Integration of a 6MeV Electron Beam LINAC with a 1.5 T MRI Scanner

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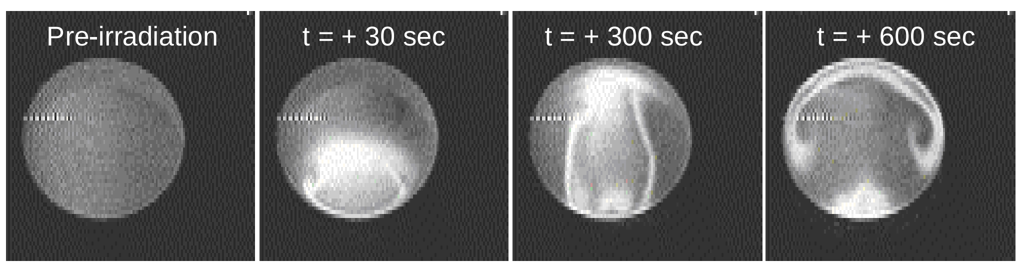
ABSTRACT: The spatial distribution of a linear accelerator (LINAC) electron beam within an aqueous solution was quantified *in situ* by ^{1}H magnetic resonance imaging (MRI). A 6 MeV electron beam was fired into a ferrous solution located at the center of a 1.5 Tesla MRI magnet. Spin-spin (T_2) and spin-lattice (T_1) relaxation weighted images were acquired to visualize the trajectory of the electron beam within the aqueous phantom. Oxidation of Fe^{2+} to Fe^{3+} by the ionizing radiation beam yielded a sufficient change in proton relaxation properties to yield high contrast images of the beam path. The time dependence and dynamics of solution convection due to e-beam interaction was monitored by MRI. Obtaining an image of a sample while simultaneously irradiating the target represents the ideal paradigm for highly accurate radiation therapy. Incorporating a radiation delivery system in an MRI scanner lays the foundation for a new generation of medical instrumentation.

INTRODUCTION: In the United States one in four people will die of cancer, making it the second leading cause of death. Ionizing radiation therapy is one means for treating cancer. Two parameters of radiation therapy that are important to a radiation oncologist are the quantity and spatial extent of absorbed radiation dose. When a tumor is detected within a MRI scanner the patient must relocate to a separate area of a hospital or another facility for radiation therapy. Moving the patient can lead to shifting of internal organs and change the tumor location – resulting in inaccurate targeting of the radiation. It would be advantageous to identify tumor coordinates and perform radiation therapy in the same environment.

METHODS: An X-band (9.3 GHz) pulsed 6 MeV linear electron accelerator (AS&E, Santa Clara, CA) was used to produce the electron beam. The accelerator gun was located 4 meters from the magnet center. The electron beam traveled down a 3 meter drift tube fitted with a thin titanium end window to allow exit of electrons with minimal attenuation. The pulse duration was 4 microseconds. Twelve pulses were delivered over three seconds. The target phantom was a 25 ml vial containing a Fricke solution (1) (1mM Ammonium iron(II) sulfate hexahydrate, 16 mM sulfuric acid) located within a home-built linear mode 12 element 6 cm i.d. birdcage proton coil. MRI experiments were performed in a Magnex 1.5 T/680mm magnet (Magnex, Abingdon, UK) interfaced to a Apollo NMR spectrometer (Tecmag, Houston, TX). MRI data was obtained prior, during and after LINAC operation with no apparent electronic interference between the two systems.

RESULTS:

- A 6 MeV linear accelerator can be used in an MR environment.
- It is possible to obtain an image of the spatial distribution of radiation in a liquid Fricke solution by MRI.



T1 weighted MRI images of convection of Fricke solution after 48 usec of e-beam irradiation.
The bright region has a shorter T1 because of oxidation of Fe(II) to Fe(III) from the ionizing radiation.

- Irradiating the Fricke solution resulted in heating, convection, and precipitation of iron.
- The LINAC produces 56 mA of current yielding an average temperature increase of 0.015º C per 4µs pulse in a 25 ml solution.

CONCLUSIONS: A LINAC can effectively and efficiently operate in an MR environment. The spatial extent of the radiation can be imaged and quantified by MRI in three dimensions. The decrease in T_1 after irradiation is due to Fe^{2+} oxidizing to Fe^{3+}. Overall, the combination of radiotherapy techniques and MRI techniques could provide for safer more effective treatment of patients.

(1) Fricke H and Hart E (1966) Radiation Dosimetry Academic Press 186-197

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