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Medical Physics Contribution:

Investigating the surface dose contribution of intrafractional kV imaging in CyberKnife-based stereotactic radiosurgery

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CyberKnife treatment consists of hundreds of noncoplanar beams and numerous intrafractional images that can be taken during a single treatment fraction; thus, doses because of imaging should be considered in this technique. The aim of this study is to investigate the in-field and out-of-field surface doses induced from kV imaging system during stereotactic radiosurgery (SRS) treatment. The imaging-induced surface doses were measured at the center of the imaging field and within ±15-cm distance from the center in both craniocaudal and lateral directions. TLD100H thermoluminescence dosimeters and EBT2 gafchromic films were used to take the measurements at the locations of 0, ±5, ±10, and ±15 cm in the 2 orthogonal directions on abdominal region of a Rando phantom. The surface dose contributions of imaging system for the 4 most commonly used energy options of 90, 100, 110, and 120 kVp with 3 mAs options of 10, 30, and 90 mAs were measured and compared. Imaging dose values have a positive correlation with both parameters of energy and mAs. The energy options of 100, 110, and 120 kVp, in average, induced 60%, 101%, and 141% more doses per mAs than 90 kVp energy in the imaging field center. A threefold increase in mAs values, *i.e.*, from 10 mAs to 30 mAs and from 30 mAs to 90 mAs, caused higher dose in field center with a factor of 2.53 ± 0.08 when the energy value was kept constant. The in-field dose distributions within ±10 cm in both directions showed a flat pattern with a standard deviation lower than 5%, whereas the out-of-field doses at ±15-cm distance from the field center suddenly dropped to almost half of the central doses. Although a single imaging attempt causes a very low dose compared with the therapeutic dose level, one should be aware of the cumulative surface dose increase with higher imaging number. Proper patient setup, fiducial usage, and reduction of both the mAs values and the imaging numbers should be, therefore, considered to keep the cumulative surface dose in a lower level.

Introduction

Stereotactic radiosurgery/radiotherapy (SRS/SRT) is used for precise targeted delivery of radiation doses.[1-4] Using image guidance, a treatment machine can deliver ablative radiation doses to a tumor volume while sparing normal tissues. Image-guided radiotherapy (IGRT) systems help to accurately perform radiation treatment by the adjustment of

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radiotherapy (RT) fields based on inter- and intrafractional evaluations.[5] Modern IGRT systems, such as cone beam computed tomography (CBCT), megavoltage (MV) portal imaging, and stereoscopic X-ray imaging systems, are compatible with different treatment machines.

A CyberKnife robotic radiosurgery system (Accuray Inc, Sunnyvale, CA) uses stereoscopic X-ray imaging not only for assuring a patient setup but also for tracking a tumor motion, and thus compensating the shifts during a treatment.[6-9] In this technique, surface markers are positioned on a patient who is located at the isocenter of the treatment room. Kilovoltage images are subsequently acquired and compared with stored digitally reconstructed radiography image library that were generated from the planning CT of the patient. Comparison with the stored images enables making translational and rotational corrections. Imaging is repeatedly performed during the treatment as a robotic arm navigates between beams. Because many intrafractional images can be acquired owing to the presence of various noncoplanar beams, the overall imaging dose is likely to be considerable. Several factors, such as the patient's physique, tumor location, tube energy (kVp), mA per image, and the duration of image acquisition (ms), affect the dose delivered to the patient during imaging. In our clinics, 60 to 80 images are taken in each of the 5 fractions of a CyberKnife-based prostate treatment. The image numbers are changed in the ranges of 40 to 80, 60 to 80, and 80 to 100 for treatments of 1 to 5 fractionated cranium, 1 to 5 fractionated head and neck, and 3 to 4 fractionated lung regions, respectively.

Accuray Inc reported typical doses induced from CyberKnife imaging system for various anatomic locations as follows: 0.22 mGy (115 kVp, 10 mAs) for the head, 0.28 mGy (120 kVp, 11.5 mAs) for the chest, and 0.91 mGy (124 kVp, 34.5 mAs) for the pelvis.[10] However, these typical values can vary with imaging parameters. To the best of our knowledge, imaging-induced 2-dimensional in- and out-of-field surface doses have not been studied for a CyberKnife unit. In the present study, we investigated the in-field and out-of-field surface doses incurred by intrafractional imaging during SRS. Our results clarify the dependence of the surface doses on the imaging parameters and the pattern of the dose distribution in 2 orthogonal directions.

Methods and Materials

IGRT with a CyberKnife treatment unit (G3, Accuray Inc, Sunnyvale, CA) uses stereoscopic X-ray imaging. In this study, we used a Rando phantom (Alderson, Research Laboratories, Stanford, CA) for measuring surface doses in both the craniocaudal and the lateral directions (Fig. 1). The abdominal part of the phantom served as the largest region to take the measurements in both directions. Assuming X-ray tubes with imaging field dimensions of approx. 20×20 cm^2 at the isocenter of the treatment room, a distance of 30 cm was found to be sufficient for in-field and out-of-field surface dose measurements. After aligning the phantom according to the isocenter of the room, the intersection point of sagittal and axial laser beams on the phantom surface was considered the center of the measurement. The peripheral dose was defined as the dose measured at any point located out of the imaging field. The imaging field was the anatomic region exposed to primary photons originating from kV X-rays.[11] TLD100H thermoluminescence dosimeters (Harshaw, Solon, OH) and EBT2 gafchromic films (International Specialty Products, Wayne, NJ) were located at 0, ±5, ±10, and ±15 cm in the craniocaudal (+: cranial; –: caudal) and lateral (–: right; +: left) directions. For dose measurements, we defined "the field center," "in-field," "field edge," and "out-of-field" at 0, ±5, ±10, and ±15 cm from the center. At each measurement point, we used 3 Thermoluminescence Dosimetry (TLD) chips. On the other hand, gafchromic EBT2 pieces with dimensions of 5×5 cm^2 were placed in each measurement point to test the performance of the EBT2 films in kV imaging energy level.

In our department, X-ray tubes of the CyberKnife system, G3 Toshiba tubes, could acquire images with the maximal beam energy of 125 kVp. Thus, the imaging doses were

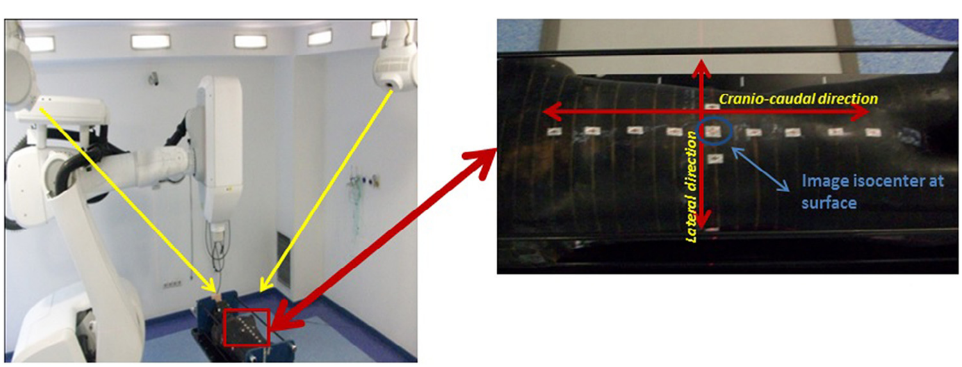

Fig. 1. The measurement locations of the TLD dosimeters and gafchromic films on the surface of the Alderson Rando phantom. The dosimeters were located at the center of the field and at the distances of ±5, ±10, and ±15 cm from the center, in the craniocaudal and lateral directions. (Color version of figure is available online.)