

論 文 内 容 要 旨

Split-VMAT technique to control the expiratory breath-hold time in liver stereotactic body radiation therapy

(肝臓癌の体幹部定位体放射線治療における呼気呼吸停止時間を制御する分割 VMAT 法)

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Purpose: The delivery time of volumetric modulated arc therapy (VMAT) is dependent on the angular velocity (e.g., degrees of gantry rotation per second) of a linear accelerator. We demonstrate the feasibility of using split-arcs in VMAT, tailored for expiratory breath-hold in stereotactic body radiation therapy (SBRT) for liver tumors. We compare it with three-dimensional conformal radiation therapy (3D-CRT) and continuous-VMAT, for ten randomly selected hepatocellular carcinoma cases.

Methods: Reproducibility of tumor position was confirmed within 5 mm using an X-ray fluoroscopy simulator (Acuity, Varian Medical Systems, Palo Alto, CA). Otherwise, Abches (Apex Medical Inc., Tokyo, Japan) was used as a monitor to self-control the respiratory motion and the tumor displacement. Radiation treatment planning images were taken, using a CT Lightspeed RT16 (GE Medical Systems, Hatfield, UK) scanner. Radiation treatment plans were created using the Pinnacle3 Planning System Version 9.6 (Philips, Fitchburg, WI), which was commissioned with the 5 mm MLC TrueBeam (Varian Medical Systems, Palo Alto, CA) linear accelerator. Four coplanar and four non-coplanar beams were used for the 3D-CRT plans. The beam angle selection was case dependent and the position of the MLC was manually adjusted in order to fit the prescribed isodose line to the planning target volume. A pair of partial arcs, chosen using a back-and-forth rotating motion, were used for the continuous-VMAT plans. Split-VMAT plans were created using the same arc range as the continuous-VMAT plans, but were split into smaller arcs ($< 90^\circ$), to simulate an expiratory breath hold of < 15 s. The prescription was 48 Gy/ 4 fractions, to 95% of the PTV, using 10 MV FFF X-ray beams. Dose distribution was measured using an EBT-eXtended Dose Gafchromic film (Ashland, Bridgewater, NJ, USA) on an I'mRT phantom (IBA Dosimetry GmbH, Schwarzenbruck, Germany). The dose difference, between the measured and the planned, was analyzed using a DD system (R-TECH, Inc., Tokyo, Japan). All VMAT plans were evaluated with a gamma criteria of 3% dose difference; and a 3 mm distance-to-agreement, at a threshold of 10% to the maximal dose. The acceptance level of the gamma agreement index was at least 95%. The treatment delivery efficiency, or total treatment time, was the summation of the patient-setup time, beam-on time, and intermediate time (e.g., the time needed for the next couch and gantry setup after the first beam was delivered). In this study, every patient-setup time was assumed to be the same, regardless of the technique of delivery. The beam-on time of VMAT was measured using a stopwatch with an estimated uncertainty of 1 s. Since no MLC segment movement was needed in the 3D-CRT planning, the dose rate was assumed to be relatively constant over the period of the 3D-CRT delivery. The beam-on time for 3D-CRT, was mathematically calculated using the obtained MU, divided by the applied dose rate 2400 MU/min. The dose distribution, treatment delivery efficiency, and patient specific quality assurance of the

VMAT, were verified to ensure that the outcomes were equal, or better than, those for 3D-CRT and continuous-VMAT.

Results: The mean dose of the liver-GTV was lower in the split-VMAT compared with that of 3D-CRT. Split-VMAT was more conformal compared with 3D-CRT. The total treatment time for split-VMAT was shorter than that of 3D-CRT. Similar dosimetric indices were observed for split-VMAT and continuous-VMAT. All VMAT plans passed the gamma acceptance test.

Conclusions: Although the continuous-VMAT had a very similar dose distribution compared with the split-VMAT, it was less efficient in controlling the beam-on time, due to the continuous gantry rotation. In the case of 3D-CRT, it could not be used to predetermine a comfortable breath-hold duration like what the split-VMAT could do. The split-VMAT in conjunction with expiratory breath-hold is a feasible clinical implementation for liver SBRT, because it does not compromise the quality of the plan compared with 3D-CRT. Since the expiratory breath-hold with Abches suppress tumor displacement within 5 mm, further verification, such as, the compliance of the gamma criteria, could firmly prove that 15 s expiratory breath-hold could be tailored using VMAT split-beams, without diminishing the quality of the plan. We have shown that this technique of delivery, a combination of expiratory breath-hold and split-VMAT, is a feasible, effective, and alternate method of 3D-CRT. The main advantages are that VMAT has a shorter total treatment time, which facilitates ease of practice, and is more patient and therapist friendly for HCC SBRT.