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On-line analysis of 4D treatment deliveries for scanned proton and carbon ion beams

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Purpose or Objective: A tool for fast dose distributions analysis in hadrontherapy is presented, which integrates on GPU a Fast Forward Planning (F-FP), a Fast Image Registration algorithm (F-IR), a Fast Gamma-Index (F-GI) and Fast DVH computations. The tool will be interfaced with the dose delivery system (DDS) of a synchrotron-based facility to investigate the feasibility to quantify, spill by spill, the effects of organ movements on dose distributions during 4D treatment deliveries.

Material and Methods: The F-FP was built by porting to CUDA the PlanKIT TPS, developed by INFN and IBA for proton and carbon scanned beams. The feature of choosing, among the 4DCT volumes, the CT volume corresponding to a specific respiratory phase (CT-phase) was added. To evaluate target movements, the 4DCT images are pre-processed (using C++ algorithms) to obtain the deformation vector fields. The F-IR uses the latter to map the dose calculated on a CT-phase to the CT volume used to plan the treatment (CT-reference). The F-FP runs twice to calculate in parallel the planned dose (on the CT-reference), and the delivered dose (on the CT-phase mapped on the CT-reference by the F-IR). Finally, the comparison between the two dose distributions is performed through fast F-GI and DVH computations to quantify the dose deformation due to intra-fraction anatomical changes.
The NVIDIA Tesla K40c in a Workstation (WS) HP Z820 (2xIntel XeE5-2670v2) was used. The WS will be interfaced with a clinical DDS and an optical tracking system (OTS) to test the operations on-line. The tool will receive in real-time the measured beam parameters through a direct and transparent connection with the DDS using FPGA boards.
Results will be promptly shown in the local control room.

Results: A preliminary version of the F-FP has been tested for physical and biological doses for protons and carbon ions, showing total execution times within 1 s, and negligible absolute differences (<10^-4 Gy) compared with PlanKIT results. The F-GI and DVHs computation times are of the order of few ms, while the F-IR will be within 1 s. The times for data transfer are negligible.
The overall system operations and the execution times are summarized in Fig 1.

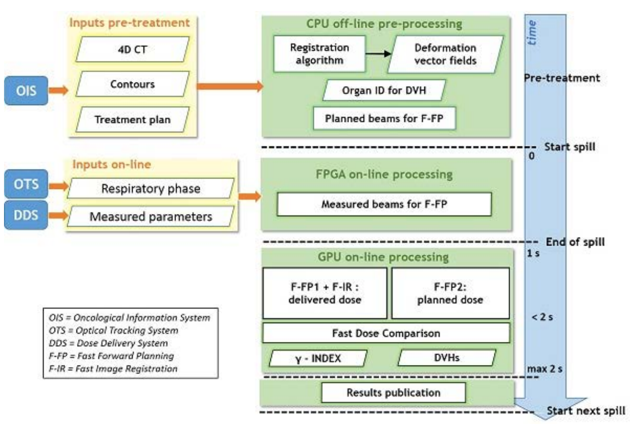

Fig. 1

Conclusion: A GPU-based tool for dose distributions analysis in hadrontherapy has been developed and will be interfaced with clinical DDS and OTS. The preliminary results suggest its possible use to on-line quantify the effects of target movements during 4D treatment deliveries with scanned proton and carbon ion beams.

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Impact of different dose calculation algorithms on aperture-based complexity metric evaluations

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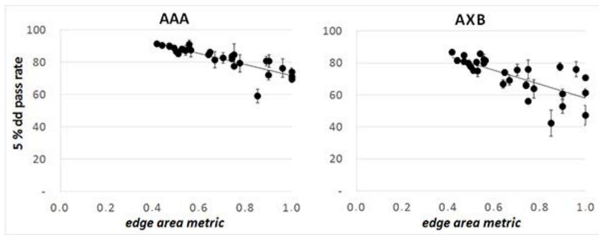
Purpose or Objective: The objective is to evaluate the impact of different dose calculation algorithms on the correlation between aperture-based complexity metric scores and field complexity, i.e. difference between calculated and delivered dose.
IMRT/VMAT treatment fields composed of small MLC sub-openings cause discrepancies between planned and delivered dose and are considered complex. Aperture-based complexity metrics have been suggested to quantify this complexity. The correlation between such metric scores and complexity, determined by comparisons of calculations and measurements, were evaluated for static MLC openings representing control points in an IMRT/VMAT treatment plan (Götstedt et al Med Phys 2015; 42: 3911). Different dose calculation algorithms have different built-in limitations that affect the deviations between calculations and measurements and thereby the correlation.

Material and Methods: The dose calculation algorithms studied were the pencil beam convolution (PBC), the analytical anisotropic algorithm (AAA) and the Acuros XB (AXB) in Eclipse treatment planning system (TPS) and the collapsed cone (CC) in Oncentra TPS. The study focus on the complexity metrics, *converted aperture metric* and *edge area metric,* described by Götstedt et al. The same 30 MLC openings of various complexity divided in series of five to describe similar patterns with increasing complexity created by Götstedt et al were used also in this study. The MLC openings were measured with Gafchromic® EBT3 film in solid water on three repeated occasions and compared to different calculations by evaluating the 3% and 5% dose difference (dd) pass rate.

Results: Examples of the correlation between the *edge area metric* and 5% dd pass rate for the 30 MLC openings are shown in the figure for AAA and AXB. The error bars show the standard deviation of the three measurements.



The linear correlations, expressed in Pearson's r-values, between the dd evaluations and the metric scores for the different calculation algorithms are summarized in the table.

	converted aperture metric		*edge area metric*	
	3% dd pass rate	5% dd pass rate	3% dd pass rate	5% dd pass rate
PBC	-0.93	-0.89	-0.95	-0.94
AAA	-0.85	-0.80	-0.90	-0.84
CC	-0.85	-0.73	-0.91	-0.85
AXB	-0.70	-0.52	-0.81	-0.71

The highest and lowest r-values were seen for the PBC- and the AXB-calculations, respectively. The r-values for the AAA- and the CC-calculations were similar. The *converted aperture*