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Iridium-Knife: Another knife in radiation oncology

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ABSTRACT

PURPOSE: Intratarget dose escalation with superior conformity is a defining feature of three-dimensional (3D) iridium-192 (^{192}Ir) high-dose-rate (HDR) brachytherapy (BRT). In this study, we analyzed the dosimetric characteristics of interstitial ^{192}Ir HDR BRT for intrathoracic and cerebral malignancies. We examined the dose gradient sharpness of HDR BRT compared with that of linear accelerator–based stereotactic radiosurgery and stereotactic body radiation therapy, usually called X-Knife, to demonstrate that it may as well be called a Knife.

METHODS AND MATERIALS: Treatment plans for 10 patients with recurrent glioblastoma multiforme or intrathoracic malignancies, five of each entity, treated with X-Knife (stereotactic radiosurgery for glioblastoma multiforme and stereotactic body radiation therapy for intrathoracic malignancies) were replanned for simulated HDR BRT. For 3D BRT planning, we used identical structure sets and dose prescription as for the X-Knife planning. The indices for qualitative treatment plan analysis encompassed planning target volume coverage, conformity, dose falloff gradient, and the maximum dose–volume limits to different organs at risk.

RESULTS: Volume coverage in HDR plans was comparable to that calculated for X-Knife plans with no statistically significant difference in terms of conformity. The dose falloff gradient—sharpness—of the HDR plans was considerably steeper compared with the X-Knife plans.

CONCLUSIONS: Both 3D ^{192}Ir HDR BRT and X-Knife are effective means for intratarget dose escalation with HDR BRT achieving at least equal conformity and a steeper dose falloff at the target volume margin. In this sense, it can reasonably be argued that 3D ^{192}Ir HDR BRT deserves also to be called a Knife, namely Iridium-Knife.

Keywords: Iridium-Knife; X-Knife; High-dose-rate; Brachytherapy; Stereotactic radiosurgery; Stereotactic body radiation therapy

Introduction

After almost 3 decades of technological advances in external beam radiotherapy (EBRT), brachytherapy (BRT) appeals to clinicians in a way it could never do in the past with especially three-dimensional (3D) high-dose-rate (HDR) BRT (1, 2) playing an important role in the safe lesion-specific treatment of various tumor entities (3–11). Not surprisingly, the character of the most sophisticated EBRT technique, stereotactic body radiation therapy (SBRT) (12), matches the intrinsic characteristics of HDR BRT. In fact, the delivery of high biologic effective doses through hypofractionation, while ensuring maximized conformity through anatomy-oriented dose optimization (13, 14), is the defining feature of 3D HDR BRT, and its clinical experiences and dosimetric attributes subsume the

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concept of SBRT (15). Although the principles and practice of SBRT were transferred from stereotactic radiosurgery (SRS) (16), both modalities do not require frame-based stereotactic patient setup anymore and can be performed using either a linear accelerator (LINAC)−based multileaf collimator (MLC) or a dedicated robotic radiosurgery device. In the first case, the technique is also known as X-Knife (17) and in the second case as CyberKnife (18).

At this point, there is a fundamental question that needs to be confronted head-on. It concerns why the two latter techniques are called knives. Is it a matter of sharpness, and if yes, how is it defined and measured? Does it refer to their characteristic dosimetric attribute of a sharp dose gradient? If this serves as the main argument, then we may plausibly name 3D HDR BRT with iridium-192 (^{192}Ir) the way it would be reasonably justified, namely Iridium-Knife. In this context, several studies assessed the dosimetric differences between ^{192}Ir HDR BRT and SBRT in the treatment of primary and metastatic tumors, showing that HDR BRT achieves higher intratarget doses with a sharper dose falloff outside the target volume and predominantly lower maximum doses to adjacent organs at risk (OARs) compared with SBRT treatment planning (19−26). To add to this experience, we designed a treatment planning study selecting patients we treated with SRS for locally recurrent glioblastoma multiforme (GBM) or with SBRT for intrathoracic malignancies (IM) for comparative 3D interstitial (IRT) ^{192}Ir HDR BRT treatment plan analysis. As for the proof of principle, image-based ^{192}Ir HDR BRT has been effectively implemented in the treatment of recurrent GBM (27, 28) and IM (29, 30).

Methods and materials

Ten patients we treated with SRS for locally recurrent GBM or SBRT for IM (five of each entity with increasing tumor volumes) were selected for comparative ^{192}Ir IRT HDR BRT treatment plan analysis. We selected patients with target lesions of different dimensions, as we were interested to study the behavior of different dose parameters in dependence of target volume size. Concerning the patients for BRT planning, we selected patients whose treatment we would consider feasible also in clinical practice. SRS and SBRT treatment plans were prepared for the LINAC Artiste (Siemens Medical Solutions, Erlangen, Germany) with 160 MLC using the Oncentra MasterPlan v4.5 treatment planning software (Elekta, Veenendaal, The Netherlands) with a 20-beam noncoplanar and a 9- to 10-beam noncoplanar arrangement, respectively, and 6 MV energy. The used MLC consisted of 80 leave pairs with a projected width of 5.0 mm for the maximum radiation field of 400 × 400 mm^2. There were additional backup jaws in y-direction to improve shielding. With regard to delivery accuracy, the intersection point of the gantry, collimator, and table rotational axis of the LINAC was within the recommended sphere of ±1.0 mm radius (31), namely 0.7 mm. Concerning mechanical factors influencing the dosimetric accuracy of MLCs (32, 33), the 160 MLC of the used LINAC had an average leakage for the entire field of 0.37%. If the leaves were covered with additional jaws, the leakage was below 0.15% with a tongue-and-groove effect of 19%. With regard to radiation field sharpness in terms of penumbra (distance between the 80% and 20% isodose lines) (32, 33), the positioning accuracy and reproducibility of the leaf placement in our treatment setting were within 0.3 mm and less than 0.1 mm, respectively. As supplementary information relating thereto, a number of studies are reporting on the influence of MLC leaf width on SRS and SBRT dosimetric treatment quality (34−44). The common conclusion is, the smaller the leaf width the better the target conformity with associated adjacent healthy tissue sparing. MLCs of 2.5 and 3.0 mm width have been shown to be dosimetrically superior over those of 5.0 and/or 10.0 mm, especially for targets of less than 1.0 cm^3 volume.

For HDR BRT planning, we used identical structure sets and prescription doses for BRT as for the original X-Knife plans. Those doses were in the range between five fractions à 5.0 Gy up to 20.0 Gy in one fraction. To ensure improved normal tissue sparing, the isodose prescribed to encompass the planning target volume (PTV) was set to be 80% of the isocenter dose. The planning goal was to match the PTV coverage with the prescribed dose (PD) to the HDR BRT plan while ensuring equivalent OARs sparing. The HDR plans were prepared using the Oncentra Brachy v4.5 software (Elekta, Veenendaal, The Netherlands) with a hybrid inverse treatment planning optimization algorithm for optimization of dose distribution (45). The number of catheters for the BRT plans ranged from 6 to 10. The source step selected for planning was 2.5 mm in all cases. The average number of activated dwell points pro cm^3 PTV was 3.01. The HDR plans for this dosimetric comparison study were prepared in the same way as we do in clinical practice. The respective techniques of IRT HDR BRT for recurrent GBM and IM have been described in detail elsewhere (28, 30).

For analysis, dose−volume histograms for each treatment plan were generated, and comparisons were made using the paired Student's t test with a p-value of 0.05 as threshold for significance. The parameters considered for the evaluation of treatment plan quality included (46−54) the following:

PTV coverage

$V_{100}/V_{95}/V_{90}/V_{150}$: percentage volume of the PTV receiving 100%/95%/90%/150% of the PD, respectively.

D_{95}/D_{99}: percentage of the prescription dose covering 95%/99% of the PTV, respectively.

D_{min}: minimum dose within PTV as percentage of the PD.