

Evaluation of interplay effects and repainting strategies in pencil beam scanning

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Purpose

For treatments of moving targets with a scanned ion beam, it is essential to evaluate the interplay effect to assess if the treatment will fulfill the original clinical goals. We present a method for evaluation of interplay effects and analyze different repainting strategies for a proton pencil-beam scanning treatment on a 4DCT data set of a lung cancer patient.

Background

One of the challenges in treating moving targets using a scanned ion beam is the interplay effect. The interplay effect will arise if the treatment delivery occurs on a similar time scale as the intra-fractional tumour motion. This will lead to parts of the plan being delivered to a changing and different patient geometry than it was planned for, and large deviations between the planned and delivered dose can result. If the effects are significant, mitigating measures must be taken either on the delivery side (e.g. repainting, gating) or by suppressing the motion (e.g. abdominal compression, breath hold), or using a combination of the two.

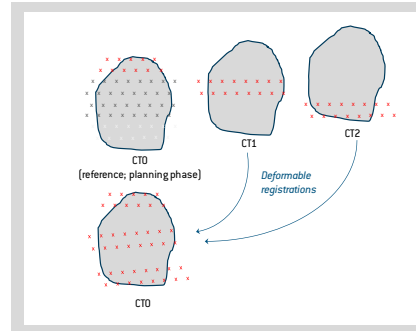


Illustration of interplay effects (first row) The dose planned to be delivered on CT0 will be different from what is actually delivered. When the target moves the spot doses are distributed over the different phases of the motion.

Evaluation of interplay effects (all rows) The interplay effect can be evaluated on a 4DCT data set, if there exists a deformable registration between each of the 4DCT phases and the planning phase. This will make it possible to accumulate the interplay doses on the planning CT to assess the difference between the resulting accumulated dose and the originally planned dose.

Principles for interplay evaluation

Prerequisites

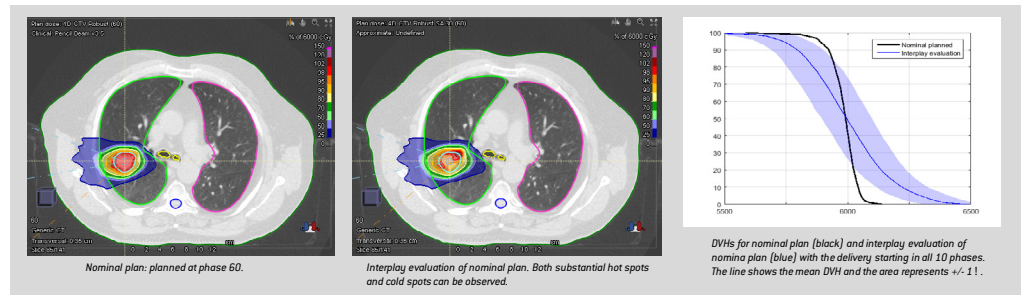
- Time structure of delivery
 - Specified by user
 - Taken from machine (simulation or log files)
- Patient movement cycle
- 4DCT data set
- Deformable registrations between each phase in the 4DCT and the planning phase

Method

- Specify start time of delivery
- Distribute spots to different phases based on:
 - Movement cycle
 - Time structure of delivery
- Compute dose on the correct image set
- Accumulate dose on reference CT

Plan study – no repainting

The method has been implemented in the scripting interface of the RayStation 5 treatment planning system (RaySearch Laboratories AB, Stockholm, Sweden) and applied for a 3 beam proton pencil beam scanning treatment plan of a lung cancer patient. The 4DCT data set consists of 10 images (phases 00-90) and the plan was prepared on phase 60. The developed script can use log files from the delivery machine for post-treatment evaluation or simulations of the delivery for pre-treatment evaluation. In the evaluation below, we have retrieved the delivery time structure from simulations with the IBA scanning control system ScanAlgo, and the delivery is assumed to start at the phase 30.



Repainting strategies

For repainting, two different strategies are commonly discussed: **layer repainting** and **volumetric repainting**. Volumetric repainting has the advantage of distributing the energy layers more randomly over the different phases of the motion cycle and therefore gives a better conformity. The drawback is that the method normally suffers from prolonged delivery due to long energy switching times. Therefore we propose to use layer repainting with a time delay between the layers to distribute all layer paintings over one motion cycle. This method, which we refer to as **synchronized layer repainting**, has the potential to reduce delivery time (as compared to volumetric repainting) and provide better mitigation for interplay effects (as compared to both layer and volumetric repainting).

Plan study – different repainting strategies

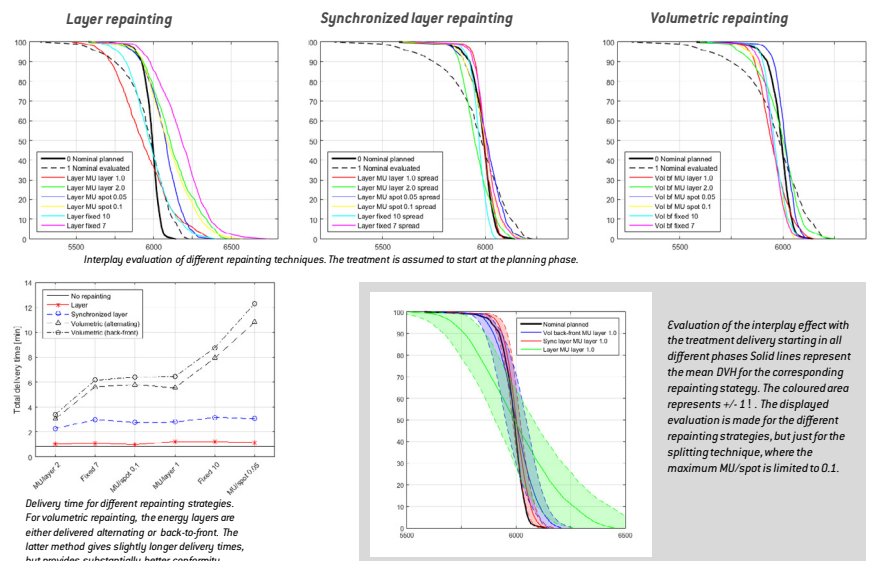
In the following study, we have evaluated the three different repainting strategies with different splitting techniques:

Splitting technique	Splitting parameters	# layers*	# spots*
No repainting	-	27	778
Fixed no of paintings	7	10	179/254
Max MU/layer	2.0	1.0	99/186
Max MU/spot	0.1	0.05	193/370
			2148/3836

*The #layers and #spots refer to the total number of layers and spot in all 3 beams. The first (second) value corresponds to the first (second) splitting parameter.

The breathing cycle is estimated to be 5 s and the delivery is assumed to start at the planning phase. For the time structure of the delivery the following default parameters have been used:

- Energy layer shift time: 2.0 s
- Motion speed between spots: 250 cm/s
- Spot delivery time: 4.0 ms/MU
- Minimum spot weight of the machine: 0.01 MU/fx



Conclusions

- Layer repainting showed poor results in mitigating the interplay effect in the studied plan.
- Volumetric repainting showed better results, but suffers from long delivery times (2-3 times longer than synchronized layer painting for appropriate splitting parameters in this plan study)
- Regardless of energy switching times, the evaluation of the studied plan indicates that the best choice for repainting w.r.t. dose conformity is to use synchronized layer repainting. We therefore propose that this method should be supported by the treatment delivery systems.

References

Seco et al., Breathing interplay effects during proton beam scanning: simulation and statistical analysis, PMB 54 (2009)

Zenkhusen et al., A study on repainting strategies for treating moderately moving targets with proton pencil beam scanning at the new Gantry 2 at PSI, PMB 55 (2010)