Reproducible immobilization for porcine heart irradiations

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Hadron therapy has already proven to be successful in cancer therapy, and might be a non-invasive alternative for the ablation of cardiac arrhythmias in humans.

In order to experimentally investigate this treatment modality, scanned carbon beams from the GSI accelerator were used to irradiate various targets in beating hearts of healthy pigs. Dose ranging from 25 Gy to 55 Gy was applied during breath-hold in the 100 % expiratory phase under anesthesia. The alignment and breathing phase during irradiation had to reproduce the situation of the treatment planning CT (TPCT) with an accuracy of a few millimeters. A pig immobilization device (PID) allowing reproducibility of shape and position was designed (cf. Figure 1).

Figure 1: A pig in irradiation position in Cave M at GSI.

Both, TPCT scans and irradiations were performed during breath-hold in the 100 % expiratory phase. Animals were kept in deep anesthesia in order to completely suppress spontaneous lung motion. A computer-controlled ventilator was used (Evita XL by Dräger Medical). With this device, animals were ventilated with intermittent positive pressure ventilation with 14 breathing cycles per minute, 350 ml tidal volume, a positive end-expiratory pressure of 0 mbar and an oxygen concentration of 20 %. A LabVIEW interface running on a personal computer was implemented for remote control, data logging and communication with the beam application and monitoring system at GSI.

TPCTs where acquired at Heidelberg Ion-Beam Therapy Center (HIT) and irradiation was applied at GSI Darmstadt a few days later. This situation was experimentally simulated to estimate the degree of reproducibility: The immobilization and TPCT scan of a test animal was repeated at HIT with about one week delay. For the analysis, one of the two TPCTs first was shifted such that the PIDs were coincident in both scans. A displacement vector field relating the two scans was derived using deformable registration with the Plastimatch module of the medical image analysis software 'Slicer' (B-spline deformable registration, regularization=0.1, grid size=20). Displacement vectors with an absolute magnitude (AM) of more than 5 mm can only be observed in the beating heart. In the remaining volume, the AM is below 5 mm. Throughout the backbone and large parts of the sternum, AM is below 3 mm. AM up to 4 mm can be observed in the lateral chest walls.

Shortly before irradiation, X-ray images were taken both in dorsoventral and lateral direction at Cave M. They were acquired under breath-hold, exactly as during irradiation. Exposure time was about one second. Therefore the target itself, the beating heart, is smeared out and nearby structures had to be used to verify reproducibility of breath-hold. Pairwise comparison of the positions of selected anatomical structures (vertebrae, sternum, diaphragm) was employed. Images were preprocessed using affine and rigid registration. The plugin Landmark Correspondences of the medical image analysis software 'ImageJ' was used. Reproducibility of breath-hold is in the order of 1 mm or below for all anatomical sites considered.

Based on the available data we estimate that the PID combined with a breath-hold, controlled by a clinical ventilator, allows to reproduce the geometrical situation of the TPCTs with an accuracy of better than about 5 mm for the anatomy surrounding the heart (backbone, sternum, chest walls). In irradiations, heart-beat motion was mitigated using the rescanning technique (cf. these proceedings). We currently investigate additional perturbations due to geometrical and temporal variability of the heart motion.

Irradiated animals were dissected after a follow-up period of about six months. The desired target regions exhibit fibrotic tissue, suggesting that immobilization and motion mitigation were sufficient. Analysis is ongoing and numerous technical and biological factors (cf. these proceedings), still under investigation, will influence the final result.

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