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Development and Imaging of the World's first Whole-Body Linac-MRI Hybrid System

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Purpose:
We designed and first whole-body clinical linac-MRI hybrid (linac-MR) system to provide real-time MR guided radiotherapy with current imaging and treatment. Installation began in our clinic in 2013, and the world-first images from a linac-MR on a human volunteer were obtained in July 2014.

Methods:
The linac-MR consists of an isocentrically mounted 6 MV linac that rotates in-unison with a biplanar 0.6 T MRI in transverse plane. The Bo field and the central axis of the 6 MV beam are parallel to each other. The optimized fringe field results in insignificant increase in entrance dose. The parallel configuration avoids large increases in dose at tissue/air interfaces and at beam exit due to electron return effect that occurs in the perpendicular configuration.
We were first to demonstrate concurrent MR imaging and linac-irradiation of head-size phantoms in 2008, on a single gantry. The head prototype have been described in our 40 peer-reviewed articles (linac-MR.ca/publications.html). The current functional whole-body rotating linac-MR system is built on the engineering and physics obtained from the head prototype.

Results:
The current system is mechanically well balanced and rotates at 1 rpm. The 3D magnetic field mapping demonstrates minimal perturbation in magnetic field homogeneity with gantry rotation which is easily and effectively shimmed by gradient coils. The Larmor Frequency varies with gantry angle due to the Bo interaction with room shielding and to the directional changes of the Earth's magnetic relative, and closely follows our predictions calculated previously. Angle dependent 3D magnetic field maps and Larmor Frequency are used to automatically and optimally create image acquisition parameters for any gantry angle. Metrics obtained at different rotating angles show that the image quality is comparable to those of clinical MRI systems, and thus satisfy the requirements for real-time MR-guided radiotherapy.

Conclusions:
The system highlights are: 1) 6 MV linac, 2) high-quality MR images during irradiation, 3) simultaneous linac and MR rotation in parallel configuration to avoid strong angle-dependent shimming, and to avoid increased dose at beam exit and tissue/air interfaces, 3) installation through the maze of an existing vault, 4) cryogen-free superconducting magnet not requiring a helium vent, and 5) ability to turn magnet off or on in a few minutes for servicing.

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