Daily IGRT QA Phantom for MR-guided Linacs

Innovation/Impact: A phantom was designed to be compatible with multiple imaging modalities (kV, MV and MRI) for the daily quality assurance (QA) of an MR-guided linac.

Introduction: Newly emerging MR-guided radiotherapy systems integrate a therapy linear accelerator and an MR scanner (i.e., MR-linac). These devices raise challenging questions regarding the implementation of machine QA. At our institution, we are in the process of installing a decoupled MR-linac system, consisting of a 1.5T Siemens Espree MR scanner on rails that can be moved and image in the immediate proximity of a Varian TrueBeam linac. The two components are connected via a robotic patient couch. For this configuration, both MR and x-ray based (kV, MV) imaging modalities will be available and will have to be mutually correlated to confirm the robustness of the RT positioning.

Methods: The authors have modified the design of an existing daily QA phantom that is compatible with kV radiographs, MV EPIDs and kV CBCT. The existing phantom consists of a 16cm³ block of solid acrylic containing 5 spherical air voids. New features were added to make the phantom also visible on MRI. A digital representation of the phantom was generated with a series of 5 opposing (MR) spheres as shown in Fig. 1a. The overall design (i.e., sphere location, size, and material) was optimized by means of numerical simulations to remove any significant MR image-related artifacts due to magnetic susceptibility-induced effects. The susceptibility artifacts were modeled by solving numerically the Maxwell equations for a static magnetic field, i.e. \( \nabla \cdot \left[ (1 + \chi_M) \nabla \Phi_M \right] = 0 \), where \( \nabla \Phi_M \) is the magnetic scalar potential, and \( \chi_M \) is the magnetic susceptibility constant. The input data required is a spatial distribution of susceptibility values throughout the modeled object, and \( \nabla \Phi_M \) at the boundary. The mechanism of susceptibility effects is highlighted in Fig. 1b. An image software analysis tool was also developed to process the data and capture all kV/MV/MRI unique characteristics. In addition, the software provides the capability of recording and tracking over time the performance of the targeting tests via control charts.

Results: A sample simulation map of the magnetic dipole surrounding phantom structures is shown in Fig. 1c. The phantom was developed to test kV/MV/MR system coincidence, 3D CBCT and 3D MR independent and cross-modality mutual registration, kV/MV and MR projection images, kV/MV coincidence, MR/linac laser and light field coincidence, remote table adjustments.

Conclusion: A novel phantom along with an image processing software package was developed for the routine daily QA of MR-guided radiotherapy system.

Figure 1. a) Graphical representation of phantom structure (blue spheres are air voids, yellow spheres contain MR contrast material); b) representation of the mechanism of susceptibility effects; c) typical magnetic field distribution map for susceptibility simulations.