Dosimetric advantages afforded by a new irradiation technique, Dynamic WaveArc, used for accelerated partial breast irradiation

Yuka Ono,a Michio Yoshimura,a,b Kimiko Hirataa, Tomohiro Onoa, Hideaki Hirashimaa, Nobutaka Mukumota,a Mitsuhiro Nakamura,a,b Minoru Inouea, Masahiro Hiraokaa, Takashi Mizowakia

a Department of Radiation Oncology and Image-applied Therapy, Graduate School of Medicine, Kyoto University, 54 Shogoin Kawahara-cho, Sakyo-ku, Kyoto 606-8507, Japan
b Division of Medical Physics, Department of Information Technology and Medical Engineering, Human Health Sciences, Graduate School of Medicine, Kyoto University, 53 Kawahara-cho, Shogoin, Sakyo-ku, Kyoto 606-8507, Japan

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ABSTRACT

Purpose: To identify dosimetric advantages of the novel Dynamic WaveArc (DWA) technique for accelerated partial breast irradiation (APBI), compared with non-coplanar three-dimensional conformal radiotherapy (nc3D-CRT) and coplanar tangential volumetric modulated arc therapy (tVMAT) with dual arcs of 45°–65°.

Methods: Vero4DRT enables DWA by continuous gantry rotation and O-ring skewing with movement of the multi-leaf collimator. We compared the dose distributions of DWA, nc3D-CRT and tVMAT in 24 consecutive left-sided breast cancer patients treated with APBI (38.5 Gy in 10 fractions). The average doses and volumes to the planning target volume (PTV) and organs at risk, especially heart and left anterior descending artery (LAD) were compared among DWA, nc3D-CRT and tVMAT.

Results: The doses and volumes to the PTVs did not differ significantly among the three plans. For the DWA plans, the mean dose to the heart was 0.2 ± 0.1 Gy, less than those of the nc3D-CRT and tVMAT plans. The D2% values of the planning organ at risk volume of the LAD were 9.3 ± 10.9%, 28.2 ± 31.9% and 20.3 ± 25.7% for DWA, nc3D-CRT and tVMAT, respectively. The V20Gy and V10Gy of the ipsilateral lung for the DWA plans were also significantly lower.

Conclusions: DWA allowed to find a better compromise for OAR which overlapped with the PTV. Use of the DWA for APBI improved the dose distributions compared with those of nc3D-CRT and tVMAT.

1. Introduction

Breast-conserving therapy is well-accepted for early-stage breast cancer [1,2]. Accelerated partial breast irradiation (APBI) targets tissues surrounding the lumpectomy cavity and reduces the doses to the organs at risk (OARs); APBI is an option after breast-conserving surgery. The National Surgical Adjuvant Breast and Bowel Project (NSABP) B-39/Radiation Therapy Oncology Group (RTOG) 0413 performed a phase III randomized trial to evaluate the effectiveness of APBI compared with whole-breast irradiation (WBI) for early-stage breast cancer patients [3]. APBI can be delivered via several techniques, including brachytherapy [4–7], intraoperative radiotherapy [8–10] and external radiotherapy [11,12] using three-dimensional conformal radiotherapy (3D-CRT), intensity-modulated radiotherapy (IMRT) and volumetric-modulated arc therapy (VMAT). In addition, it was proposed to use dedicated devices such as the Cyberknife (Accuray, Incorporated, Sunnyvale, CA) or the Vero4DRT (Mitsubishi Heavy Industries, Ltd., Japan and BrainLAB AG, Feldkirchen, Germany) [13–15].

Although the toxicities associated with breast irradiation are rather infrequent today, breast irradiation has been associated with cardiac toxicity [16–18], radiation pneumonitis [19,20] and poor cosmesis [21]. APBI planning studies have been conducted using several delivery techniques [22,23]. Among them, IMRT and VMAT spread the low-dose regions toward the heart, lungs and contralateral breast. Even low-dose irradiation can trigger secondary cancers in early-stage breast cancer patients [24,25]. To resolve this problem, Shaitelman et al. and Popescu et al. suggested a new irradiation technique: continuous arc rotation of the couch (C-ARC) or continuous couch and gantry dynamic arc therapy [26,27]. This technique maintains the benefits of standard tangent beam APBI performed using non-coplanar 3D-CRT (nc3D-CRT), the
couch is rotated through one medial and one lateral arc. In addition, the technique reduces radiation doses to the OARs without compromising target coverage and is similar to VMAT. To put it simply, C-ARC exhibits the best features of both nc3D-CRT and VMAT. Although C-ARC is theoretically possible, C-ARC is seldom applied in practice, because most linear accelerator units do not possess the necessary capabilities. Moreover, C-ARC may be associated with setup errors caused by intra-fraction motion when dynamically rotating the couch.

Dynamic WaveArc (DWA) therapy is a new irradiation technique implemented in Vero4DRT [28]. The Vero4DRT has a unique feature of the O-ring gantry (Fig. 1). The gantry head can be rotated ± 180° around the inner circumference. The O-ring can be rotated 360° around the isocenter and can be skewed ± 60° around its vertical axis [29]. DWA therapy is a novel irradiation approach that represents the continuous and simultaneous rotation of both the gantry head and O-ring. The O-ring skewing replaces couch rotation; non-coplanar irradiation is performed effectively and safely. Our group developed a commissioning and quality assurance procedure for DWA [30,31]. The clinical application of DWA has been realized using RayStation for Vero4DRT [32]. We hypothesized that we could use Vero4DRT to create ideal irradiation for APBI.

In the present study, we adapted the novel DWA technique for APBI and generated two arcs of DWA trajectory to avoid direct beam entry into OARs, especially the heart. To explore dosimetric advantages afforded by DWA treatment, we compared the dose distributions of DWA, nc3D-CRT and coplanar tangential VMAT (tVMAT) with dual arcs of 45–65°. Furthermore, to verify that DWA could be delivered, we employed a three-dimensional diode array and measured the delivery time. To the best of our knowledge, this is the first attempt to perform APBI using DWA.

2. Materials and Methods

2.1. Patient population

From November 2011 to April 2016, 48 breast cancer patients were treated with APBI using nc3D-CRT in a single-institution clinical trial approved by our institutional review board. The eligible patients were women > 40 years with early-stage breast cancer (maximum diameter 3-cm) eligible for breast-conserving surgery; clipping of the surgical margin was required. In the present study, we examined the data from 24 consecutive left-sided breast cancer patients in terms of the irradiated volumes in the heart and coronary artery. The distances from the surface of the heart to the cavity were measured three dimensionally, and the closest distance was defined as the distance from the heart to the cavity. Table 1 lists the tumor locations and heart-to-cavity distances.

2.2. Contouring of target volumes and OARs

CT images (2.5-mm thick) were obtained from the mandible to the upper abdomen and transferred to the treatment planning system. The lumpectomy cavity was outlined, and the clinical target volume (CTV) was expanded by adding 1-cm margins. The planning target volume (PTV) was defined by adding 1-cm margins to the CTV. To evaluate dose coverage, PTV evaluation (PTV_EVAL) was performed, excluding 2-mm beneath the body surface. The heart was contoured from the level at which the pulmonary trunk branched into the left and right pulmonary arteries [3]. The left anterior descending artery (LAD) was contoured using the University of
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