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Physics Contribution

Dosimetry of an In-Line Kilovoltage Imaging System and Implementation in Treatment Planning

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Summary

The concomitant dose due to daily image guidance in radiation therapy needs to be assessed even for kilovoltage imaging modalities. For the new Siemens Artiste kVision imaging system, the dosimetric properties have not hitherto been presented. We show dosimetric measurements and their first implementation in the Philips Pinnacle treatment planning system. The model is validated by measurements in an anthropomorphic phantom, which also provide first estimates of the imaging dose by several standard kVision CBCT protocols.

Purpose: To present the beam properties of the Siemens 70-kV and 121-kV linear accelerator-mounted imaging modalities and commissioning of the 121-kV beam in the Philips Pinnacle treatment planning system (TPS); measurements in an Alderson phantom were performed for verification of the model and to estimate the cone-beam CT (CBCT) imaging dose in the head and neck, thorax, and pelvis.

Methods and Materials: The beam profiles and depth−dose curve were measured in an acrylic phantom using thermoluminescent dosimeters and a soft x-ray ionization chamber. Measurements were imported into the TPS, modeled, and verified by phantom measurements.

Results: Modeling of the profiles and the depth−dose curve can be achieved with good quality. Comparison with the measurements in the Alderson phantom is generally good; only very close to bony structures is the dose underestimated by the TPS. For a 200° arc CBCT of the head and neck, a maximum dose of 7 mGy is measured; the thorax and pelvis 360° CBCTs give doses of 4-10 mGy and 7-15 mGy, respectively.

Conclusions: Dosimetric characteristics of the Siemens kVision imaging modalities are presented and modeled in the Pinnacle TPS. Thermoluminescent dosimeter measurements in the Alderson phantom agree well with the calculated TPS dose, validating the model and providing an estimate of the imaging dose for different protocols. © 2014 Elsevier Inc.

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Introduction

Daily image guidance in radiation therapy has increasingly become state of the art as advanced techniques such as intensity modulated radiation therapy and volumetric modulated arc therapy allow highly conformal radiation therapy with further reduction of margins. Linear accelerator (linac)-mounted imaging systems, which provide positioning verification by portal imaging (EPID) or cone beam CT (CBCT), can operate either in the kilovoltage (kV) or megavoltage (MV) energy range. Although simpler in technical implementation, MV imaging suffers from reduced soft-tissue contrast and generally requires considerably higher imaging doses, leading to the introduction of kV modalities. Even in kV imaging, however, a number of studies (refs. 1-3 and others below) have pointed out that daily CBCT may contribute nonnegligible concomitant dose.

General approaches to estimating the imaging dose usually rely on phantom measurements or Monte Carlo simulations; some analytic studies also exist (eg, ref. 4). To our knowledge, only few attempts have been made to implement the imaging dose in a treatment planning system (TPS) (5, 6) for calculation of the dose delivered to the individual patients. This requires detailed dosimetric measurements of the x-ray tube for modeling. The aim of our study is to present the dosimetric characteristics of the recently introduced Siemens kVision system (Siemens Healthcare, Erlangen, Germany) for the Artiste linac and its commissioning in the Philips Pinnacle TPS (Philips Healthcare, DA Best, Netherlands).

The Siemens kVision system differs from other vendors in that the x-ray tube and detector are antiparallelly aligned with the treatment beam. This geometry allows the detection of tumor and organ movement perpendicular to the treatment beam, where dose gradients tend to be highest. For the Siemens Artiste, this new imaging system provides an alternative to the existing treatment beam line 6-MV and imaging beam line 1-MV imaging systems, with improved image quality and reduced dose (7). In contrast to the Varian and Elekta solutions, the Siemens kVision relies on an auto-exposure mechanism to determine the dose needed for each patient anatomy. Although the performance of this system has been presented before (7-9), the dosimetric characteristics have not hitherto been investigated, and calculations of the dose distribution in patient anatomy have not been possible to date. For the verification of our dose computation in the TPS, we performed measurements in an anthropomorphic phantom for 3 typical CBCT settings (head and neck, thorax, and pelvis). In addition to testing the TPS model, these doses give an estimate of the imaging dose from this modality, which has not been presented in the literature.

Methods and Materials

The Siemens kVision imaging system is designed in a reverse treatment geometry, in which an amorphous silicon flat-panel detector can be rotated underneath the treatment head, and a diagnostic x-ray tube (Siemens Optitop 150/40/80 HC-100) extended opposite from it. The kV beam is therefore aligned along the same axis, but in the opposite direction, as the treatment beam.

The x-ray tube can be operated at different potentials. For EPIDs, 4 different protocols can be chosen: "head and neck" (70 kV), "thorax" and "pelvis" (both 121 kV), or "obese" (140 kV). Cone beam CT always uses 121 kV; here, no anatomy protocols are distinguished—the user can only choose between a full (360°) and a partial (200°) rotation. Filtration is identical for all applications (10.3 mm Al/80 kV), and no additional filters are applied. The 121-kV energy for CBCT is hence identical to the 121-kV 2-dimensional (2D) protocols; its half-value layer is 8.2 mm Al. The 2D protocols use a field size of 28×28 cm^2, whereas the CBCTs are taken at 30×30 cm^2. Neither EPIDs nor CBCTs require the choice of dose or milliamperes (mAs), because this is determined by an auto-exposure mechanism using 1 preshot of 0.5 mAs at the starting gantry angle.

At our institution only the 70-kV and 121-kV EPID protocols are used and are therefore presented here. Because the dose from CBCT by far exceeds the 2D imaging dose, only the 121-kV energy used for CBCT is modeled in the TPS.

Because the x-ray tube cannot be manually programmed, no irradiation is possible without complete image acquisition by a protocol. Therefore, the measurements are carried out in service mode, rotating the gantry so that the x-ray source is positioned at 0° for a static 2D geometry. In this setting there is no possibility of placing the water phantom under the source. For these reasons we perform the beam profile measurements using thermoluminescent dosimeters (TLDs; Harshaw TLD 100H, Thermo Fisher Scientific, Waltham, MA) and the percentage depth dose (PDD) measurements by a soft x-ray plane-parallel ionization chamber (PTW 23342, PTW Freiburg, Germany) in an acrylic phantom composed of 30×30-cm^2 plates of various thicknesses. The open field is 28×28 cm^2 at a source-to-surface distance (SSD) of 100 cm, and images are taken in cine view with 10-second irradiation (93.8 mAs for 70 kV and 126.6 mAs for 121 kV). The SSD for the measurements is set to 73 cm to create a field opening of 20×20 cm^2 on the phantom surface. Depth is scaled to water depth in the PDD and for commissioning of the data in the TPS by a factor of 1.136, corresponding to the ratio of half-value depths in water and acrylic (10).

In- and cross-plane profiles at the surface and at 5-cm depth (acrylic) were measured by TLDs spaced 1 cm apart. Surface measurements were repeated 3 times over the course of 1 month to assess the stability of the measurements. For a better 2D representation of the heel effect, the surface intensity was measured in all 4 quadrants of the field, resulting in a total matrix of 32×32 cm^2, with TLDs placed every 2 cm and extending the measurements to 40 cm along the axes and the diagonals. The uncertainty in the placement of the TLDs on the phantom plate was generally within 1 mm, with few deviations of up to 3 mm.

The depth−dose curve was measured using the soft x-ray ionization chamber at the central axis of the beam below phantom slices of different thicknesses. All measurements were repeated 3 times and averaged.

The TLDs were read, heated, and annealed with the Harshaw TLD 5500 reader (Thermo Fisher Scientific) with the vendor-recommended time−temperature protocol (preheating at 145°C for 5 seconds, acquisition at 10°C/s with a maximum temperature of 260°C for 23 1/3 seconds, and annealing for 20 seconds at 260°C, using hot nitrogen gas). For calibration, the TLDs were placed inside an ^{90}Sr/^{90}Y irradiatior (Thermo Electron) to obtain a charge-to-dose calibration factor for each chip (^{137}Cs equivalent dose). To determine the sensitivity of the TLDs at x-ray energies, TLD measurements at SSD 100 cm with 70 kV, 63 mAs were compared with the absolute dose measured with the PTW DALi detector and 77334 ionization chamber. Because the energy