Motion induced interplay effects for hypo-fractionated FFF VMAT treatment of liver tumours

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Purpose or Objective: The mutual movement of the tumour and treatment delivery during VMAT might cause hotspots and coldspots in the dose distribution, so-called interplay effects. These can be hard to predict and might be of great concern for hypo-fractionated VMAT treatments. The purpose of this study was (1) to develop a method to calculate the absorbed dose to moving tumours for VMAT treatments, (2) verify the proposed method by measurements, and (3) use the proposed method to investigate the dosimetric impact of interplay effects for hypo-fractionated FFF VMAT treatment of moving liver tumours.

Material and Methods: Treatment plans using 6 MV FFF VMAT (1400 MU/min) were created for three liver metastases (TrueBeam and Eclipse, Varian Medical Systems). The prescribed dose was 36 Gy in 3 fractions. The arcs were divided into sub-beams (one for every two control points) using an in-house developed software and the isocenter was shifted for every sub-beam to simulate sinusoidal motion in the superior-inferior direction. The sub-beams were calculated in Eclipse, generating a 4D dose distribution including effects of motion. For each treatment plan, combinations of three different motion amplitudes (5, 15 and 25 mm peak-to-peak) and periods (3, 5 and 7 s) were simulated. To separate the interplay effect from dose blurring, the original 3D dose distribution was convolved with the motion pattern and subtracted from the simulated 4D dose distribution, and the resulting D1%-D99% was calculated for the ITV. To verify the method, simulated treatment plans were delivered in developer mode to the Delta4 phantom positioned on Hexamotion (ScandiDos), which was either static or moving sinusoidally with a peak-to-peak distance of 15 mm and a period time of 5 seconds during irradiation. The measured and simulated dose distributions were compared using gamma analysis (2%/2 mm local dose, cut-off dose 10%) in the Delta4 software. To synchronize the isocenter shifts in the simulations with the motion during the measurements, kV images were acquired asynchronously during beam delivery.

Results: Gamma analysis show good agreement between the simulated 4D dose distribution and the dynamic measurement, comparable to the original 3D dose distribution and the static measurement (table 1). The impact of the interplay effects, expressed as D1%-D99%, varies considerably between targets as well as the combination of tumour amplitude and period time (figure 1), with a maximum difference in D1%-D99% compared to no motion of 2.8 Gy (target 2, 25 mm, 7s).

Conclusion: A method to calculate the absorbed dose to moving tumours was developed and verified by measurements. Using this method, it was shown that large interplay effects may occur, with no obvious relation to the motion pattern. Therefore, caution should be taken before using FFF VMAT for moving liver tumours without using motion management techniques.

Table 1 Comparison of static and dynamic measurements with the 4D and original 3D calculated dose distributions, presented as average gamma pass rate (range) for criteria 2%/2 mm local dose

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<th>Gamma pass rate (%)</th>
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<tr>
<td>Static measurement vs 3D dose</td>
<td>98.6 [98.7 - 99.7]</td>
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<tr>
<td>Dynamic measurement vs 3D dose</td>
<td>76.5 [66.0 - 83.7]</td>
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<tr>
<td>Dynamic measurement vs 4D dose</td>
<td>95.7 [99.5 - 100.0]</td>
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Figure 1 Difference in D95-D0% compared to no motion (ΔD95-D0%) as a function of tumour amplitude and period time for three targets
Conclusion: We can improve treatment-plan quality for lung SBRT treatments by providing the planner with a quality parameter associated with the dose gradient around the PTV. This index does not depend on GTV volume and position and is suited to compare all patients treated for SBRT without making corrections for size and position of the tumor and is suitable for multiple tumors.

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Integration of fMRI and MEG functional maps into a Cyberknife planning system: a feasibility study
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Purpose or Objective: In recent years Magnetoencephalography (MEG) and Functional Magnetic Resonance Imaging (fMRI) have imposed as non-invasive methods providing localization of eloquent brain areas for pre-surgical planning. With the advent of radiosurgery, the impact of these neuroimaging techniques in preventing neurological morbidity is under investigation in the clinical conditions for which radiotherapy is the treatment of choice. This study aimed to develop a method of integrating MEG and fMRI maps into a Cyberknife system to optimize dose planning.

Material and Methods: A patient with a recurrent brain metastasis affecting both the left pre-central and the post-central gyrus underwent functional imaging of the hand motor cortex two weeks prior its scheduled radiosurgery treatment. MEG data were acquired with a 306 sensors whole-head system while the patient performed self-paced motor activation of right hand and index finger. Epochs were extracted in the window ranging from -3 to +3 seconds with respect to the movement onset and then averaged. Source of the motor-related activity was assessed by means of sLORETA algorithm. A day after MEG acquisition, fMRI was performed using a 3 T MR Philips Achieva scanner. Motor activation of right hand and index finger was obtained through a block designed paradigm. Stimulation modality and duration both for MEG and fMRI were chosen to maximize time course signal to noise ratio. Magnetoencephalography and fMRI maps were integrated into a Cyberknife system for treatment planning optimization, considering the boolean sum of activations as organ at risk.

Results: Localization of the hand motor cortex was obtained for both functional investigation methods within close proximity of the lesion. Integration of the fMRI data into the Cyberknife system was easily achieved through the customary Cyberknife import protocol. More problematic was the integration of the MEG images, and for the purpose a customized Dicom import software had to be developed.

Figure show the results of the MEG and fMRI functional areas implemented into the Cyberknife system: the fMRI area (indicated in yellow) and the MEG area (indicated in green) result partially overlapped. Only small differences were observed between MEG and fMRI activation areas after image co-registration. Inclusion of the activation area into the plan optimization process allowed a reduction of 19% of the mean dose to the motor cortex

Conclusion: Nowadays, the availability of advanced neuroimaging techniques is playing a more and more important role in radiosurgical planning strategy. The authors developed an effective method to co-register fMRI and MEG data sets in a Cyberknife treatment planning system. This additional information can improve dose sparing of eloquent areas, and MEG information in particular might be valuable when BOLD effect is disturbed by pathological vascularization.

OC-0465
Quality of treatment plans in hybrid IMRT and VMAT for prostate radiotherapy
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