Quantification of prostate positioning accuracy and movement during SBRT with CBCT imaging

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INTRODUCTION

The prostate moves. To quantify **interfraction** and **intrafraction motion**, prostate fiducial positions were identified on CTs and CBCTs collected before and during prostate SBRT delivery. For intrafractional motion, **internal motion** (the prostate moves within the body) and **external motion** (the patient moves despite immobilization) were quantified by identifying the position of fiducial markers relative to the pelvic bony anatomy.

AIM

- To automatically identify 3D fiducial positions on CT and CBCT images.
- To compare expected (planning CT) and actual (CBCT) fiducial positions prior to prostate SBRT treatment.
- To quantify internal prostate motion and size over multiple timescales (minutes – weeks).
- To differentiate between internal and external intrafractional motion of the prostate.

METHODS

PROSTATE SBRT TREATMENTS:

- CBCT images were collected immediately prior to treatment. If triggered on-board kV images showed any of the three fiducials persistently strayed farther than 3 mm from planning-expected positions, the treatment was interrupted, another CBCT of the patient was obtained, and corrective shifts were applied prior to continuing treatment delivery.
- The patient was immobilized with a CIVCO SBRT board, employing a posterior Vac-Loc and two small, anterior Vac-Loc pads at abdomen and thigh.

DATA:

- Retrospectively, the fiducial marker positions were automatically identified on the planning CTs and 101 CBCTs of 15 patients undergoing prostate SBRT.
- Corrective couch motion was gathered from CBCT and OBI kV image DICOM headers.
- The pelvic bony anatomy in the CBCTs was rigidly registered to the planning CT, and internal motion was calculated based on fiducial positions identified in these registered CBCTs.
- By comparing internal motion to corrective couch movements (global motion), the extent of external patient motion was identified.
- The relative prostate size was measured by calculating the area of the triangle formed by the three fiducial markers.

METHODS (CONTINUED)

FIDUCIAL IDENTIFICATION ON CT/CBCT:

1. Zeroed CT/CBCT image for HU < 550.
2. Calculated Laplacian, L: $$L(x,y,z) = \frac{\partial^2 HU}{\partial x^2} + \frac{\partial^2 HU}{\partial y^2} + \frac{\partial^2 HU}{\partial z^2}$$
3. Created a binary image, B: $$B(x,y,z) = \begin{cases} 1, & L(x,y,z) < 0 \\ 0, & L(x,y,z) \geq 0 \end{cases}$$
4. Identified connected regions (potential fiducials).
5. Filtered connected regions by size and distance from expected position.
6. Found the weighted mean of the connected region along x, y, and z. For each voxel, i, in connected region: $$x_{pos} = \frac{\sum_i x_i \cdot HU_i}{\sum_i HU_i}$$
7. Kept 3 identified fiducial positions whose distances from the expected 3 positions were minimized.

PELVIC BONE REGISTRATION:

1. Zeroed CT/CBCT image for HU < 300 to remove all but the bony anatomy.
2. To focus on the pelvic bone, zeroed CT/CBCT image outside of a box that extended 10 cm left, 10 cm right, 4 cm posterior, 8 cm anterior, 6.5 cm inferior, and 8 cm superior of isocenter (isocenter centered on prostate).
3. Fused the CBCT pelvic bone images to the CT pelvic bone image in MIM software.

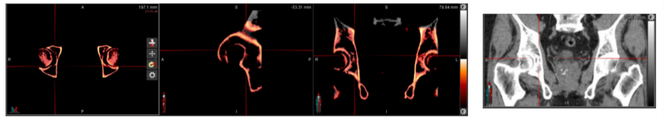

Figure 1: The bone-filtered CBCT (red) was registered to the bone-filtered CT (gray) to determine the position of the prostate fiducials relative to the bony anatomy. At right, the original CT without filtering is shown.

INTERNAL VS EXTERNAL INTRAFRACTION MOTION:

- As identified based on couch movements, global fiducial motion relative to room coordinates (isocenter) may be due to external and/or internal motion (Figure 2, column 1).
- Internal prostate motion was measured by comparing the fiducial positions identified on CBCT images registered to bony anatomy collected before and in the middle of radiation delivery.
- The extent of external motion was then quantified by comparing global (couch) motion to internal motion.

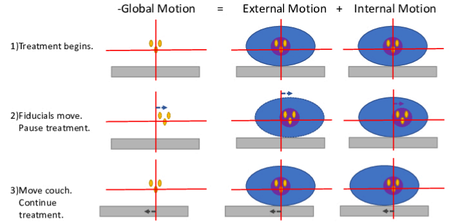

Figure 2: Depiction of external and internal intrafractional motion.

RESULTS

- To assess setup accuracy, the positions of the fiducials were identified on the CBCT and compared to their expected positions. 96.2% of fiducials identified on CBCT were within 3 mm of their expected, planning positions (Figure 3A).
- The internal motion was calculated based on fiducial positions identified on CTs and CBCTs that were registered based on bony anatomy. The change in prostate fiducial position center-of-mass (COM) was calculated pair-wise between each 3D image of each patient (Figure 3B). The largest measured change in position was 20 mm.
- By calculating the triangular area between the fiducial positions, the size of the prostate was measured as a function of time following the initial CT (Figure 3C).
- Of the 50 fractions investigated, treatment was interrupted in 16 cases.

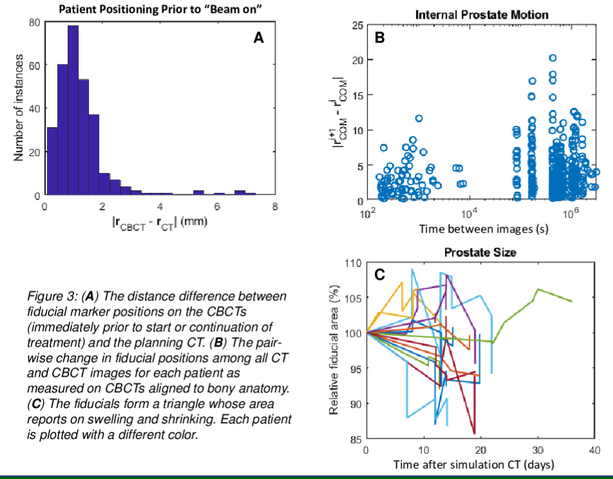

*Figure 3: (**A**) The distance difference between fiducial marker positions on the CBCTs (immediately prior to start or continuation of treatment) and the planning CT. (**B**) The pair-wise change in fiducial positions among all CT and CBCT images for each patient as measured on CBCTs aligned to bony anatomy. (**C**) The fiducials form a triangle whose area reports on swelling and shrinking. Each patient is plotted with a different color.*

RESULTS (CONTINUED)

- All intrafraction corrective couch shifts were within 2 mm of the identified internal prostate motion, suggesting that the cause of treatment interruption is internal prostate motion, not external patient motion.

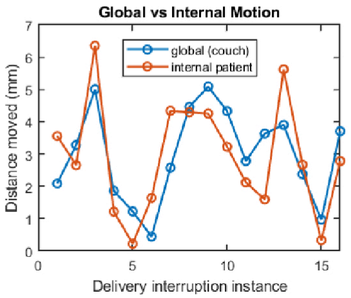

Figure 4: When the prostate was detected to persistently move > 3 mm during treatment, the global couch shifts and internal motion were calculated. Agreement between the two suggests the cause of the prostate movement was internal motion, not external motion.

CONCLUSIONS

- Software was developed to automatically identify fiducial positions in CBCT images and register the CBCT to the planning CT based on bony pelvic anatomy.
- The coincidence of couch motion to internal prostate motion suggests that patients are properly immobilized, and that treatment interruptions (prostate fiducials straying >3 mm from their planning positions) are due to internal motion.

REFERENCES

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