Journal of
Nuclear Medicine & Radiation Therapy

Monzen et al., J Nucl Med Radiat Ther 2015, 6:4
DOI: 10.4172/2155-9619.1000238

Research Article Open Access

Impact of the Vero4DRT (MHI-TM2000) on the Total Treatment Time in Stereotactic Irradiation

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Received date: June 29, 2015**, Accepted date:** July 29, 2015, **Publication date:** July 31, 2015

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Abstract

Background: This study compared features of the Vero4DRT system with those of conventional systems, focusing on the total treatment time and patient safety.

Methods: Individual treatment times for brain stereotactic radiotherapy (SRT) and stereotactic body radiation therapy (SBRT) were compared among the Vero4DRT, Novalis, and Clinac iX systems. The mean total treatment time was calculated by summing the entire time required for the radiation treatment. The total treatment time for both brain SRT and SBRT with non-coplanar fields was markedly shorter with the Vero4DRT system than the others.

Results: For SBRT, the treatment time with the Vero4DRT system was reduced by 40%, compared with the time using a Clinac iX (13.8 vs. 20.3 min). For SRT, the treatment time with Vero4DRT was 20% shorter than with the Novalis system. With Vero4DRT, all treatments were completed within 14 min, with a significant reduction in the kV-image acquisition and image merging times.

Conclusion: The total treatment time using the Vero4DRT system was significantly shorter compared with conventional options in clinical settings; the shorter treatment time also offered the advantages of minimal intrafractional body movement, as well as better patient throughput.

Keywords: Vero4DRT; Stereotactic irradiation; Non-coplanar beam delivery; Patient throughput; Treatment time

Introduction

Jointly developed by Kyoto University, Mitsubishi Heavy Industries, and the Institute of Biomedical Research and Innovation [1-3], the Vero4DRT system is a high-precision radiotherapy system with dynamic tracking irradiation. One of the major features of this system is its circular gantry or O-ring. The biaxial rotational function of the O-ring of the Vero4DRT system (hereafter, O-ring function) allows non-coplanar field treatment, without having to move the couch, as shown in Figure 1.

With conventional general-purpose linear accelerators, the operator must enter the treatment room to rotate the couch before beginning non-coplanar field irradiation. With the Vero4DRT system, there is no need to move the couch; consequently, seamless treatment can be provided remotely from the control room, shortening the treatment time. Hoogeman et al. showed that the patient's drift from their initial position during a treatment fraction becomes significant for high-precision treatments with treatment times of 15 min or longer [4]. The total treatment time is important factor for high-precision treatments and these features of the Vero4DRT system may effectively reduce intrafractional body movement, minimizing patient distress and improving patient throughput.

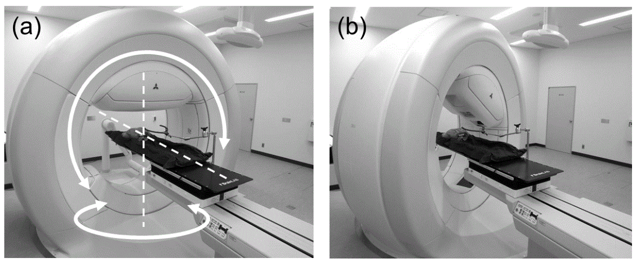

Figure 1: O-ring function of the Vero4DRT system. Biaxial rotation of the O-ring facilitates stable treatment without moving the couch. The range of rotation of the O-ring is ±60 degrees: (a) coplanar and (b) non-coplanar fields.

Previous studies using Vero4DRT showed that its multileaf collimator (MLC) could achieve high leaf position accuracy and low leakage led to highly accurate intensity-modulated radiotherapy (IMRT) [5]. It was also shown that the unique gimbaled x-ray head of a Vero4DRT is capable of high-accuracy x-ray-image-based and infrared-marker-based dynamic tumor-tracking irradiation [6,7]. The vero4DRT system is available for many radiotherapy techniques such as dynamic tracking irradiation, three-dimensional conformal radiotherapy, dynamic conformal arc therapy and intensity-modulated radiotherapy, stereotactic (body) radiotherapy, for malignant neoplasm of lung, liver, brain and prostate.

In this study, we assessed the usefulness of the Vero4DRT system by comparing the total treatment time in stereotactic irradiation required to complete the treatment plans prepared for phantom studies with the Clinac iX and Novalis systems.

Materials and Methods

Equipment

Three linear accelerators were compared in this study: Vero4DRT (MHI-TM2000, Mitsubishi Heavy Industries, Japan, and Brainlab, Feldkirchen, Germany), Clinac iX (Varian Medical Systems, Palo Alto, CA), and Novalis (Brainlab, Feldkirchen, Germany). Individual treatment times for brain SRT were compared between the Vero4DRT and Novalis systems. The treatment times for SBRT were compared among the Vero4DRT, Clinac iX, and Novalis systems. Figure 2 shows the immobilization devices for the head-and-neck mask system (Brainlab, Feldkirchen, Germany) and BodyFIX (Medical Intelligence, Schwabmunchen, Germany) prepared for each humanoid phantom (PBU-10; KyotoKagaku, Kyoto, Japan) of the head and chest. Computed tomography (CT) images for treatment planning were acquired with a GE LightSpeed RT16 CT simulator (General Electric Medical Systems, Milwaukee, WI, USA). Treatment plans were prepared using iPlan ver. 4.1.2 (Brainlab, Feldkirchen, Germany).

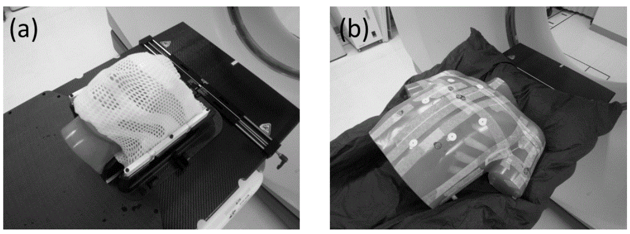

Figure 2: (a) Head and (b) chest phantom studies with an immobilizer.

Measuring the treatment time

The prepared treatment plans were forwarded to each linear accelerator. Phantoms were irradiated with a static multi-leaf collimator, and the treatment times were measured. For the Vero4DRT, Clinac iX, and Novalis systems, the dose rates were 500, 500, and 480 cGy min−1, respectively. We did not correct the beam delivery time for different dose rates, because the difference was minimal (at most 7.2 s). The total treatment time was calculated by summing the individual times required for (a) the initial laser setup, (b) image acquisition, image registration, and couch correction, (c) verification of the patient position, (d) cone beam CT (CBCT) acquisition for SBRT, and (e) beam delivery time. For SBRT, the couch correction for the Clinac iX and Novalis systems was measured only for three-dimensional (3D) correction. By contrast, the couch correction for the Vero4DRT was measured separately for 3D and six-dimensional (6D) correction. CBCT imaging was performed at our hospital in a clinical setting, using the following parameters. For the Vero4DRT system, scans were acquired using a gantry rotation of 200° and a field of view (FOV) of 215 mm for all treatment plans. For the Clinac iX system, scans were acquired in half-fan mode with a large FOV (gantry rotation 360°; FOV 450 mm).

SRT (Vero4DRT versus Novalis)

Two SRT treatment times, which are shown Table 1(a), were acquired during the irradiation process by pairs of experienced radiation therapists or medical physicists. For brain SRT, the irradiation parameters are summarized in Table 1. SRT treatment was performed using the conformal arc technique.

SBRT (Vero4DRT versus Novalis and Clinac iX)

For SBRT, the dose per fraction was set at 1200 cGy, and seven fields were used; four of the seven were non-coplanar. The irradiation parameters are summarized in Table 1. Data were acquired during the irradiation process by pairs of experienced radiation therapists or medical physicists. The mean times were calculated from three sets of acquired data, and the treatment times were compared.

(a) SRT(Vero4DRT versus Novalis)					
Plan	Dose (cGy/fraction)	Arc number	Ring or Couch (degree)	Gantry (degree)	Monitor unit
A	180	1	0	20 - 160	63
		2	320	60 - 160	74
		3	40	200 - 300	54
		4	0	230 - 340	52
B	180	1	315	40 - 150	84
		2	0	50 - 130	50
		3	45	205 -325	77
		4	0	240 - 320	45
(b) SBRT(Vero4DRT versus Novalis and Clinac iX)					
Dose (cGy/fraction)		Field number	Ring or Couch (degree)	Gantry (degree)	Monitor unit
		1	0	175	226
		2	20	210	232
		3	340	255	281
	1200	4	280	280	259
		5	340	350	196
		6	0	350	204
		7	0	25	209

Table 1: Treatment plan parameters for brain stereotactic radiotherapy (SRT) and stereotactic body radiotherapy (SBRT).

Results

Tables 2 and 3 show the treatment times for brain SRT and SBRT, respectively. For each of the brain SRT irradiation methods, the treatment time per patient using the Vero4DRT system was approximately 20% shorter than that for the Novalis system (8.4 vs. 10.6 min). The treatment times with the Vero4DRT for SBRT using a non-coplanar field was markedly shorter, with treatment provided in about three-fifths of the time required for the Clinac iX system (13.8 vs. 20.3 min). The SBRT irradiation method and treatment time per patient for the Vero4DRT system were shorter than those measured for the Novalis system (13.8 vs. 16.1 min); however, the Vero4DRT system was functioning in cone-beam CT imaging mode. To evaluate the throughput for multiple patients in a scenario closer to that of a clinical setting, we conducted a simulation of the number of patients that could be treated with similar treatments within a 1-h period (Table 3). For SBRT, the hourly patient throughput for the Vero4DRT system, compared with the Clinac iX and Novalis systems, was about 4.6, 3.0 and 3.7 patients, respectively.

	Time (min)			
Treatment device	**Vero 4DRT**		**Novalis**	
Treatment plan	A	B	A	B
Brain SRT				
Initial laser setup	0.94	1.28	1.61	1.66
Image acquisition, image registration, and couch correction	1.43	1.23	1.67	1.25
Verification of the position (Option)	0.94	0.86	1.02	0.89
Beam delivery	4.92	5.17	6.81	6.21
Total	8.23	8.54	11.11	10.1

Table 2: Comparison of the treatment time for SRT (Vero4DRT versus Novalis).

	Time (min)			
Treatment device	Vero 4DRT		Clinac iX	Novalis
Couch correction	3D	6D	3D	3D
SBRT				
Initial laser setup	1.50		1.05	1.32
Image acquisition, image registration, and couch correction	1.08	1.35	2.48	1.23
Verification of the position (Option)	0.50		1.22	0.80
Cone beam CT imaging	2.08		4.74	-
Beam delivery	7.92		10.80	12.77
Total	13.08	13.35	20.29	16.12

Table 3: Comparison of the treatment time for SBRT (Vero4DRT versus Novalis, Clinac iX).

Discussion

The total treatment time for the Vero4DRT system was shorter than that measured for the Clinac iX and Novalis systems. When providing treatment using a non-coplanar field with the Clinac iX or Novalis systems, the operator must enter the treatment room to rotate the couch. In the treatment plans used in our study, the Novalis operators had to enter and leave the treatment room at least twice for brain SRT and at least three times for SBRT. However, using the O-ring function of the Vero4DRT system, the operator was not required to enter the treatment room for couch adjustments, which might have led to the shortened treatment time.

Given the slight time difference observed among individual patients, we speculated that a substantial difference would be evident in a clinical setting when multiple patients were involved. Note that the times required for patient movement and gowning were not included in the treatment times; these results must be regarded as reference values only and would differ depending on the number of patients in the clinical setting. With the Clinac iX and Novalis systems, the operator has the additional task of adjusting the couch manually. This not only adds to the treatment time, but also contributes to the patient's psychological burden and anxiety due to couch movement. By contrast, the Vero4DRT system features fully automated control using the O-ring function from the control room. High spatial accuracy can be achieved with the Vero4DRT, without any movement of the couch, potentially reducing patient anxiety and increasing safety by a significant margin. In addition, because there is no need to move within the room, the Vero4DRT system offers an advantage in terms of safety management in that the patients can be monitored constantly.

Compared with 3D correction for the Vero4DRT system, 6D correction capabilities could be added to this system with a small increase in the treatment time of about 15 s. The Novalis system was one of the first to be equipped with 6D couch-correction capabilities. By combining 3D movement in the vertical, longitudinal, and lateral directions with three rotational directions (roll, pitch, and yaw), 6D correction can be achieved. 6D patient setup verification and automatic correction provide more accurate compensation of the setup geometrical deviation than 3D correction in SBRT [8]. With the Vero4DRT system, the O-ring functionality adds ring rotation of the couch to the three horizontal directions (vertical, longitudinal, and lateral) and two rotational directions (roll and pitch), providing a unique mechanism for achieving 6D correction. This 6D correction mechanism is unique to the Vero4DRT; the system navigates an operation-reproducible and speedy setup for radiation therapy.

In addition to the advantage of providing treatment in a non-coplanar field in a short time, the CBCT imaging time with the Vero4DRT was shorter. Compared with the CBCT imaging time of 4.74 min for the Clinac iX system, the imaging time for the Vero4DRT was less than half that, at 2.08 min for SBRT. A previous study reported that the average IGRT procedure time using a kV imaging system attached to a medical linear accelerator was 3–4 minutes [9]. There are two perpendicularly arranged x-ray tubes in the Vero4DRT system; consequently, simultaneous irradiation is possible without having to move the x-ray tube or detector to the required imaging position. In addition, a bow-tie filter is not necessary. Consequently, the Vero4DRT system facilitates efficient extra scanning.

Shorter treatment times might affect the intrafractional patient motion. Hoogeman et al. showed that the patient's drift from their initial position during a treatment fraction becomes significant for high-precision treatments with treatment times of 15 min or longer [4]. Tables 2 and 3 showed that all of the measured individual treatment times for Vero4DRT were within 14 min. According to the previous report, the mean treatment time for Helical TomoTherapy performing IGRT was 18.3 min per patient treatment [10]. The Vero4DRT is superior to conventional systems in terms of minimizing intrafractional patient motion. Furthermore, previous studies showed that shortening the treatment time using this recent change in technology could improve patient throughput, allowing more patients to be treated per hour [11]. This effect would significantly improve the linear accelerator throughput of a clinic and provide economic benefit.

Our results indicate that compared with conventional methods, high-precision irradiation using the Vero4DRT in a non-coplanar field requires considerably less time. The system holds promise for improving beam-delivery precision by reducing the intrafractional setup error. The use of the Vero4DRT, compared with other systems, minimizes patient stress by reducing the amount of time under prolonged restraint, with the added economic benefit of improved throughput.

By contrast, in the Clinac iX and Novalis systems, arc arrangement from a caudal direction is usually difficult to achieve, due to the risk of collision between the gantry head and patient undergoing stereotactic irradiation. For small tumors, arcs from only horizontal and cranial directions would be sufficient for high-dose treatment homogeneity to the target. For large tumors, however, this approach might be insufficient, due to the inhomogeneity of the dose distribution within the targets from the cranial to caudal direction, such that fewer doses are delivered to the caudal part of the target. Ogura et al. reported that the caudal directions using Vero4DRT could improve target homogeneity and conformity for skull-base tumors, compared with other stereotactic irradiation systems [12].

Conclusion

Compared with conventional treatment systems, use of the Vero4DRT therapeutic system can greatly shorten the treatment time; additional economic benefits were achieved with improved patient throughput. The system reduced the psychological burden on operators and patients via its fully automated control using the O-ring function.

Acknowledgments

This work was supported in part by Grants-in-Aid for scientific research from the Ministry of Education, Culture, Sports, Science, and Technology, Japan (24591838), and the Center of Innovation Program from Japan Science and Technology Agency, JST. The sponsor played no role in the study design; i.e., in the collection, analysis, and interpretation of the data; nor in the writing or the decision to submit this manuscript for publication.

References

1. Kamino Y, Miura S, Kokubo M, Yamashita I, Hirai M, et al. (2007) Development of an ultrasmall C-band linear accelerator guide for a four-dimensional image-guided radiotherapy system with a gimbaled x-ray head. Med Phys 34: 1797-1808.
2. Kamino Y, Tsukuda K, Kokubo M, Miura S, Hirai E, et al. (2007) Development of a new concept automatic frequency controller for an ultrasmall C-band linear accelerator guide. Med Phys 34: 3243-3248.
3. Kamino Y, Takayama K, Kokubo M, Narita Y, Hirai E, et al. (2006) Development of a four-dimensional image-guided radiotherapy system with a gimbaled X-ray head. Int J Radiat Oncol Biol Phys 66: 271-278.
4. Hoogeman MS, Nuyttens JJ, Levendag PC, Heijmen BJ (2008) Time dependence of intrafraction patient motion assessed by repeat stereoscopic imaging. Int J Radiat Oncol Biol Phys 70: 609-618.
5. Nakamura M, Sawada A, Ishihara Y, Takayama K, Mizowaki T, et al. (2010) Dosimetric characterization of a multileaf collimator for a new four-dimensional image-guided radiotherapy system with a gimbaled x-ray head, MHI-TM2000. Med Phys 37: 4684-4691.
6. Mukumoto N, Nakamura M, Sawada A, Takahashi K, Miyabe Y, et al. (2012) Positional accuracy of novel x-ray-image-based dynamic tumor-tracking irradiation using a gimbaled MV x-ray head of a Vero4DRT (MHI-TM2000). Med Phys 39: 6287-6296.
7. Mukumoto N, Nakamura M, Sawada A, Suzuki Y, Takahashi K, et al. (2013) Accuracy verification of infrared marker-based dynamic tumor-tracking irradiation using the gimbaled x-ray head of the Vero4DRT (MHI-TM2000). Med Phys 40: 041706.
8. Spadea MF, Baroni G, Riboldi M, Luraschi R, Tagaste B, et al. (2008) Benefits of six degrees of freedom for optically driven patient set-up correction in SBRT. Technol Cancer Res Treat 7: 187-195.
9. Burnet NG, Adams EJ, Fairfoul J, Tudor GS, Hoole AC, et al. (2010) Practical aspects of implementation of helical tomotherapy for intensity-modulated and image-guided radiotherapy. Clin Oncol (R Coll Radiol) 22: 294-312.
10. Fox TH, Elder ES, Crocker IR, Davis LW, Landry JC, et al. (2006) Clinical implementation and efficiency of kilovoltage image-guided radiation therapy. J Am Coll Radiol 3: 38-44.
11. Delaney GP, Shafiq RJ, Jalaludin BB, Barton MB (2005) Technology enhancements and changes in radiotherapy throughput in New South Wales. Clin Oncol (R Coll Radiol) 17: 305-310.
12. Ogura K, Mizowaki T, Ishida Y, Hiraoka M (2014) Dosimetric advantages of O-ring design radiotherapy system for skull-base tumors. J Appl Clin Med Phys 15: 4608.