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DEVELOPMENT OF AN EFFICIENT PHASE SPACE FOR LEKSELL GAMMA KNIFE PERFEXION USING MONTE CARLO SIMULATIONS

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The Leksell Gamma Knife (LGK) is a non-invasive stereotactic radiosurgery device used to treat brain tumors and functional disorders. It delivers highly precise gamma radiation from 192 high-activity cobalt-60 sources. Each sector of the Leksell Gamma Knife Perfexion (PFX) contains 24 cobalt-60 sources and can move independently between five different positions. Three of these positions correspond to collimator sizes of 4, 8, and 16 mm, while the other two are a blocked position and a home position. Leksell GammaPlan version 11.0.3 (LGP, Elekta Instruments), which is used to design treatment plans for the Leksell Gamma Knife (LGK), calculates the patient's absorbed dose using the Tissue Maximum Ratio (TMR) algorithm. However, since the TMR algorithm assumes that all material within the patient is equivalent to water, it introduces an inherent error due to the actual heterogeneity of tissues.
The effects of this error have been evaluated in several studies using Monte Carlo (MC) simulations. Additionally, MC simulations have become increasingly common for assessing shaped and small-field radiation beams, as they are the most reliable tool for determining dosimetric quantities. The effects of this error have been evaluated in several studies using Monte Carlo (MC) simulations. Additionally, MC simulations have become increasingly common for assessing shaped and small-field radiation beams, as they are the most reliable tool for determining dosimetric quantities. However, these simulations require extensive computation time to determine absorbed doses, particularly for small-field beams like those used in the Leksell Gamma Knife (LGK). In order to reduce the time required for simulations a unique phase space method was proposed to simplify all repetitive steps in the process. First, the three collimators of different sizes (4, 8, and 16 mm) are created with precise geometric accuracy. Then, the exact positions (θ, ϕ) of the 24 sources in each sector are calculated. Subsequently, the unique phase space is then rotated according to these coordinates, and the 24 sources are combined to form the first sector. The unique phase space is then rotated according to these coordinates, and the 24 sources are combined to form the first sector. To account for all eight sectors in each simulation, this sector is rotated in 45-degree increments around the Z-axis.
For each phase space file (PSF) corresponding to each collimator, 1.0×10^8 primary photons were generated. The phase space data files contain detailed information about the particle type, energy (E), statistical weight (w), Cartesian position components (x, y, z), and directional components of linear momentum (u, v, w). Using these phase space data files for the LGK PFX, a first-in, first-out (fifo) method was employed, which first reads a file with the angular positions (θ, ϕ) of each sector, followed by reading the PSF and applying the respective θ and ϕ rotations for each sector. This process is repeated sequentially from sector 1 to sector 8. Thus, a second phase space file (PSF2) can be created to contain the information for one sector, all sectors, or even interchanged sectors as required by the treatment plan.
For the PSF2, 1×10^{15} histories were defined, using different initial seed values for the random number generator. The results of this simulation, using the developed method, were validated by comparing the phase space interacting with a 160 mm diameter spherical phantom against the results obtained from radiochromic film measurements at the Ruber International Hospital in Madrid, Spain.
Dose profiles were calculated along the X, Y, and Z axes using the general configuration of PenEasy, as well as 2D dose maps, which were compared with dose distributions measured with radiochromic film. A good agreement was achieved for the dose profiles, especially in the central region with a maximum discrepancy of less than 2%. Conversely, the largest difference, of less than 5%, was noted in the penumbra region. This

demonstrated excellent concordance for all three collimators.

Abstract

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