Proton Radiography as a Means to Verify Surface-Imaging Localization Accuracy

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Objectives

To evaluate surface-based target localization accuracy for spot scanning proton treatments in a 360° compact gantry using transmission proton radiographs.

Introduction

- Surface Guided Radiation Therapy (SGRT) systems provide three key functionalities:
  1. Guidance during initial setup using patient's body contour.
  2. Relative intra-fraction monitoring i.e., acquiring a reference surface image after x-ray based IGRT has been performed to track a site specific region of interest.
  3. Absolute monitoring i.e., using surface information without the aid of x-ray based imaging to position and track the patient.
- Absolute monitoring requires the validation of the relationship between SGRT coordinates and radiation isocenter.
  This work describes a methodology to associate the spatial information provided by a surface imaging system and the irradiation field of a spot scanning proton therapy system. The measurements described here enable quantification of SGRT/radiation isocenter coincidence.

Methods

1. Surface imaging vs radiation isocenter coincidence

- A CT simulation of the phantom was performed to make available the external contour as a localization surface.
- Using our treatment planning system (TPS), isocenter was placed on the central sphere of the phantom.
- The structure set from the TPS was exported to the AlignRT system to perform surface measurements.
- For comparison purposes, the phantom was placed at isocenter using x-ray based IGRT and SGRT separately.
- Proton transmission radiographs where generated using a nominal proton energy of 156.6 MeV, a squared field of 10.5 × 10.5 cm^2 and 0.5 cm spot spacing.

Figure 1:Isocube placed on top of a 2D-Ionization Chamber array. The 2D-IC was used as detector to produce proton transmission radiographs.

2. QA tests for nonradiographic localization and positioning systems

Prior to acquiring proton radiographs, the standard commissioning tests recommended by TG-147[1] were performed:

- Spatial drift (translational and rotational)
- Spatial reproducibility
- Static localization accuracy.

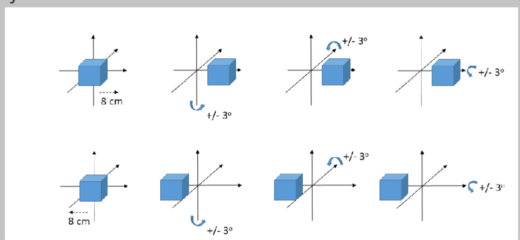

Figure 2:Translational shifts and rotations applied to test reproducibility and localization accuracy.

- Determination of field of view (FOV)

The parameter used to evaluate SGRT performance regarding FOV was the fluctuation in the real-time delta values (RTDs).

Results

1. Surface imaging vs radiation isocenter coincidence

- Figure 4 shows that SGRT localization accuracy matched x-ray based IGRT performance. The difference between the two images was assessed using the gamma test γ=1.0% /0.5 mm.
- After introducing a known shift of 1 mm to the phantom position based on surface imaging, the gamma passing rate decreased from 99 % to 76 %.

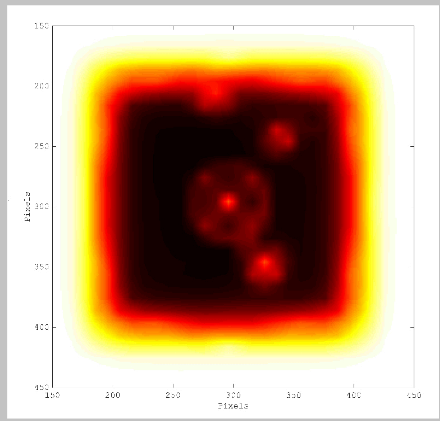

Figure 3:Isocube proton radiography obtained with a 2D-IC array.

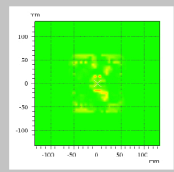

Figure 4:IGRT based localization vs surface-imaging based localization. γ= 99%

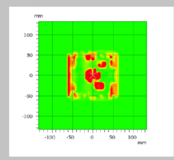

Figure 5:IGRT based localization vs surface-imaging based localization + 1 mm shift. γ= 76%

2. QA tests for nonradiographic localization and positioning systems

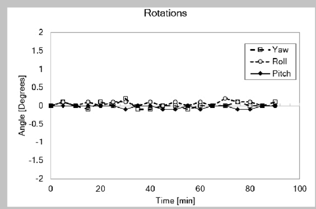

Figure 6:AlingRT rotational drift.

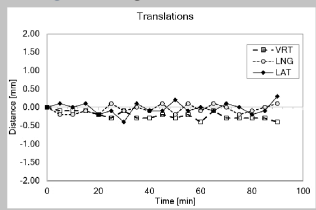

Figure 7:AlingRT translational drift.

- Spatial drift and reproducibility showed values < 1.0 mm & < 0.5°
- Static localization accuracy showed values ≤ 1.0 mm & < 0.5°

- The FOV available for accurate localization was found to be 12.5% less in comparison to the scanning plane dimensions in the beam's eye view (BEV).

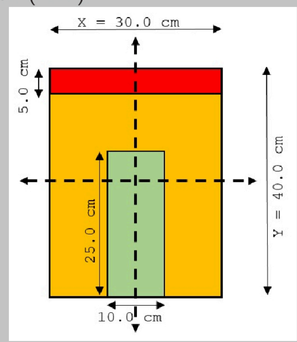

Figure 8:AlignRT FOV performance relative to the scanning area of the Hitachi PROBEAT system (30×40 cm^2). Green = Optimal, Yellow = Acceptable, Red =Poor.

- RTDs fluctuaction - Green area ≤ **0.2 mm**, Yellow area < **1.0 mm**, Red area ≥ **1.5 mm**.

Conclusions

- Proton radiography using a 2D-IC array provides a fast method to associate surface-imaging information and the irradiation field of the proton machine.
- Due to FOV limitations, surface-based localization in a 360° compact proton gantry has reduced capabilities.
- Current performance restrains the applicability of AlignRT to relative mode only.
- Inter and intra-fraction motion tracking appropriateness must be evaluated case by case.

References

[1] Willoughby, Twyla, et al. "Quality assurance for nonradiographic radiotherapy localization and positioning systems: report of Task Group 147." *Medical physics* 39.4 (2012): 1728-1747.

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