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Commissioning of and preliminary experience with a new fully integrated CT-linac

L. YU[1,2], J. ZHAO[1,2], J.Z. WANG[1,2], Z. ZHANG[1,2] and W.G. HU[1,2*]
1.Department of Radiation Oncology, Fudan University Shanghai Cancer Center, Shanghai, China
2.Department of Oncology, Shanghai Medical College, Fudan University, Shanghai, China

INTRODUCTION

Nowadays, the image-guidance technique is indispensable in radiation therapy for managing the geometric variations in patient setup and internal organ position [1-2]. A newly designed CT-integrated linac named uRT-linac 506c was introduced into the market recently by United Imaging Healthcare (UIH) Co., Ltd (Shanghai, China). It has a **diagnostic-quality** helical CT system compactly fixed behind the gantry of a C-arm linac, and the patient is sent through the scanner by moving the couch longitudinally. The combination of CT and a linac enables a seamless workflow from simulation to treatment. Diagnostic-quality daily CT, as a familiar and mature technology widely accepted by physicians, provides a straight comparison of patient anatomy with planning CT and offers direct access to online adaptive replanning, accounting for interfractional anatomic changes.

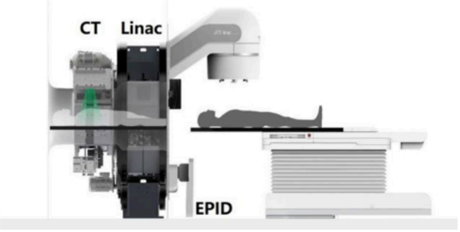

Fig.1: Schematic view of the uRT-linac 506c platform

AIM

The objectives of this work are to (a) introduce the main technical specifications of this new treatment platform, including the mechanical precision, CT-IGRT accuracy and clinical workflow; (b) summarize the procedures of beam data collection and commissioning tests; (c) present the results of beam data measurements and end-to-end tests for the entire clinical scheme; and (d) report the quality assurance (QA) results from the first period of clinical operation.

METHOD

- Technical specifications of uRT-linac 506c:

Feature	Description
Configuration	C-arm linac integrated with 16-slice helical CT
Enclosed CT bore	70 cm in diameter
Linac gantry rotation	-362°~182°, 7°/s rotation speed
Treatment beam	6 MV (FF/FFF) X ray
Nominal dose rate	25~600 MU/min (FF), 75~1400 MU/min (FFF)
MLC design	1.0 cm×20 pairs, 0.5 cm×40 pairs, 2.5 cm/s leaf-only speed, 5.5 cm/s with carriage together
Maximum field size	40×40 cm^2
Delivery techniques	3D-CRT, sIMRT, dIMRT, uARC
Imaging systems	MV portal, MV-CBCT, kV-FBCT
Treatment couch	Carbon fiber couch with movable base

- Isocenter verification [3]: spoke-shot test, EPID-based Winston Lutz (WL) test
- Imaging test [4]:
  - Image quality: spatial and contrast resolution tested by CatPhan phantom
  - Geometric accuracy: IGRT tests with different loads (40/100 kg) and couch extensions
- Commissioning data collection [5]: PDD, profile, OFs, MLC transmission and MLC offset
- TPS validation: IMRT commissioning using AAPM TG-119 test suite [6]
- End-to-end verification (**45 cases** in total): breast (18), NPC (9), lung (6), rectum (3), cervix (3) and lung_SBRT (6) using sIMRT/dIMRT/uARC delivery techniques.

RESULTS

- Gantry/collimator/couch isocentricity: 0.63 mm in radius

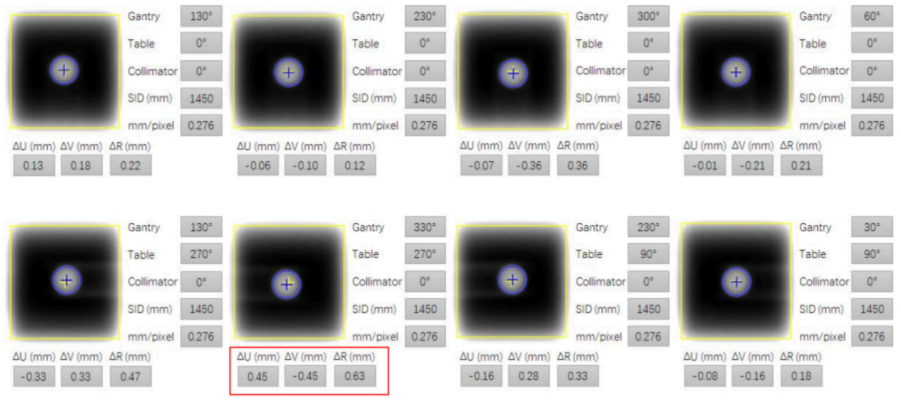

Fig.2: WL results of the in-house analysis (projected at the isocenter). The boundary and center are shown in yellow for the radiation field and in blue for the BB. ΔU, ΔV and ΔR denote the crossline, inline offset and 2D distance between the two crosses, respectively.

- Imaging tests
  - Image quality:
    - Spatial resolution:
      Portal: 11 lp/cm @ 10%MTF
      CBCT: 6 lp/cm @10%MTF
      FBCT: ≥15 lp/cm @10%MTF
    - Low contrast resolution:
      CBCT: 9 mm @1% @16 mGy
      FBCT: 2 mm @0.3% @ 40 mGy
  - Geometry accuracy:
    - **Real-time correction** of CT coordinate
    - An overall **submillimeter** IGRT accuracy was achieved by MV portal/CBCT/FBCT under all conditions.

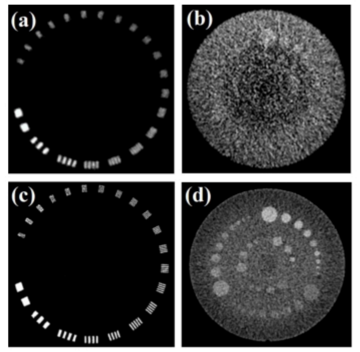

Fig.3: (a,b) CBCT and (c,d) FBCT slices of CatPhan phantom

- Commissioning data and TPS validation:

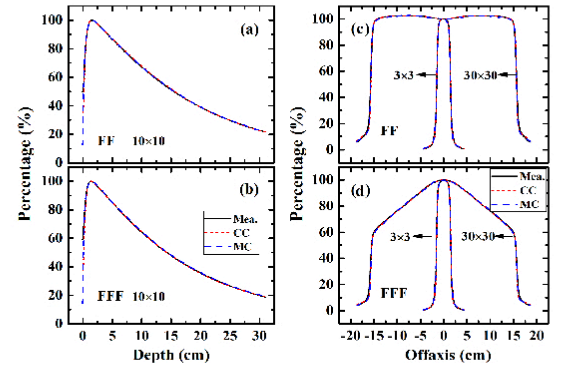

Fig.4: PDDs and profiles in TPS calculations and measurements for 6XFF (a,c) and 6XFFF (b,d)

- Average MLC leaf transmission: 0.9% for 6XFF and 6XFFF modes
- TPS models (collapse cone convolution method, CC and Monte Carlo method, MC) were in agreement with the beam commissioning data within 1% deviation.
- TG-119 IMRT commissioning resulted in ≤ 2% point dose difference and ≥ 98% gamma passing rate by ArcCheck (2% DD, 2 mm DTA)

- End-to-end tests
  The absolute point dose difference for all the cases was within 3%, and the gamma passing rate of the 2D dose distribution measured by EBT3 film was better than 90%, averagely 96.9±2.3% for CC method and 96.7±2.0% for MC method (3% DD, 3 mm DTA and 10% threshold).

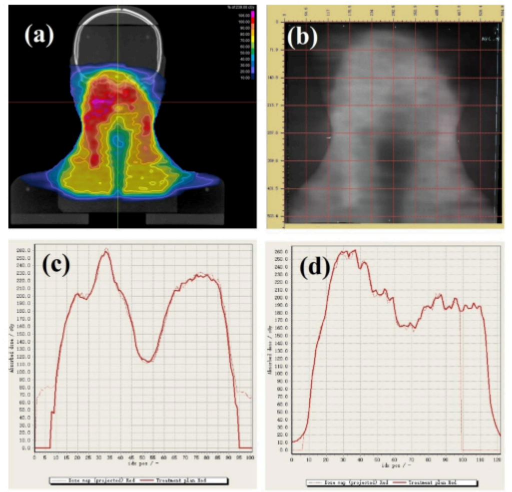

Fig.5: End-to-end test of an NPC case. (a) Planned dose distribution. (b) Dose map converted by FilmQA Pro. (c) horizontal and (d) vertical profiles of planned dose (solid) and measured dose (dotted).

- Preliminary experience in clinical operation
  - Temporal stability: over half a year, CAX deviation from the reference was -0.43±0.30% for 6XFF and -0.53±0.23% for 6XFFF, respectively. Changes in homogeneity (for 6XFF only), symmetry and beam quality factor (BQF) were found to be less than 1%.

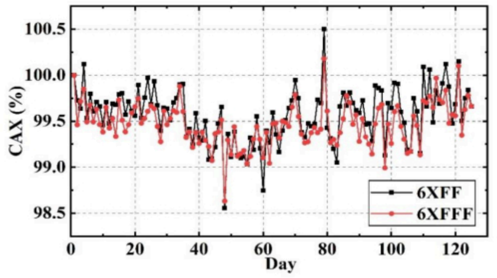

Fig.6: Daily output of uRT-linac 506c during the past six months

  - Patient-specific QA
    More than 150 patients have been treated on this unit. The point dose difference was within 2% for sIMRT plans and within 3% for dIMRT/uARC plans. Gamma passing rates of 3D dose distributions measured by Delta4 were better than 99% per plan and 95% per beam (3% DD, 2 mm DTA and 10% threshold) for all plans.
  - Clinical CT-IGRT workflow
    Generally, it takes approximately 1 min for the CT-IGRT process, whose efficiency is comparable to the standard kV-CBCT procedure, with faster scanning speed, fewer motion artifacts, better image quality and longer scanning range.
  - Future prospect
    Non-rigid changes in some patients' anatomy have been observed. Online adaptive radiotherapy based on the daily CT can be expected in the near future by employing auto-segmentation and auto-planning.

CONCLUSIONS

This study summarized the commissioning process of a new fully integrated CT-linac, the uRT-linac 506c, and preliminary experiences in clinical operation. The commissioning and QA results indicate that this system exhibits comparable performance in treatment efficiency and accuracy compared with linacs from other vendors, with a stable output over half a year. As the first clinical model type, its long-term reproducibility and stability are still under inspection. The integrated CT system, as a highlight, allows a diagnostic-quality visualization of internal patient anatomical structures for more accurate image guidance with submillimeter localization precision, and paves the way towards online adaptive radiotherapy.

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CONTACT INFORMATION

*Correspondence to: jackhuwg@gmail.com