
Motivation

Atrial fibrillation is the most common cardiac arrhythmia [ESC10] [CE09]. One out of four people over forty are estimated to suffer from this condition in the course of their lifetime. While genetics play a role in the development of atrial fibrillation in younger patients, age is an important risk factor for this cardiac arrhythmia and the prevalence is estimated to double in the next fifty years due to aging of society. In atrial fibrillation, an unorganized atrial activity leads to a quivering motion and hence the heart is not able to sustain a healthy pumping rhythm. This is not in itself life threatening but it alters the quality of life of the patients and increases the risk of the patients to suffer a stroke [Ben98] [Wol91].

A typical treatment modality for atrial fibrillation is catheter ablation. Based on the landmark paper by Haissaguerre et al. [Hai98], where electrical signals causing atrial fibrillation were found to originate from the pulmonary veins in 97% of the studied cases, it is assumed that atrial fibrillation is triggered and sustained by the same anatomical site in the majority of patients. With catheter ablation flexible catheters are inserted into the patient to deposit radiofrequency energy around the junction between pulmonary veins and atria. This creates a scar which inhibits the signal propagation from the pulmonary veins into the heart's conduction system. Catheter ablation requires the anesthetization of the patient for multiple hours while it offers only a limited treatment success rate. Major complications and even death may occur due to this procedure [Cap05] [Cap10]. Alternative treatment modalities are thus warranted.

Radiosurgery has the potential to become a new technique for such a treatment. In a study by Sharma et al. [Sha10] it was demonstrated that the irradiation of various target sites in the heart with a focused photon beam changed the electrical pathway of the heart's conduction system. Based on the experience gained in cancer radiotherapy an improved treatment outcome for such a deep seated target is expected for carbon ions. Compared to photons, particles like carbon ions deposit their energy in a defined area at the end of their particle track, the so called Bragg peak. This enables to deposit a high dose to the target while sparing the surrounding tissue. The physical and biological properties of carbon ions, combined with the active beam delivery and beam shaping, led to successful clinical results in treatment of deep seated, static tumors in the GSI pilot project from 1997 to 2009. Based on the convincing treatment outcome other centers like the Heidelberg Ion-Beam Therapy Center (HIT) and CNAO (centro nazionale di adroterapia oncologica, Pavia, Italy) were build, where patients are now treated with scanned carbon ion beams on a regular basis [PTCOG13].

Scope of this work

This is the first *in silico* survey to study the feasibility of a non-invasive treatment modality for atrial fibrillation with carbon ion radiosurgery. Thereby the irradiation of ablation sites in the junction between pulmonary veins and atria will be studied in human data. Another potential ablation site for atrial fibrillation, the AV node, will be studied in porcine data sets. A single fraction dose of 25Gy will be applied on the cardiac target volumes.

When intending to irradiate non-static targets interference effects between target motion and the actively applied ion beam cause local under and over dosages [Phi92] [Ber08]. In order to deposit a homogenous dose in the target area, motion mitigation techniques are needed. Different motion mitigation techniques will be used in this dissertation. The interrupted irradiation during a selected part of the motion cycle (gating) [Kub96] as well as the repeated scanning of the same slice with a reduced dose so that averaging effects cause a homogenous dose deposition in the target volume (rescanning) [Phi92] will be analyzed. For the feasibility of a non-invasive treatment modality for atrial fibrillation with carbon ions, two independent motion influences have to be considered. On the one hand the heart beat, a fast but small amplitude motion, and on the other hand the respiration of the patient, a typically slow motion with big amplitude. Respiration and heartbeat gated CTs of human patients will be studied and the resulting treatment planning studies will be presented. In preparation for animal studies planned at GSI in the summer of 2014 also treatment plan results for porcine data will be investigated.

The structure of this dissertation is as follows. Chapter 1 will give an overview over the physical and biological fundamentals of radiotherapy. Different radiotherapy applications will be presented and a special emphasis will be given on the treatment of moving targets. Furthermore, the cause of atrial fibrillation and its resulting risk factors will be presented. Currently existing therapies and the potential benefit of a non-invasive treatment modality will be discussed. In chapter 2 the influence of the respiratory motion on pulmonary veins ablation sites in humans will be discussed. The feasibility to use gating as motion mitigation technique for this case will be investigated. In chapter 3 the displacement of the pulmonary veins ablation site due to heartbeat will be examined in human data. Rescanning will be studied as motion mitigation technique for this motion component. In preparation for the planned animal experiments, which will be carried out as a first experimental feasibility study in the summer of 2014 at GSI, chapter 4 will discuss an AV node ablation with carbon ions in porcine data. The underlying heartbeat motion will be studied and rescanning as motion mitigation technique will be utilized. Discussion of the overall results will be given in chapter 5, while chapter 6 will conclude the findings and give a short outlook on future directions.

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