Title: Tracking Palladium Seeds Implanted in Prostate Using Shape Analysis Approach

Innovation/Impact: The surgical procedure used in the source implantation can cause significant prostate swelling (edema) in the permanent prostate brachytherapy. Edema-induced tissue and source movements can introduce significant deviations in the dose delivered to individual patients. Nonetheless, none of the existing treatment planning systems can perform patient-specific implant dosimetry in the presence of prostate edema. The innovation of this work involves the use of shape analysis approach to track the movement of source position and prostate tissue during edema resolution which enables accurate post-implant dosimetry to be performed for each individual patient. This work will have a positive impact on all patients receiving permanent prostate brachytherapy.

Purpose
To develop and test a shape-based image registration algorithm to register and analyze serial CT image datasets of a given patient, and then to track the motions of the implanted seeds for a quantitative characterization of prostate deformation and edema.

Method and Materials
Sequential 3D CT image datasets for a prostate cancer patient, acquired before palladium source implantation and after implantation, were used to perform deformable image registrations with shape-based algorithm to track the sources motions. The seed centers were detected in a group-wise fashion after extracting the seed surfaces, i.e. using consistency across the sequence of images acquired from the same subject as an extra constraint, to maximize the reliability of seed detections.

In the serial CT images, the image intensity of bone and metal seeds are similar. The homogeneity of the image intensity and the high signal-to-noise ratio makes it easy to extract their surfaces. The procedure for seed surface extraction follows 4 steps: (I.) The iso-surfaces of all objects with density equal or greater than bone structures were extracted; UH value 1200 was chosen for iso-surface extractions that resulted in the surfaces of both pelvis and radiation seeds. For all the images acquired, no object was found in the pelvis cavity except for those of radiation seeds. This made the extraction of seeds straight forward as described in step 2,3 and 4. (II.) The object-surfaces were parsed according to the connectivity of iso-surfaces, where the largest surface for each image was the pelvis; (III.) Pelvises were aligned to remove the rigid translation and rotation between different scans(rigid shape registration). For the shape alignment a partial surface matching was conducted since the image content was slightly different. Articulated movement was observed for the leg part, which was natural. During optimization the similarity measure only counted the best 50% of all surface points. Also a deterministic scheme was adopted to expedite the optimization and also to improve the robustness: the mesh of the surfaces under alignment was gradually refined during the optimization process, from1%to 16%of the original mesh size. (IV.) The seed surfaces were labeled using BioImage Suite[1]. The cavity of pelvis in the image of day 0 was manually segmented. Surfaces (among those obtained in step 2) that locate within this cavity were treated as seeds. The rest of the images were, first transformed into the space of day 1 using the result of last step, then the labeling was performed. Figure 1 illustrates the object surfaces labeled from images, and the rigid registration of pelvises.

A clustering method was used to find the seed centers for the seed surfaces while registering the seed surfaces from different images simultaneously. The method adopted here is an extension of our previous work[2]. The major extension is from 2D to 3D. Using the correspondence between seeds to estimate the deformation of prostate. Thin plate spline is used to interpolate and extrapolate the deformation between seed surfaces to the surface of the prostate or the volume of the prostate.

Results
The shape analysis approach described above was applied to the series of CT scans at day 0, 1, and 30 for one prostate cancer patient. The motion of seeds was visualized in Figure 2, from which the non-rigid deformation of prostate was interpolated. Results were shown in Figure 3 and 4. It was observed that the prostate volume was shrinking from Day 0 to Day 30, while it expanded from Day 0 to Day 1. This confirmed the results of Waterman, et al. [3] and our previous work[4]. Prostate edema resolution is that the prostate edema expanded first, and then gradually shrunk. From the figures, we also knew that the prostate deformation caused by the resolution of prostate edema was anisotropic[5].
Conclusions

A shape analysis approach was developed for quantitative characterization of post-implant seed tracking and the prostate deformation. The advantage over other methods is that the constraints of consistency among different images made our method more reliable than other seed localization methods that estimate the seed centers for each image individually. The precise localization of implanted seeds as function of time would enable a more accurate calculation and proper summation of radiation dose delivered to each tumor sub-volume in post-implant dosimetry.

References