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Target Definition and Target Tracking in Radiation Therapy – Resolved and Unresolved Problems

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Abstract. The lecture presented a brief review of the current achievements in radiation therapy and a description of some of the outstanding problems in this field related to tumor definition prior to treatment and to tumor tracking during the treatment.

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Vast technological advancements in radiation dosimetry, in radiation delivery techniques, in patient imaging, and in immobilization and monitoring during treatment have led to high radiation therapy accuracy [1–4]. This has allowed increasing of the delivered doses, which resulted in improved treatment efficacy and survival probability [5]. The development of stereotactic radiosurgery (a highly accurate radiation therapy procedure performed using a three dimensional coordinate system for accurate tumor targeting) and the introduction of high single dose treatments have further contributed to this success [6]. Despite these advances, not all patient treatments are successful [7]. At the same time the higher doses pose a higher risk for damaging normal tissue and function [8, 9]. This imposes higher demands on the accuracy with which the position and the boundaries of the tumor target are defined during three phases of the treatment process: i) prior to planning for the development of the irradiation treatment plan in a procedure called treatment simulation; ii) immediately prior to start the treatment to set-up the patient on the treatment table; and iii) for tumor position verification during the treatment, a processes also known as tumor tracking.

The tumor target is defined using the images produced during treatment simulation. At present state-of-the-art target definition is performed by using images produced on one of the following imaging devices: Computer Tomography scanners (CT), combined positron emission tomography (PET) and CT scanners (PET/CT), Magnetic Resonance Imaging scanners (MRI) and recently combined

PET/MRI scanners. CT produces high resolution anatomical images which are not sensitive to lesion metabolism. PET has a very high sensitivity and specificity for tumor lesion detection since it allows to create images tagged to molecular processes including glycolysis, proliferation and hypoxia [4]. However, PET has poor spatial resolution and the PET images are also subject to other biological, physical and technical artifacts [10]. MRI brings very high resolution and increased contrast between the different soft tissues as well as possibilities for functional imaging. The above imaging modalities are subject of intensive research efforts in order to enhance their role in the radiation treatment planning process.

The images needed to correctly position the tumor when the patient is on the treatment table and to further verify this position during the treatment, can be obtained using kV x-ray sources and amorphous silicon or other solid state based planar detectors. They can produce planar x-ray images for verification of the patient position prior to or during treatment. If these images and sources are attached to the gantry which delivers the treatment beam, recording consecutive images during gantry rotation around the patient allows performing a CT scan, called cone-beam CT (CBCT) due to the divergent x-ray beam. Alternative approaches for patient set-up and position verification include: electronic portal imaging devices (EPID), which detect the megavoltage beam transmitted through the patient; infra-red cameras, which observe infrared markers placed on the patient; stereoscopic visual cameras, which monitor the topology of the patient skin; ultrasound probes; and electromagnetic transponders implanted in the tumor.

Disadvantages of the kV and MV imaging devices are that they can image well only the bones and not so well the soft tissues and that they deliver extra dose to the patient. For this reason, special interest is recently also given to attaching an MRI scanner to the radiation therapy machine, which provides the advantage of identifying the position of the different soft tissues in real time during treatment. Various techniques for stopping the treatment beam when the tumor moves away from the planned position or for tracking the motion of the tumor due to respiratory motion have been developed. Different approaches for gating of the imaging procedures with the respiratory cycle have also been implemented [11].

The brief description of the accuracy and limitations of the above technologies provided in the lecture was intended to identify the areas needing further research and development from the physicist prospective.

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