Cureus

A Monte Carlo Model of a Compact Radiosurgery System for Patient-Specific Quality Assurance and Validation of TPS Base Data

Open Access
Abstract
Published 02/11/2022

Markus L. Alber [1] , Michael Eder [2] , Theresa Hofmann [3] , Dochka Eftimova [2] , Christoph Furweger [4]

1. Medical Physics, Scientific RT GmbH, Munich, DEU 2. Medical Physics, European Cyberknife Center Munich, Munich, DEU 3. Physicist, European Cyberknife Center Munich, Munich, DEU 4. Medical Physics, European Radiosurgery Center Munich, Munich, DEU

Corresponding author: Markus L. Alber, markus@scientific-rt.com

Categories: Medical Physics, Radiation Oncology
Keywords: small field dosimetry, stereotactic radiotherapy (srt), quality assurance and radiation safety, monte-carlo

How to cite this abstract
Alber M L, Eder M, Hofmann T, et al. (February 11, 2022) A Monte Carlo Model of a Compact Radiosurgery System for Patient-Specific Quality Assurance and Validation of TPS Base Data. Cureus 14(2): a678

Abstract

Objective: The ZAP-X system (ZAP Surgical Systems, San Carlos, USA) is a novel device for brain radiosurgery that can deliver a 3 MV flattening-filter-free beam through circular collimators of 4 - 25 mm diameter. Here, we describe the creation and validation of a Monte Carlo (MC) model of this device for the purpose of independent secondary dose computation for patient-specific quality assurance. As a secondary objective, the MC model was employed to validate the base data measurements, which need to be obtained in a complex setup.

Methods: The MC model of the ZAP-X device, starting from the electron target, was built from construction drawings kindly supplied by the vendor. The MC source model was coupled to the MC code SciMoCa (Scientific RT, Munich, Germany) for water phantom calculations. Base data, consisting of output factors (OF) and depth-dose-curves (DDC) measured with a PTW 60019 Micro Diamond detector (PTW, Freiburg, Germany) and cross-profiles measured with a PTW 60018 SRS Diode, were used to determine the energetic properties of the electron beam and the focus spot size. All data were acquired in a water tank (PTW) within the enclosure of the device at SSD 450 mm with a reference depth for OF of 7 mm (depth of dose maximum for largest collimator). The energy spectrum was tuned only with the DDC of 15 and 25 mm collimators so as to avoid field-size dependent over-response of the Micro Diamond. DDC of all other collimators were used for validation.

Results: For field sizes >= 10 mm, MC reproduced the DDC with an error of less than 0.6% up to depths of 250 mm. DDC of smaller fields showed field-size dependent detector effects of up to 2.4% for the 4 mm field. This can be attributed to the very strong dependence of detector behaviour on field size for the smallest fields and the rapidly diverging beams, owing to the short 450 mm source-isocenter-distance. All DDC appeared to be shifted relative to the MC simulations by 0.6-0.7 mm, indicating a constant experimental setup error.
OF measurements were corrected for field-size effects with values derived from various publications. Still, MC disagreed with measurements in the range of 3% for the smallest fields. Notice that due to the very compact design of the device, manufacturing and assembly tolerances of tenths of mm as well as variations of the electron spot size by hundredths of mm already result in several per cent OF change for the 4 and 5 mm collimator. Ultimately, these uncertainties limit the accuracy of MC and would necessitate collimator-specific correction factors. Another source of uncertainty lies in the fact that the dose maximum of the smaller fields lies in front of the 7 mm reference depth; here, a greater reference depth would remove ambiguities between measurements and simulations.
Agreement of cross-profiles was well within 2%/0.2mm after tuning collimator diameters in the range of 0.1-0.2 mm.

Conclusion: A MC model of the ZAP-X device was built that achieves very good agreement to relative dose measurements of depth-dose-curves and cross-profiles. Agreement of absolute doses for fields < 10 mm is hampered by experimental difficulties, the very high sensitivity of the ultra-compact device design to small manufacturing tolerances, and detector effects for very small fields. Thus, the MC simulations highlight the need for further optimization of the base data and QA protocols for this novel device. With the help of measurement-derived correction factors for the smallest collimators, the MC model can be deployed for independent secondary dose computation with maximum uncertainties of < 1%.