Comparative Research on the IMRT Plan Quality of Varian IX Linac and uRT-linac 506C for Gastric Cancer

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Research

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Abstract

Purpose: uRT-Linac 506C, designed and produced by UIH, is the first computerized tomography imaging guided linear accelerator in the world. This study aims to compare the dosimetric parameters of treatment plans designed on Varian Eclipse v13.5 TPS of Varian IX linac and uRT-TPS of uRT-Linac 506C respectively, in condition of intensity-modulated radiation therapy (IMRT).

Method: In this retrospective study, 10 patients with gastric cancer were involved and planned with Varian Eclipse v13.5 TPS and uRT-TPS for IMRT treatment, respectively. All treatment plans were made by the same experienced physicist and were clinically acceptable. To effectively compare the quality of the treatment plans, dosimetry parameters of planing target volume (PTV) andorgans at risk (OARs), and monitoring unit (MU) efficiency are included in the comparison. Quality assurance process were performed to evaluate the delivery accuracy of the accelerator systems with gamma-index parameters.

Result: In terms of dose conformity and coverage of target volume, uRT-TPS (CI =0.89 ± 0.01, HI = 1.04 ± 0.00) was superior to Varian Eclipse TPS (CI =0.87 ± 0.03, HI = 1.06 ± 0.01). The same was the parameter of V45/%, Varian Eclipse TPS equal to 96.40 ± 1.65 and uRT-TPS equal to 97.82 ± 0.78. These differences are statistically significant (P_{CI} = 0.047, P_{HI} = 0.005, P_{V45} =0.005). Concerning the left kidney, the Dmax of Varian Eclipse TPS was significantly lower than that of uRT-TPS (4132.60±730.54 cGy VS 4291.00±667.99 cGy, P_{Dmax} =0.009). However, the Dmean, V10 and V20 of Varian Eclipse TPS (Dmean=807.80±173.21 cGy; V10=23.09%±7.61%; V20=8.77%±5.22%) were significantly higher than uRT-TPS (Dmean=733.90±136.54 cGy, V10 = 20.67% ±6.67%; V20=6.30%±3.72%), with the P values of 0.005; 0.022 and 0.017 respectively. For the right kidney, the Dmean and V5 of Varian Eclipse TPS (Dmean=755.00±176.69 cGy; V5=49.03%±8.66%) were significantly higher than that of uRT-TPS (Dmean=687.20±150.94 cGy; V5=45.27%±10.07%), with the P values of 0.009 and 0.047 respectively. As for liver's Dmax and V5, these of Varian Eclipse TPS (Dmax=4915.40±80.85 cGy; V5=88.47%±4.27%) were significantly higher than those of uRT-TPS (Dmax=4822.90±35.96 cGy; V5=84.90%±5.77%), with the P values of 0.017 and 0.022 respectively.

Conclusion

All uRT - linac 506c treatment plans were recognized as clinically acceptable and had statistically better OAR sparing with higher delivery efficiency. The dose parameters of some target areas and organs at risk of URT-TPS are better than Varian eclipse TPS.

Background

Gastric cancer is one of the most common malignancies in the world [1].At present, surgical treatment is still the most important way to treat gastric cancer, but with surgical treatment alone, the survival rate of patients is relatively low. The INT0116 study in the U.S showed that concurrent chemo-radiotherapy could significantly improve local control rate and survival rate [2-3]. IMRT and VMAT has basically replaced the conventional conformal radiation therapy, because it can provide more suitable dose distribution in the shape of the target area, effectively optimize the target dose uniformity and reduce affecting the surrounding normal tissues. Thus, it can improve the gain ratio in accordance with clinical treatment [4-6]. This is a milestone for the era of precise radiotherapy [7-8].

Yet the doses of IMRT are determined by multiple factors, say, Treatment Planning System(TPS), the technics used to realize modulated radiation intensity, as well as the shape of beam(fan beam or cone beam)[10], etc. The modes of intensity modulated include static IMRT, dynamic IMRT and VMAT. Different TPS calculating the dose of the same beam and segment sequence can give inconsistent results. Yet, this discrepancy is much smaller than dose differences induced by various optimization strategy adopted by TPS manufacturers [11].

Based on internationally cutting-edged technologies, uRT-linac 506 series are the medical linear accelerators developed by UIH, while uRT-linac 506c is the first CT imaging guided IMRT in the world [figure 1]. uRT-linac 506c is distinguished in its innovative combination of diagnostic spiral CT and intensity-modulated accelerator with high dose rate, as the worldwide only available accelerator equipped with high-definition image-guided IMRT and patient CT simulation. Hence, the precision and efficiency of radiotherapy are greatly enhanced. uRT-linac 506c is promising in evolving the radiation therapy.

Machines from Varian, as one of the most common medical accelerators, are famous for their high stability, efficiency and long service life. The study aims to provide a reference for an appropriate radiotherapy scheme for gastric cancer by comparing the planned dosimetry differences between the two TPSs.

Methods

Selection of Accelerators for Patients

From July to December 2017, ten postoperative gastric cancer patients with pathological stage T3 ~ T4 in Zhongnan Hospital of Wuhan University were selected. The age ranges from 43 to 67 years old. The median age is 57.

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

Parameters	Varian Millennium 120	UIH MLC
Leaf number	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

The patients' positions were fixed with Klarity vacuum pad during the CT simulation. The CT scanner used is Siemens Somatom. Sensation 16-slice spiral CT. And the scanning range is from 5 cm above the diaphragm to the 3rd or 4th lumbar vertebra.

Dose Prescription

CT images were transmitted to Varian Eclipse 13.5 (Varian Medical Systems, Palo Alto, CA, USA) workstation where the target volumes CTV and PTV, organs at risk (OAR) were delineated before being imported into uRT - TPS of UIH. In this way, the planning CT and ROI structures were ensured to be consistent. In this research, the CTV, PTV and OAR were outlined by professional radiotherapists. The CTV delineated in our hospital includes tumor beds, anastomotic sites and lymphatic drainage areas. According to our routine clinical practice, 95% and 99% of PTV shall receive 45.00 and 42.75 Gy respectively, with 25 fractions for each treatment plan. The radiotherapy plan should also meet the following requirements to protect OARs: the functional kidney volume receiving 5Gy and 15Gy should not exceed 65% (V5≤65%) and 50% (V15≤50%), respectively. Normal liver volume receiving 10 Gy, 30Gy and 40 Gy shall not exceed 70% (V10≤70%), 40% (V30≤40%) and 30% (V40≤30%) respectively.

Plan Design

All treatment plans were performed on both Varian Eclipse 13.5 workstation and UIH uRT-TPS. The photon energy adopted is 6 MV, and the angles of 9 coplanar beams are respectively 100°, 70°, 40°, 10°, 340°, 320°, 181°, 25° and 335°. In line with doctor's prescription dose, appropriate optimization parameters were carefully chosen. All radiotherapy planning were designed by the same experienced physicist and met related clinical requirements.

Plan Comparison

We compare the two planning systems in terms of target dose distribution as well as the dose volume histograms (DVH) of PTV and OARs. In this study, HI (Heterogeneity index) and CI(Conformity index) were used to evaluate target dose distribution. The ideal value of HI is 1 and it increases with inhomogeneous dose distribution. HI is defined by $D_{5\%}$ / $D_{95\%}$, where $D_{x\%}$ is the radiation dose received by x% of target volume [12]. CI is calculated by ($PTV_{100\%}$/PTV) ($PTV_{100\%}/V_{100\%}$) , where the PTV represents the actual planned tumor target volume, $PTV_{100\%}$ is the PTV volume irradiated by 100 percent of the prescribed dose, and $V_{100\%}$ is the total volume irradiated by 100 percent of the prescribed dose. The CI value ranges from 0 to 1. The larger the CI value, the better the conformal degree [13].

Delivery verification

The delivery verification process was implemented on Varian IX and UIH 506c. The total MU numbers were compared. For IMRT, the gantry was normalized to 0°. The dose distribution of film in the TG119 report was replaced with the detector array I'mrt MatriXX (IBA, Scanditronix Wellhoferm, Germany). After the detector array was placed in a phantom and preheated, the treatment planning was transferred to accelerators to start the radiation therapy. The real dose distribution measured by the detector array was compared with the verification plan derived from TPS. OmniPro I'm RT (IBA, Scanditronix Wellhoferm, Germany) was used for analysis. Its accuracy was assessed using gamma-index (3%/3, 2%/3, 2%/ 2-mm) while excluding doses less than 10% of the threshold value.

Statistical Approaches

The above parameters were processed via Wilcoxon signed rank test with software SPSS 19.0(IBM Corp., New York, NY; Formerly SPSS Inc., Chicago, IL), where $P < 0.05$ is considered as statistical significance.

Results

Plan comparison

According to table 2, concerning the Dmean of PTV, Varian Eclipse TPS (Dmean=4642.20±24.97 cGy) performed better than uRT-TPS (Dmean=4613.30±12.67 cGy), with a statistical significance (P_{Dmean} =0.005). Whereas regarding the dose conformity and uniformity of target areas, uRT-TPS (CI =0.89±0.01, HI = 1.04±0.00) outperformed Varian Eclipse TPS (CI =0.87±0.03, HI = 1.06±0.01), with p values equal to 0.047 and 0.005 respectively. About V45/%, Varian Eclipse TPS (96.40%±1.65%) was not as good as uRT-TPS (97.82%±0.78%), and the difference was statistically significant (P_{V45} =0.005). The PTV Dmax of the two TPS were not significantly different (P_{Dmax} = 0.139). In addition, Varian Eclipse TPS MU (1187.71±290.38) was higher than uRT-TPS MU (973.50±117.60), which had a statistical significance (P_{MU} = 0.009). Concerning the OARs, the two TPSs showed statistically significant differences in Dmax, Dmean, V10 and V20 of the left kidney, as well as Dmean, V5 of the right kidney. There were no any other significant differences in other parameters.

For Dmax of the left kidney, Varian Eclipse TPS was significantly lower than that of uRT-TPS (4132.60±730.54 cGy VS 4291.00±667.99 cGy, P_{Dmax} =0.009). However, for Dmean, V10 and V20, Varian Eclipse TPS (Dmean=807.80±173.21cGy; V10 = 23.09%±7.61%; V20=8.77%±5.22%) was significantly higher than uRT-TPS (Dmean=733.90±136.54 cGy; V10 = 20.67%±6.67%;V20=6.30%±3.72%), and the P values were respectively 0.005, 0.022, 0.017. The Dmean and V5 of the right kidney, in Varian Eclipse TPS (Dmean=755.00±176.69 cGy;V5=49.03%±8.66%) were significantly higher than these of uRT-TPS (Dmean=687.20±150.94 cGy; V5=45.27%±10.07%) with P values equal to 0.009, 0.047. Concerning liver Dmax and V5, Varian Eclipse TPS (Dmax=4915.40±80.85 cGy;V5=88.47%±4.27%) was significantly higher than that of uRT-TPS (Dmax=4822.90±35.96 cGy, V5=84.90%±5.77%), where the P values were 0.017 and 0.022.

Tab.2 Comparison of PTV parameters among 3 plans

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

Tab.3 Comparison of organs-at-risk parameters among 3 plans

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

There was almost no difference in the Gamma pass rate between the two accelerators. Both showed high pass rates.

Table 4 of Gamma pass rates

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

The stomach is surrounded by radiation-sensitive tissues and organs such as the liver, kidney, spinal cord, and blood system. Therefore, when patients receive radiotherapy, the surrounding tissues shall be protected by minimizing the exposure of organs at risk as much as possible, on the premise of not affecting treatment effectiveness [14]. Studies by researchers Beauvois S have shown that the kidney receiving over 10Gy radiation can show sequela such as renal function damage in 10-15 years [15]. But Dawson, LA et al. believe that if patients do not have renal ischemia or glomerular filtration rate (glomeruar filtration rate, GFR) reduction in 2 years after radiotherapy, subsequent chronic damages are unlikely to emerge [16]. Although the results are mixed, it is certain that the kidney is quite sensitive to radiation doses. So the physicist should design the plan maximizing the protection of kidneys.

Protecting OAR in radiotherapy should not only be considered in treatment plans but also in high quality image-guided systems, so as to achieve the precise dose implementation. The UIH accelerator is equipped with MV-CBCT and KV level diagnostic CT while Varian IX has MV-EPID、MV-CBCT、 and KV-CBCT. Both accelerators are installed with MV-EPID, which can provide accurate image registration for patients with metal implants, as well as offer the possibility of in-vivo dose verification in future. Compared to Varian's KV level CT imaging guidance system, the diagnostic CT implemented in uRT-Linac 506C has advantage of higher image resolution and allows for the image registration for tumors which have a great size in head and feet direction, which can reduce the dose deviation caused by position errors.

In this study, we compared the radiation dose distribution between Varian Eclipse 13.5 and the uRT-TPS treatment planning system based on CT image data of 10 patients with gastric cancer. The dose distribution of PTV and OAR calculated by the two planning systems both meet the clinical requirements. In terms of PTV radiation dose, the Dmean of Varian Eclipse TPS was higher than that of UIH uRT-TPS, but UIH uRT-TPS showed a better dose conformity and homogeneity than Varian Eclipse TPS. Regarding OAR doses, the average dose of the left and right kidneys of uRT-TPS were lower than these of Varian Eclipse TPS. However the maximum dose of the left kidney of Varian Eclipse TPS was lower than that of uRT-TPS. Regarding the volume at dose parameters in OAR, there was no significant differences in volumes of high dose regions (V45, V40, V30) between the two planning systems, whereas Varian Eclipse TPS showed significantly lower V20, V10 in left kidney and V5 in right kidney and liver. This can possibly be explained by lower leaf transmission rate in uRT-linac 506c compared to Varian IX linac. The leaf transmission rate in uRT-linac 506c was measured by 1.1%, while varian accelerator by 1.5%, which was similar to those published in literatures (1.4%–1.5%) [17,18]. Li has found that the accelerator with low leaf transmission rate could reduce V5 for the low-dose region [19]. In the implementation process of this study, the physiologist had known the evaluation results of the patient treatment plan in Varian eclipse TPS when making the treatment plan on the uRT-TPS, which may be one of the reasons that some target area and organ endangering dose parameters of uRT-TPS were better than Varian eclipse TPS.

Furthermore, MUs of UIH uRT - TPS was lower than that of Varian Eclipse TPS. This is related to the two manufacturers using different optimization strategies to calculate the shape of beam segment sequences. Lower MUs can shorten the plan execution time and reduce unnecessary radiation exposure on the patients. In the future, we will compare more patient data for more accurate results.

Conclusions

All uRT - linac 506c treatment plans were recognized as clinically acceptable and had statistically better OAR sparing with higher delivery efficiency. The dose parameters of some target areas and organs at risk of URT-TPS are better than Varian eclipse TPS.

Abbreviations

IMRT: Intensity-modulated radiation therapy; PTV: Planing target volume; OAR: Organs at risk; MU: Monitoring unit ; CI: Conformity index; HI: Heterogeneity index; TPS: Treatment planning system; Dmax: The maximum point dose received; CTV: Clinical target volume;Dmean: The mean dose; OAR: Organs at risk; DVHs: dose volume histograms; CT: Computed tomography; V n%: The volume percentage corresponding to the dose of nGy;

Declarations

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Authors' contributions

DJ and XW conceived of this study and wrote the article. DW, JS, DW, FZ and LH participated in data collection. CX and HL supported the research and provided ideas. CX and HL guided the paper revision. All authors read and approved the final manuscript.

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Availability of data and materials

Please contact author for data requests.

Ethics approval and consent to participate

This study was approved by the Regional Ethics Committee of Zhongnan Hospital of Wuhan University and all patients signed informed consents before treatment.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interest.

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Figures

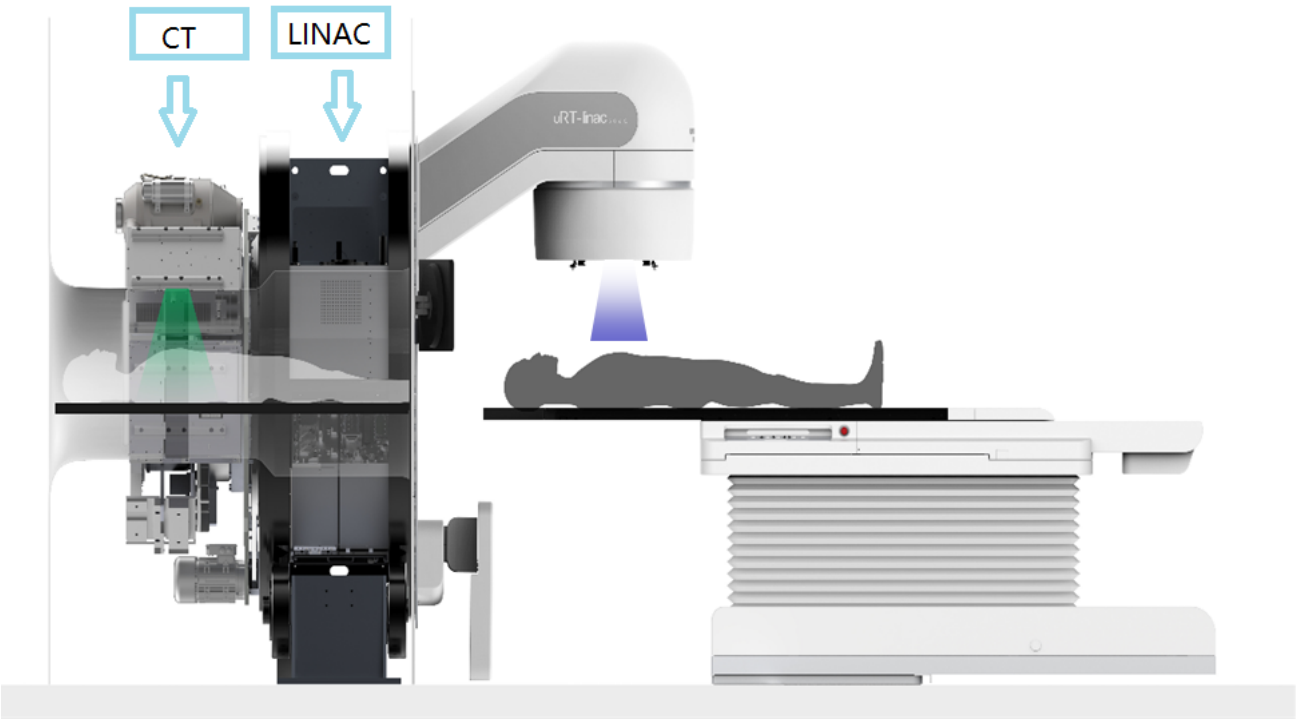

Figure 1

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

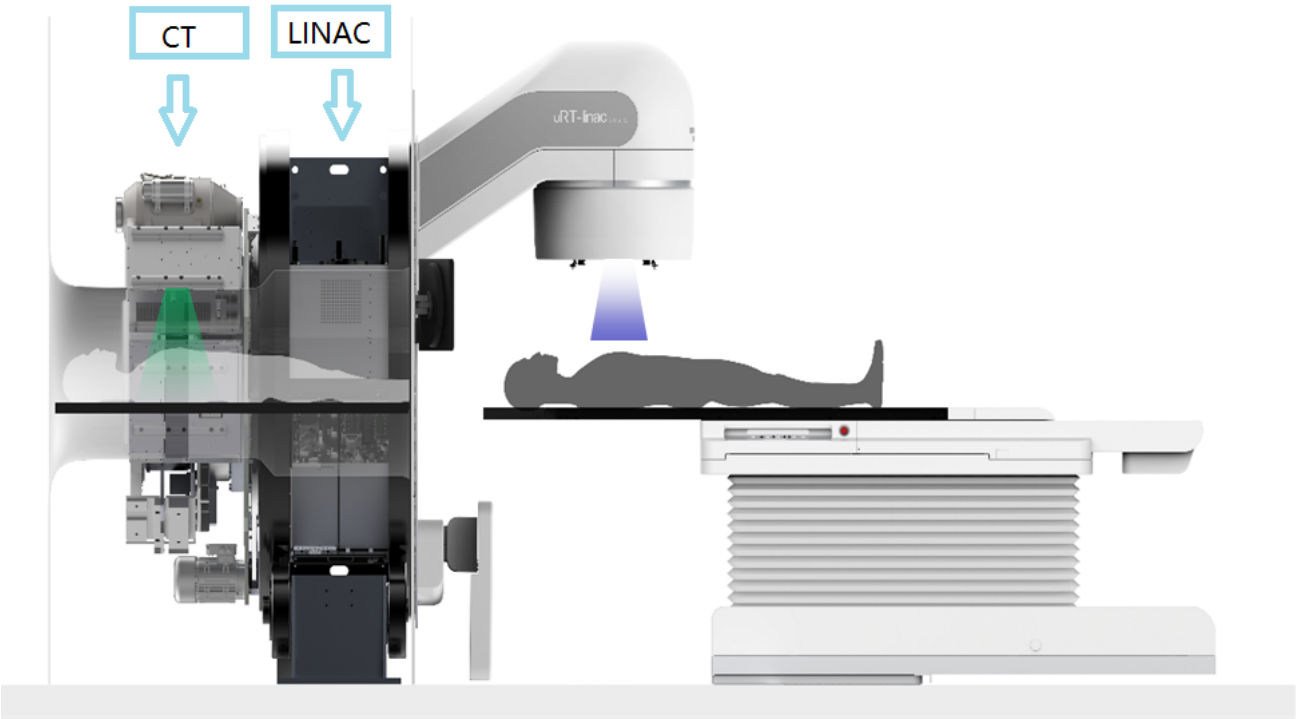

Figure 1

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