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Comparison of spinal Stereotactic Body Radiotherapy (SBRT) planning techniques: intensity-modulated radiation therapy, modulated arc therapy, and helical tomotherapy

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A B S T R A C T

Stereotactic body radiotherapy (SBRT) delivers a highly conformal, hypofractionated radiation dose to a small target with minimal radiation applied to the surrounding areas. Therefore, using the proper treatment planning techniques for SBRT is important. Intensity modulation techniques, such as static intensity-modulated radiation therapy (IMRT), modulated arc therapy (mARC), and helical tomotherapy (HT), are useful for spinal SBRT because of a rapid dose fall-off and spinal cord avoidance. This study compared the planning characteristics for hypofractionated spinal SBRT administered using 3 treatment techniques. The factors evaluated for spinal SBRT planning were dose coverage, cord avoidance, target conformity, homogeneity, and dose spillage. Target coverage was 82.74% ± 3.35%, 80.92% ± 0.81%, and 85.01% ± 7.27% for IMRT, mARC, and HT, respectively. HT was therefore a powerful technique with respect to target coverage. The spinal cord dose for HT (mean, 1763.96 cGy; standard deviation [SD], 164.48) was significantly different from those for mARC (mean, 1991.75 cGy; SD, 248.00) and IMRT (mean, 2053.24 cGy; SD, 164.48). In addition, the partial spinal cord volume at 2000 cGy for HT (mean, 0.12 cc, SD, 0.01) was significantly different from those for IMRT and mARC (0.50 ± 0.10 cc and 0.56 ± 0.25 cc, respectively). The conformity index was 1.30 ± 0.12, 1.08 ± 0.05, and 1.36 ± 0.23 for IMRT, mARC, and HT planning, respectively. mARC showed the highest conformity ($p = 0.000$). HT used a narrow field fan beam and exhibited remarkable improvement of target coverage and cord dose, offering an important benefit to spinal SBRT. mARC had the highest target conformity and better high- and intermediate-dose spillage than HT and IMRT did, respectively. These planning techniques have different advantages. In the case of spine SBRT, HT should be used for cord avoidance. In some cases, such as for a short treatment duration when the patient is considered to be in a poor general condition, mARC can be used.

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Introduction

Hypofractionated spinal stereotactic body radiotherapy (SBRT) has been shown to relieve pain effectively and rapidly and to improve neurologic function in patients with or without epidural cord compression.[1] SBRT permits minimal radiation exposure outside the target; the most critical issues associated with this procedure are related to spinal cord dose tolerance. Depending on the vertebral level of spinal metastasis, adjacent organs should be considered organs at risk (OARs). The tolerance of OARs to radiation from conventional fractionated radiation therapy is based on the entire organ or on a considerably large irradiated volume. SBRT delivers a highly conformal, hypofractionated radiation dose to a small target with minimal exposure of the surrounding areas to radiation.[2] Therefore, using proper treatment planning techniques for SBRT is important. Intensity modulation techniques, such as static intensity-modulated radiation therapy (IMRT), modulated arc therapy (mARC), and helical tomotherapy (HT), are useful for spinal SBRT because of target conformity, avoidance of the spinal cord, and rapid dose fall-off. Depending on the clinical cases or situation, the required techniques can be different. This study compared the planning characteristics for hypofractionated spinal SBRT administered using 3 treatment techniques.

Methods and Materials

This retrospective analysis of 18 patients treated with spinal SBRT at Seoul St. Mary's Hospital was approved by the Institutional Review Board (IRB No.: KC16RISI0763).

Patient demographics

This study included 18 patients with spinal lesions treated using HT at Seoul St. Mary's Hospital. mARC and IMRT plans were replanned. Table 1 shows the patient demographics.

Table 1
Patient demographics

Patient Demographics	
Sex	
Male (*n*)	10
Female (*n*)	8
Median age (y)	54
Histology	
Renal cell cancer (*n*)	5
Pancreatic cancer (*n*)	3
Breast cancer (*n*)	3
Hepatocellular carcinoma (*n*)	2
Colon cancer (*n*)	2
Intrahepatic cholangiocarcinoma (*n*)	2
Esophageal cancer (*n*)	1
Lesion	
C spine (*n*)	1
T spine (*n*)	10
L spine (*n*)	7

C, cervical; T, thoracic; L, lumbar.

Treatment planning techniques and equipment

HT, mARC, and IMRT were compared for OAR dose reductions and target coverage improvement. All plans were mono-isocentric, with the isocenter placed in the structural center of the planning target volume (PTV). A 6-MV flat photon beam was used. IMRT plans were generated using the Pinnacle^3 version 9.10 treatment planning system (Pinnacle^3 9.10, Philips, Amsterdam, The Netherlands). The IMRT plans consisted of 11 fixed-gantry angle beams oriented to cover the PTV. Most of the beams' gantry angles were spaced apart equally by 30°. However, some beams were oriented differently as needed to preferentially avoid certain organs that were at risk of damage from the radiotherapy, such as the lung. Digital Imaging and Communications in Medicine images of each patient with complete target and organ segmentation information were transferred into the tomotherapy planning system (Hi-Art 5.1.0, Accuray, Madison, WI). In HT, a narrow intensity-modulated pencil beam was delivered from a rotating gantry while the patient was simultaneously moved through the bore, in contrast to the much wider intensity-modulated beam and static patient in conventional IMRT.[3] To increase cord avoidance and target coverage, the field width and pitch parameters considered were 1.05 cm and 0.105 cm, respectively. Tomotherapy treatment used only a nonflat 6-MV energy photon (Tomo Hi-Art, Accuray, Sunnyvale, CA). mARC consisted of modulated arc therapy using the "burst mode" in the arc planning system (Prowess Panther 5.20.4218, Prowess Inc., Concord, CA). Burst mode delivery differs from continuous mode delivery because the dose is not delivered while the multileaf collimator leaves are moving. Instead, the dose is delivered in bursts over very short arc angles and only after a multileaf collimator segment shape has been completely formed and verified by the controller.[4] However, it is similar to continuous mode arc therapy with respect to the number of control points. mARC plans were assigned to 255 control points in each plan. These plans used 3 full arcs to avoid the spinal cord, with 1 arc with the collimator at 0° and 2 arcs with the collimator at 90°. The control points of the 3 full arcs barely overlapped. IMRT and mARC used a Siemens image-guided radiation treatment system (Artiste CT with CT on rail, Siemens, Erlangen, Germany).

Target and organ delineation

Figure 1 shows a diagram of spine metastases and corresponding clinical target volumes (CTVs).[5] Figure 1A shows