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Comparison of dosimetric parameters in radiotherapy plans for gastric cancer between two accelerators

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► ***Short Report***

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ABSTRACT

Background: This study compares treatment plans for gastric cancer patients generated using the Varian IX linear accelerator (linac) and the uRT-Linac 506C. ***Materials and Methods:*** A retrospective analysis was performed on ten gastric cancer patients. Treatment plans were initially created using Varian Eclipse v13.5 treatment planning system (TPS) and uRT-TPS for intensity-modulated radiation therapy (IMRT), respectively; all plans were developed by an experienced physicist and determined to be clinically acceptable. Dosimetric parameters were compared for the planning target volume (PTV) and organs at risk (OARs), including the conformity index (CI), homogeneity index (HI), and monitor unit (MU) efficiency. The delivery accuracy of both accelerator systems was assessed using gamma index analysis. ***Results:*** Results indicated that the uRT-Linac 506C provided superior dose conformity and target volume coverage compared to the Varian IX linac, as evidenced by a higher V45/% parameter for the uRT-Linac 506C. For the left kidney, the Varian IX linac had a significantly lower maximum dose (Dmax); however, its mean dose (Dmean), V10, and V20 were significantly higher than those of the uRT-Linac 506C. Similar trends were observed for the right kidney and liver, where the Varian IX linac exhibited significantly higher doses and volumes for specific parameters. ***Conclusion:*** In conclusion, both linacs can achieve clinical requirements for gastric cancer radiotherapy; however, the uRT-Linac 506C demonstrated improved dose conformity and target coverage in this study. Further research is warranted to validate these findings and investigate potential clinical implications.

INTRODUCTION

Gastric cancer remains a significant global health concern as one of the most commonly diagnosed malignancies [1]. While surgery is a primary treatment modality, patients treated with surgery alone often experience limited survival. The INT0116 trial, a seminal study conducted in the United States, demonstrated that concurrent chemoradiotherapy significantly improves local control and survival in patients with gastric cancer [2, 3]. These findings highlight the crucial role of radiotherapy as part of a multidisciplinary approach to treating gastric cancer.

Advancements in technology have led to the widespread adoption of intensity-modulated radiation therapy (IMRT) and volumetric modulated Arc therapy (VMAT), which have largely superseded conventional conformal radiation therapy. These modern techniques provide improved dose distribution, closely conforming to the shape of the target area, while optimizing target dose homogeneity and minimizing radiation exposure to surrounding healthy tissues [4-6]. This shift reflects the increasing emphasis on precision radiotherapy, which aims to deliver highly accurate radiation to maximize therapeutic effects and reduce treatment-related toxicities [7-9].

Several factors influence IMRT dose delivery, including the Treatment Planning System (TPS) used, the modulation techniques applied, and the beam configuration (fan beam or cone beam) [10]. While variations in TPS calculations for the same beam and segment sequence can lead to different results, these differences are typically less pronounced than the variations resulting from different optimization strategies implemented by TPS manufacturers [11]. Therefore, a thorough understanding of these factors is essential for optimizing radiotherapy outcomes.

Recent advancements have led to the introduction of the uRT-linac 506 series by United Imaging Healthcare Technology Co., Ltd., marking a significant shift in the field of medical linear accelerators. Notably, the uRT-linac 506c is recognized as the world's first CT imaging-guided IMRT system. This innovative device integrates diagnostic spiral CT technology with a high-dose-rate intensity-modulated accelerator, making it the only system equipped with both high-definition image-guided IMRT and patient CT simulation capabilities [12-14]. This unique combination greatly enhances the precision and efficiency of radiotherapy, positioning the uRT-linac 506c as a promising advancement in

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radiation therapy.

Varian accelerators, recognized for their reliability, efficiency, and long lifespan, remain a mainstay in the medical accelerator field. These systems have been extensively validated and employed in diverse clinical settings, contributing to their widespread acceptance. However, with the increasing importance of precision in radiotherapy and the emergence of innovative technologies such as the uRT-linac 506c, a comparative assessment of their dosimetric performance against established systems like Varian machines is essential. This study seeks to provide valuable insights into selecting the most appropriate radiotherapy approach for gastric cancer by carefully comparing planned dosimetry differences between the uRT-linac 506c and Varian accelerators. By highlighting the novel integration of CT imaging with IMRT in the uRT-linac 506c and its potential to enhance treatment precision and outcomes, this research contributes to the continuous advancement of radiotherapy technology. Although prior studies have investigated the uRT-linac 506c [12, 13], this study uniquely focuses on a direct comparison of these two advanced systems, which have not been extensively evaluated in this manner.

MATERIALS AND METHODS

Patients

From July to December 2017, ten postoperative gastric cancer patients at pathological stages T3 to T4 were enrolled at the Zhongnan Hospital of Wuhan University. The patients' age range was 43 to 67 years, with a median age of 57 years. This study was approved by the medical ethics committee of the Zhongnan Hospital of Wuhan University [2022144k].

The MLC-related parameters of the Varian IX accelerator and UIH 506c accelerator are shown in table 1. The UIH 506c accelerator is illustrated in figure 1.

Table 1. MLC-related parameters of Variance IX accelerator and UIH 506c accelerator.

Parameters	Varian	UIH
Leaf number (pieces)	120	120
Central high resolution leaf width (central 20 cm, leaf width projected at isocenter)(mm)	5	5
Outboard leaf width (outer 20 cm, leaf width projected at isocenter)(mm)	10	10
Maximum leaf retract position from center line (cm)	20.1	20
Maximum leaf extend position over center line (cm)	20	20
Maximum Leaf Out-ff-carriage Distance (cm)	15	20
Mean leaf transmission (measured)(%)	1.5	1.1
Maximum leaf leakage (measured) (%)	1.8	1.5
Penumbra (measured) (mm)	4.4±0.2	4.4±0.3

Patient CT simulation

Patient positioning was fixed using Klarity (Klarity Medical & Equipment Co., Ltd.). A slice spiral CT scanner (Siemens, Erlangen, Germany) was used, with a scanning range extending from 5 cm above the diaphragm to the 3rd or 4th lumbar vertebra.

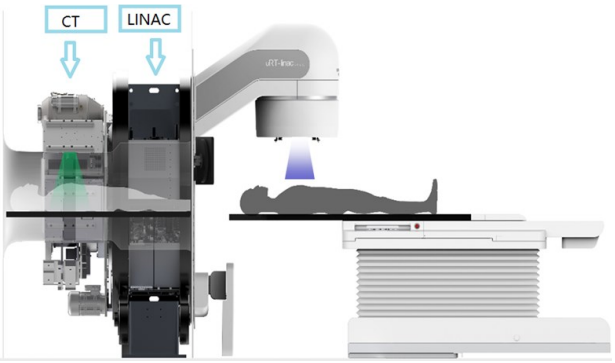

Figure 1. The linear accelerator of United Imaging Healthcare's CT linac uRT-Linac 506C.

Dose prescription

CT images were transferred to the Varian Eclipse 13.5 workstation (Varian Medical Systems, Palo Alto, CA, USA) for delineation of the target volumes (CTV and PTV) and the organs at risk (OARs). These structures were then imported into the UIH uRT-TPS system to ensure consistency between the planning CT and the region of interest (ROI) structures. The CTV, PTV, and OARs were outlined by professional radiotherapists. The CTV included tumor beds, anastomotic sites, and lymphatic drainage areas. According to our routine clinical practice, 95% and 99% of the PTV were prescribed to receive 45.00 Gy and 42.75 Gy, respectively, delivered in 25 fractions. The radiotherapy treatment plan aimed to protect OARs by ensuring that the functional kidney volume receiving 5 Gy (V5) did not exceed 65%; the volume receiving 15 Gy (V15) did not exceed 50%; the normal liver volume receiving 10 Gy (V10) did not exceed 70%; the volume receiving 30 Gy (V30) did not exceed 40%; and the volume receiving 40 Gy (V40) did not exceed 30%.

Treatment planning

Treatment plans were generated using both the Varian Eclipse 13.5 workstation and the UIH uRT-TPS system. Photon energy of 6 MV was used, with nine coplanar beams at angles of 100°, 70°, 40°, 10°, 340°, 320°, 181°, 25° and 335°. The optimization parameters were selected based on the prescribed dose, and all radiotherapy planning was designed by the same experienced physicist so as to meet the clinical requirements.

Comparison of the planning systems

We compared the two planning systems in terms of their target dose distribution and dose-volume histograms (DVHs) for PTV and OARs. The target dose distribution was evaluated using homogeneity index (HI) and conformality index (CI). HI was defined as D5%/D95%, where Dx% represents the dose received by x% of the target volume [15]. CI was

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calculated using the formula (PTV100%/PTV)/(PTV100%/V100%), where; PTV is the planned tumor target volume, PTV100% is the PTV volume irradiated by 100% of the prescribed dose, and V100% is the total volume irradiated by 100% of the prescribed dose. An HI value close to 1 indicates a more homogeneous dose distribution, while a larger CI value (range from 0 to 1) indicates better conformality [16].

Delivery verification

Delivery verification was performed on Varian IX and UIH 506c accelerators. The total monitor units (MUs) were compared. For IMRT, the gantry was normalized to 0°. The dose distribution was measured using the I'MRT MatriXX detector array (IBA, Scanditronix Wellhoferm, Germany). After placing the detector array in a phantom and preheating it, the treatment plan was transferred to the accelerators for radiation therapy. The measured dose distribution was compared with the verification plan derived from the TPS using the OmniPro I'm RT software (IBA, Scanditronix Wellhoferm). Gamma-index analysis (3%/3 mm, 2%/3 mm, 2%/2 mm) was used to assess accuracy, excluding doses below 10% of the threshold value.

Statistical approaches

Statistical analysis was performed using the Wilcoxon signed-rank test with SPSS 19.0 software (IBM Corp., Armonk, NY, USA). $P<0.05$ was considered to indicate statistical significance.

RESULTS

The comparison of the two radiation therapy plans, as detailed in tables 2, 3 and 4, yielded the following results:

For the planning target volume (PTV), the Varian Eclipse TPS achieved a significantly higher mean dose than the uRT-TPS. Conversely, the uRT-TPS demonstrated superior performance in terms of dose conformity index (CI) and HI compared to the Varian Eclipse TPS. Furthermore, the volume of the PTV receiving at least 45% of the prescribed dose was greater with the uRT-TPS than with the Varian Eclipse TPS. However, no significant difference was observed in the maximum dose delivered to the PTV between the two systems. Regarding MU, the Varian Eclipse TPS utilized a significantly higher number of MUs than the uRT-TPS.

Analysis of the OARs, as detailed in table 3, revealed statistically significant differences between the two TPS for several dosimetric parameters.

Concerning the OARs, the two TPSs showed statistically significant differences in maximum dose (Dmax), mean dose (Dmean), V10, and V20 of the left kidney, as well as Dmean and V5 of the right kidney. Specifically, for the left kidney, the Varian Eclipse TPS delivered a significantly lower maximum dose (Dmax) but significantly higher mean dose (Dmean) and V20 compared to the uRT-TPS. Similarly, for the right kidney, the Varian Eclipse TPS resulted in significantly higher Dmean and V5 than the uRT-TPS. Furthermore, the Varian Eclipse TPS delivered significantly higher Dmax and V5 to the liver compared to the uRT-TPS. No other statistically significant differences were observed in the remaining OAR parameters.

As shown in table 4, the gamma analysis revealed negligible differences in the pass rates between the two accelerators, with both exhibiting high pass rates.

Table 2. PTV parameters in Varian Eclipse TPS and uRT-TPS.

Plan	D_{max}/cGy	D_{mean}/cGy	V_{45}/%	CI	HI	MU
UIH	4895.70±78.32	4613.30±12.67	97.82±0.78	0.89±0.01	1.04±0.00	973.50±117.60
Varian	4927.10±72.51	4642.20±24.97	96.40±1.65	0.87±0.03	1.06±0.01	1187.71±290.38
Z value	-1.48	-2.80	2.80	1.99	-2.80	-2.60
P value	0.139	**0.005**	**0.005**	**0.047**	**0.005**	**0.0090**

PTV: Planning target volume; CI: Conformity index; HI: Homogeneity index; MU: Monitor unit.

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Table 3. OAR parameters in Varian Eclipse TPS and uRT-TPS.

Organs-at-risk	Group	D_{max}/cGy	D_{mean}/cGy	V_{45}/%	V_{40}/%	V_{30}/%	V_{20}/%	V_{10}/%	V_5/%
Kidney Left	UIH	4291.00±667.99	733.90±136.54	0.11±0.26	0.57±0.57	2.19±1.91	6.30±3.72	20.67±6.67	46.02±10.95
	Varian	4132.60±730.54	807.80±173.21	0.02±0.06	0.57±0.62	2.62±2.40	8.77±5.22	23.09±7.61	50.90±10.70
	Z Value	2.60	-2.81	1.16	-0.17	-1.13	-2.40	-2.29	-1.58
	P Value	**0.009**	**0.005**	0.248	0.866	0.260	**0.017**	**0.022**	0.114
Kidney Right	UIH	3583.10±580.93	687.20±150.94	0.00±0.00	0.055±0.16	0.64±0.88	4.64±2.62	21.98±9.96	45.27±10.07
	Varian	3362.0±1377.5	755.00±176.69	0.00±0.00	0.09±0.19	1.07±1.44	6.78±5.52	24.21±8.70	49.03±8.66
	Z Value	0.255	-2.60	0.00	-0.67	-0.10	-0.97	-1.68	-1.99
	P Value	0.799	**0.009**	1.000	0.500	0.917	0.333	0.093	**0.047**
Liver	UIH	4822.90±35.96	1773.50±291.30	7.37±2.31	11.34±3.27	20.01±5.73	34.82±9.83	60.29±11.97	84.90±5.77
	Varian	4915.40±80.85	1814.00±290.23	7.49±2.41	11.52±3.85	21.17±7.59	36.76±10.02	59.12±9.48	88.47±4.27
	Z Value	-2.40	-1.48	-1.13	-0.76	-1.17	-1.58	0.56	-2.29
	P Value	**0.017**	0.139	0.26	0.445	0.241	0.114	0.575	**0.022**
Spinal cord	UIH	2938.70±350.85							
	Varian	3063.60±592.44							
	Z Value	-1.22							
	P Value	0.221							
Pancreas	UIH	4811.30±49.01	4034.00±331.27	61.30±16.22	70.18±14.59	80.85±13.07	95.54±6.09	99.17±1.47	99.99±0.02
	Varian	4823.50±39.61	4005.90±325.19	62.72±15.98	70.06±14.47	78.70±11.36	95.10±6.40	99.19±1.34	99.95±0.15
	Z Value	-0.76	1.68	-1.78	0.15	1.48	1.54	0.67	1.00
	P Value	0.445	0.093	0.075	0.879	0.139	0.124	0.500	0.317
Small intestine	UIH	4860.10±74.64	2085.70±384.57	10.09±6.59	15.59±8.10	26.01±10.06	48.25±11.61	71.42±12.30	82.76±9.66
	Varian	4854.20±57.84	2052.40±395.01	10.23±6.54	15.56±8.58	26.19±10.34	47.08±13.79	68.72±13.85	81.16±9.60
	Z Value	-0.05	1.17	-0.46	-0.05	-0.15	1.17	0.56	0.77
	P Value	0.959	0.241	0.646	0.959	0.878	0.241	0.575	0.441
Body	UIH	4901.40±77.26	969.70±167.01	4.66±0.95	6.28±1.21	10.21±1.82	18.94±3.28	31.29±6.40	42.40±8.90
	Varian	4927.30±72.42	977.20±171.82	4.63±0.93	6.23±1.23	10.07±2.12	19.11±3.65	30.85±6.40	42.75±9.11
	Z Value	-1.07	-1.02	0.71	0.61	0.56	-0.87	1.78	-0.97
	P Value	0.285	0.307	0.475	0.540	0.575	0.386	0.075	0.333

OAR: Organs At Risk; Dmax: Maximum dose; Dmean: mean dose; Vxx: The dose received by x% of the target volume.

Table 4. Gamma pass rates in Varian Eclipse TPS and uRT-TPS.

Plan	3mm, 3%(%)	2mm, 3%(%)	3mm, 2%(%)	2mm, 2%(%)
UIH	99.85±0.47	99.34±1.09	99.16±1.13	97.19±3.42
Varian	99.95±0.11	99.28±1.11	99.13±1.12	97.42±2.69
Z value	-0.184	-0.954	-1.00	-0.668
P value	0.854	0.340	0.37	0.504

DISCUSSION

This study compared the dosimetric parameters of radiotherapy plans generated by the Varian IX linac and the uRT-Linac 506C for gastric cancer patients. The results indicated that both linacs are capable of meeting clinical requirements for radiotherapy in this patient population. However, notable differences were observed between the two systems, particularly concerning dose conformity and target volume coverage. Specifically, the uRT-Linac 506C demonstrated superior dose conformity and target volume coverage compared to the Varian IX linac. This was evidenced by a higher V45/% parameter for the uRT-Linac 506C, indicating improved distribution within the target volume. Furthermore, the uRT-Linac 506C exhibited enhanced performance in dose homogeneity and conformity indices, further highlighting its advantages in delivering precise radiotherapy.

Analysis of the dose to OARs revealed statistically significant differences between the two TPS. Specifically, for the left kidney, the Varian IX linac delivered a significantly lower maximum dose (Dmax); however, its mean dose (Dmean), V10, and V20 (volumes receiving 10% and 20% of the prescribed dose, respectively) were significantly higher than those of the uRT-Linac 506C. Similar trends were observed for the right kidney, where the uRT-Linac 506C demonstrated lower Dmean and V5 values. These findings suggest that the uRT-Linac 506C may provide improved sparing of critical organs during radiotherapy for gastric cancer patients.

Minimizing radiation dose to OARs, particularly the kidneys, is of paramount importance due to the potential for long-term sequelae such as renal dysfunction [17-19]. Studies, such as those by Beauvois *et al.,* have indicated that kidneys receiving doses exceeding 10 Gy may exhibit renal dysfunction within 10 to 15 years post-irradiation [18]. Conversely, Dawson *et al.* suggest that if patients do not experience renal ischemia or a reduction in glomerular filtration rate (GFR) within two years following radiotherapy, subsequent chronic damage is less likely to occur [19]. Despite these varying perspectives, the kidney's sensitivity to radiation is well-established. Consequently, it is crucial for radiotherapy planners to design treatment plans that maximize the sparing of these organs while ensuring adequate target volume coverage. Our findings suggest that the uRT-Linac 506C, with its improved dose conformity and coverage, may be better suited for this purpose compared to the Varian IX linac.

The uRT-Linac 506C offers further benefits due to

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its integrated CT imaging capabilities. As the first CT imaging-guided IMRT system, it uniquely combines diagnostic spiral CT with a high-dose-rate intensity-modulated accelerator. This integration enhances the precision and efficiency of radiotherapy by enabling real-time imaging and treatment adjustments. This capability is particularly crucial in gastric cancer, where accurate target localization and dose delivery are essential for achieving optimal patient outcomes.

While these results are promising, the relatively small sample size of our study should be considered a limitation. Consequently, the findings should be interpreted cautiously, and further research is necessary to validate these results with a larger dataset. Future studies should also explore the potential clinical implications of these dosimetric differences, such as their impact on patient outcomes and toxicity rates, within real-world clinical settings.

CONCLUSION

In conclusion, our preliminary findings suggest that the uRT-Linac 506C demonstrates improved performance in several dosimetric parameters compared to the Varian IX linac for radiotherapy in gastric cancer patients. These advantages, combined with its innovative CT imaging-guided capabilities, highlight the potential of the uRT-Linac 506C as a promising advancement in precision radiotherapy. However, further research is warranted to validate these findings and investigate their potential clinical impact.

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***Author contribution*:** LH (the corresponding author) is responsible for ensuring that the descriptions are accurate and agreed by all authors. All authors approved the revised version. All authors read and approved the final manuscript

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