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kV-energy fan-beam CT imaging performance of a novel biology-guided radiotherapy (BgRT) machine

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INTRODUCTION

In image-guided radiation therapy (IGRT) and biology-guided radiation therapy (BGRT), localization imaging plays an important role. It provides precise tumor location and contributes to treatment effectiveness. High-quality and accurate localization imaging can also empower adaptive treatment planning. Recently, RefleXion™ developed X1, a novel radiotherapy machine. In this machine, a fully integrated fast-rotation kV-energy fan-beam CT (kV-FBCT) is utilized to provide localization imaging.

AIM

The aim of this study is to provide a first report on the imaging performance of the kV-FBCT.

METHOD

RefleXion X1 radiotherapy machine is among the first linear accelerators to integrate a 16-slice kV-FBCT scanner for patient alignment and target localization, as shown in Fig.1. The kV-FBCT is located on the front gantry ring of the radiotherapy machine. The CT imaging central plane is 386 mm from the treatment plane.

The kV-FBCT has a curved detector with longitudinal coverage of 20 mm, a 50-cm field-of-view, and an image matrix size of 512x512. Imaging is performed using helical scan mode wherein the couch moves at 10 mm/s, while the gantry housing both the CT scanner and the LINAC rotates at 60 RPM.

Image quality of the kV-FBCT is evaluated under the typical imaging protocol of tube voltage of 120 kV, tube current of 150 mA, gantry speed of 60 RPM, couch speed of 10 mm/s, and nominal slice thickness of 1.25 mm. The phantoms used are: a Catphan 600 phantom, a 20-cm-diameter water phantom, and a commercially available anatomical phantom.

Fig. 1 RefleXion X1 radiotherapy system with kV-FBCT integrated (kV-FBCT and LINAC shares the gantry)

RESULTS

Quantitative evaluation

<u>CT number accuracy</u> is evaluated on 20-cm-diameter water phantom at a central circular ROI. The measured numbers are ≤ 10 HU (Fig. 2(a)). <u>CT number uniformity</u> is evaluated on Catphan CTP486 module as the difference of mean CT number between peripheral ROI and central ROI. The measured numbers are ≤ 3 HU (Fig. 2(b)). <u>Image noise</u> is measured on 20-cm-diameter water phantom at a central circular ROI, and the measured numbers are ≤ 20 HU. (Fig. 2(a)). <u>Scale and distance accuracy</u> is measured on Catphan CTP404 module as the distance accuracy between two fixed points. The measured accuracy is ≤ 1 mm (Fig. 2(c)). <u>In-plane spatial resolution</u> is measured on Catphan CTP528 module. The 9-lp/cm in test mode (10-cm DFOV, Fig. 2(d)) and ≥ 4-lp/cm line pairs in clinical mode (50-cm DFOV, Fig. 2(e)) are resolvable. <u>Low-contrast detectability</u> is measured on Catphan CTP515 module. The 5-mm object of 1% contrast is detected (Fig. 2(f)). The dose level for these measurements is 2.54 c Gy.

kV-FBCT image metrics are compared with typical kV-CBCT, and typical MV-FBCT metrics (Table 1), numbers of kV-CBCT and MV-FBCT as reported in Ref. 1,2,3.

Visual evaluation

kV-FBCT images are evaluated visually with 20-cm-diameter water phantom, Catphan 600, and anatomical phantom. Representative images are shown in Fig. 2 and Fig. 3. The water and various Catphan sections show high-quality images, consistent with ground truth. The anatomical phantom images show high-quality anatomical details and low contrast differentiation in both head and body, with few image artifacts.

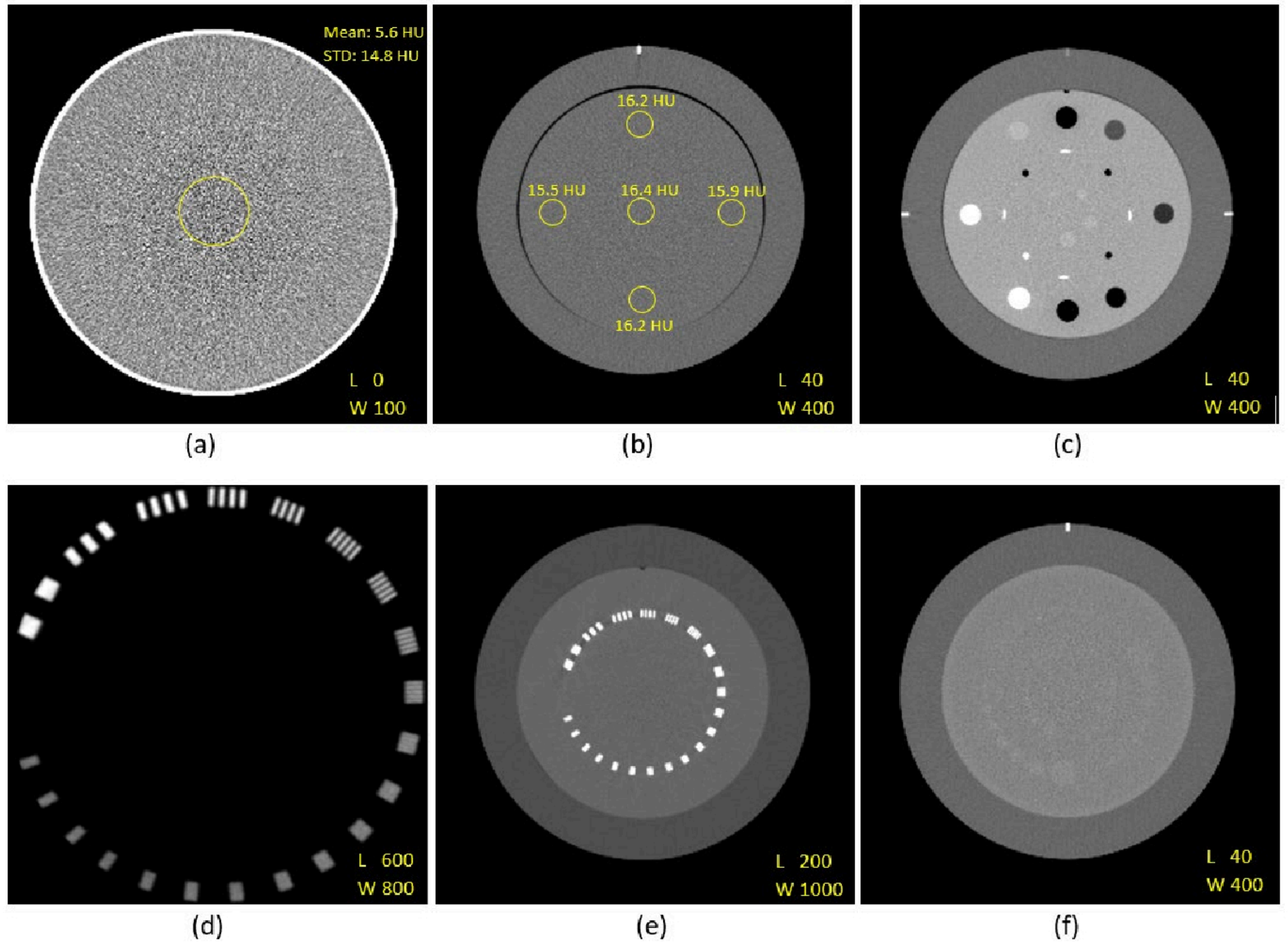

Fig. 2 kV-FBCT images. (a) 20-cm water phantom. (b)-(e) Catphan 600 phantom: (b) CTP486, (c) CTP404, (d) CTP528 (central 10 cm zoom-in test mode), (e) CTP528 (e) CTP515. (Note: in (a), (b), (c), (e), and (f), central 25-cm cropped out of original 50-cm reconstructed image is in display. In (d), it is the whole 10-cm reconstructed image with a zoom-in-reconstruction test mode.

Table 1 Image quality metrics of kV-FBCT compared with kV-CBCT and MV-FBCT

	kV-FBCT	kV-CBCT	MV-FBCT
CT number accuracy	≤ 10 HU	≤ 40 HU[1]	≤ 30 HU[2]
CT number uniformity	≤ 3 HU	≤30 HU[1]	≤ 25HU[2]
Scale and Distance Accuracy	≤ 1 mm	≤ 1 mm[1,3]	≤ 1mm[3]
In Plane spatial Resolution	≥ 9 lp/cm (zoomed in) ≥ 4 lp/cm (clinical)	≥ 5 lp/cm[1]	1.6mm[2,3]
Low contrast detectability	5 mm at 1% contrast	7 mm at 1% contrast[3]	13 mm at 2% contrast[3]

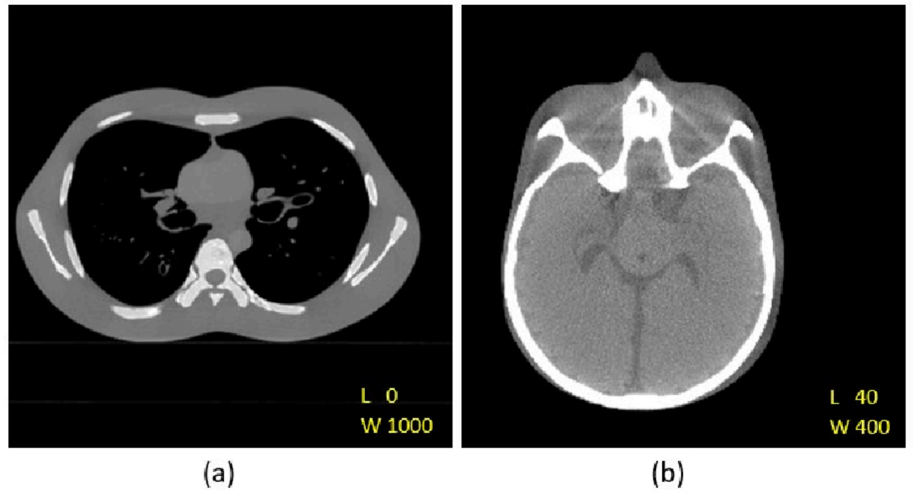

Fig. 3 kV-FBCT images of anatomical phantom. (a) Body (central 36 cm cropped out of original 50 cm reconstructed image in display), (b) head (central 25 cm cropped out of original 50 cm reconstructed image in display).

CONCLUSIONS

This is the first report of the kV-FBCT performance of the RefleXion X1 machine, indicating high image quality for radiotherapy localization. It empowers possible treatment adaptation based upon intra-course CT information.

Future work will focus on assessing imaging performance in the setting of target motion and demonstrate the potential of flexibility in temporal resolution for radiotherapy localization applications.

REFERENCES

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CONTACT INFORMATION

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