Gamma Knife Perfexion™ dosimetry: A Monte Carlo model of one sector

Innovation/Impact: Our model represents the first successful implementation of a third-party dosimetry system for the Gamma Knife Perfexion. External verification of the accuracy, precision, and performance of radiosurgical devices is necessary for their safe and effective clinical use as well as for advanced research studies.

Introduction: The Gamma Knife Perfexion (GK PFX) is a radiosurgical treatment device that uses 192 Cobalt-60 sources to irradiate targets in the head. Tungsten collimators are organized into eight movable sectors of 24 sources each with three selectable collimation sizes (4 mm, 8 mm, and 16 mm nominal diameters at the focus). Leksell GammaPlan (LGP) software is used to plan the delivery of treatments. LGP dosimetry algorithms prior to version 10.1 use a homogenous density assumption that leads to errors in the calculation of radiation dose near heterogeneities such as bone and sinus.[1] LGP version 10.1 uses convolution algorithms which avoid some of the problems near heterogeneities[2], but are not yet well examined in the literature. Monte Carlo (MC) methods that model radiation interactions and track radiation transport have been demonstrated to calculate dose more accurately in heterogeneous volumes than other dosimetry models. This study used Penelope, an established set of Monte Carlo codes, to model the geometric and radiological characteristics of the Elekta GK Perfexion, as relevant for GK SRS accuracy, precision, and radiation safety. The single sector simulation can be rotated about the z-axis to model all eight GK sectors. GK dosimetric aspects examined include: 1) output factors (OF) for each of the three GK collimator sizes, 2) OFs for each source row and collimator size, and 3) dose distribution profiles along the x- and z-axes, compared to film measurements and dose calculations from the Leksell GammaPlan (LGP) workstation. Both individual row OFs and average collimator OFs have been determined, as required for the Perfexion geometry.

Simulation specifics: Internal geometry of the collimators was provided by Elekta, A.B. through a non-disclosure agreement. The Co-60 sources were modeled as 2 cm linear sources. The simulations were divided into two steps by the use of phase space files (PSFs). Photons reaching a simulated surface on the downstream end of the collimators were recorded in a PSF. In a second step of the simulation the collimation geometry was removed and the dosimetry sphere target put in place, and the contents of the PSF were played back. To model the full sector, the positions and trajectories of photons in the PSF were rotated about the z-axis to match the geometry of a GK sector’s sources. Alignment of a single GK PFX source in its source bushing is shown in Figure 1.

![Alignment of a single GK PFX source](image1.jpg)

Dose Distribution Profiles: A dose distribution simulating a full Perfexion was created by rotating the sector dose distributions about the z-axis in a stepwise fashion and summing the dose from each of the eight sectors. A dose profile was taken along the x- and z-axes. See Figure 2.
Figure 2: Dose profile curves calculated by our MC method in red circles and by LGP’s TMR10 dose algorithm in blue squares (top row = x-axis profiles; bottom row = z-axis profiles). The dotted black line shows the absolute difference between the curves at that point along the horizontal axis. The largest disagreement is on the inferior side of the 16 mm collimator’s z-axis.

**Output Factors:** The row output factors and collimator output factors were calculated by recording the simulated dose deposited in a simple, mathematically defined dosimeter at the center of a 16 cm diameter solid water dosimetry sphere. The absolute doses were recorded for each row, and the row OFs were calculated by dividing each absolute dose by the dose from 16 mm collimator, row B – the row with the highest output. Our row OF calculations were within 4% of manufacturer values in all cases, and within 2% in all but a few cases. For the collimator OF results, the absolute dose delivered by the 16 mm collimator’s sources is set to an OF of 1.0, and the OFs for the 8 mm and 4 mm collimators are calculated by dividing their absolute dose deposited with the 16 mm collimator value. Our collimator OF results are within 3% of the manufacturer’s values.

**References:**