less effective; thus larger margins are necessary. However, it is very difficult to predict a patient’s breathing pattern in advance. To ensure sufficient CTV coverage, generally a 5mm PTV isocentric margin is used in planning. This may not be adequate for patients who cannot breathe regularly. A paper published recently studied how to determine the tracking uncertainties using synchrony signals. This could be used to determine the PTV margins necessary for a specific patient. The purpose of this study is to investigate a swift and easy way to adjust the treatment plan without re-planning if extra margins are needed.

The CyberKnife system uses the Iris collimator to confine beams with cone sizes ranging from 5 mm to 60mm. A typical CyberKnife plan contains approximately 30~50 nodes and 80~150 beams. It can have one or multiple beams per node. The solid line in figure 1 shows a schematic beam arrangement from one node. Dose from one node does not provide conformal coverage to the target; however, with dose painted from all of the nodes, a CyberKnife plan can deliver a very conformal dose. For a patient with a moving target, figure 2 provides the work flow to determine whether the treatment plan needs to be adjusted. For cases that require different margins, we propose a method to adjust the treatment plan directly, which includes the cone size adjustment, beam coordinate adjustment and monitor unit adjustment, etc. Generally, if a larger target region needs to be covered by the prescription dose, the size of the beams will be larger and beams will need to be moved in the direction of the peripheral area to avoid a hot spot. Multiple algorithms have been developed to accomplish this adjustment. Dose is recalculated and renormalized. If the dose of the new plan covers the new PTV with acceptable conformality and coverage, the plan will be used for treatment. Otherwise, more iterations of the adjustment are performed. Dose calculations are limited to a small region surrounding the target to reduce calculation time.

5 clinical cases (3 lungs, 1 liver and 1 adrenal) have been tested in this study. Generally the dose margin can be extended as desired. The average PTV coverage is 98.7% compared to 99.1% in the original plans and the average CI is 1.22, which is slightly less than the 1.24 in the original plan. Figure 3 shows a lung case (prescription dose: 12 Gy*4) with the original PTV diameter of approximately 24 mm; 5mm additional margins were added in this study.

In conclusion, treatment margins can be sufficiently expanded resulting in satisfactory plan quality.