Correction of Bulk Motion and Assessment of Non-rigid Deformations in Follow-Up Examinations of the Pelvis

Julien Senegas[1], Christian Buerger[1], Torbjoern Vik[1], Peter Mazurkewitz[1], and Peter Koken[1]
[1]*Philips Research Laboratories, Hamburg, Germany*

INTRODUCTION – For applications involving the comparison of scans at multiple time points, it is desirable to reproduce the baseline acquisition geometry with respect to the target anatomy in the consecutive scan sessions. While differences in patient positioning can be corrected to some extent before image acquisition by adapting the slice off-center and angulation, local, non-rigid deformations can also be found, especially in the abdomen or the pelvis. These may be related to physiological changes such as different levels of bladder and rectum filling, or to disease progression and treatment response, such as tumor growth, tumor shrinkage, and weight loss. The focus of this work is on the pelvis area, as MRI is being more and more established as imaging modality to assess and monitor prostate cancer [1] and is expected to play an increasing role in the adaptive planning of radiation therapy [2]. We investigated in volunteers a method to correct for bulk motion between consecutive examinations and analyzed the amplitude of local, non-rigid deformations as the consequence of bladder and rectum filling, with particular focus on the prostate.

METHODS – Five healthy volunteers were scanned repeatedly on a 1.5T scanner (Achieva, Philips Healthcare) with a 16-element torso coil. Different time intervals (1 hour, 1 week, and 2 weeks) between consecutive scan sessions were investigated. The protocol consisted of a multi-shot T2W fast spin echo scan (TR / TE: 4391 /80 ms) and a 3D T1W spoiled gradient echo scan (TR / TE: 14.9 /4.6 ms, flip angle: 25º), both with a FOV of 450x450x225 mm and a voxel size of 1.0x1.0x2.5 mm. These scans, allowing for complete coverage of the pelvis, are typically used for organ delineation in radiation therapy planning. The first scan session was defined as baseline (BL), with slices positioned manually in the transverse plane and the imaging volume centered at the prostate location.

- To correct for bulk motion resulting from differences in positioning of the subject with respect to the isocenter, the acquisition geometry of the follow-up (FU) scans was computed automatically by rigidly registering each BL scan to be repeated with a 3D survey scan acquired at the beginning of the FU session, according to a method previously applied in the brain [3] (“re-scan”).
- To assess the accuracy of the re-scan planning method and to measure the extent of local, non-rigid deformations, the displacement field between each pair of BL and FU scans was computed using an adaptive non-rigid registration algorithm [4] and measured at 24 anatomical landmarks chosen manually across the whole FOV (8 in the pelvis, 4 in the prostate, 6 in the femoral bones, 6 in muscles at different locations). Based on these measurements, the mean localization error of the re-scan planning method and the relative displacement of the prostate with respect to the pelvic bones were computed.

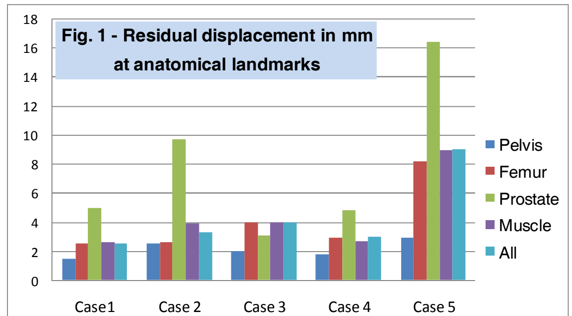

Fig. 1 - Residual displacement in mm at anatomical landmarks

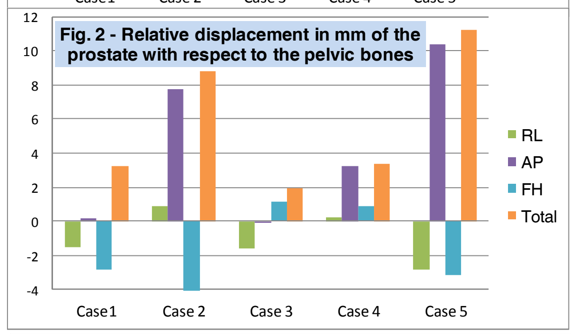

Fig. 2 - Relative displacement in mm of the prostate with respect to the pelvic bones

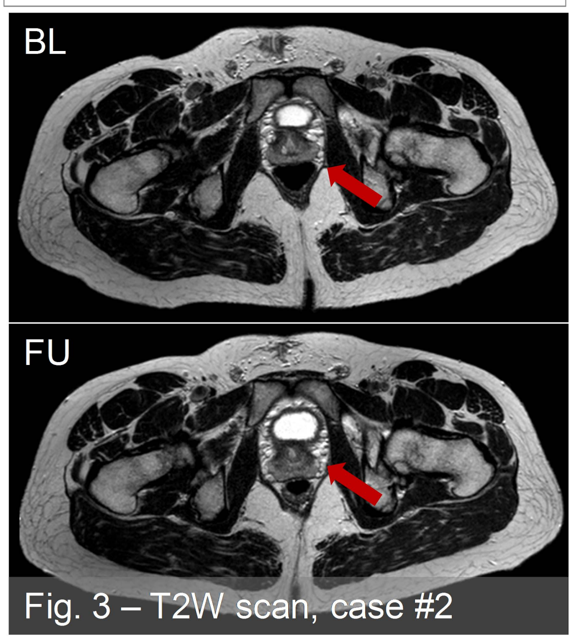

Fig. 3 – T2W scan, case #2

RESULTS – The table below shows an overview of physiological changes observed in the volunteers between BL and FU scan sessions. Increasing levels of bladder and rectum filling are indicated on a 4 point scale (--, -, +, ++):

Case:	**#1**	**#2**	**#3**	**#4**	**#5**
Bladder filling (BL / FU)	+ / +	+ / -	-- / --	-- / -	- / ++
Rectum filling (BL / FU)	+ / +	+ / --	++ / +	+ / +	+ / +
Time interval	1 week	2 weeks	1 week	1 hour	2 weeks

The mean absolute residual displacements measured for each organ group are shown on Fig. 1, while the relative displacements of the prostate with respect to the pelvic bones are shown on Fig. 2. An example of slice alignment obtained with the “re-scan” technique (T2W TSE scans, case #2) is shown on Fig. 3. A significant displacement of the prostate gland in the anterior-posterior direction as a consequence of different rectum filling can be observed (red arrows).

DISCUSSION and CONCLUSION – The mean residual displacements for the pelvic bones were around 2 mm in all cases, which suggests that the “re-scan” technique achieved an alignment of the rigid structures between BL and FU close to the image resolution. Reproducibility of the T1W scan geometry was slightly better in case of large differences in bladder filling, certainly because of the low signal of the bladder in this scan (results not shown). Residual displacements up to 16 mm were measured in the prostate and up to 9 mm in the muscles and the femoral bones, indicating that the amplitude of non-rigid deformations between BL and FU were significant. It was found that the relative displacement of the prostate with respect to the pelvic bones was up to 11 mm when bladder and / or rectum filling levels were significantly different between BL and FU, with the main direction of displacement being along the anterior-posterior axis. We think that the methodology proposed in this work to control bulk motion and assess local deformations between consecutive imaging sessions has important applications in therapy planning and image-guided therapy delivery, especially in the field of radio-therapy.

REFERENCES – [1] Hoeks et al. Radiology. 2011; 261(1):46-66 [2] Dowling et al. Int J Radiat Oncol Biol Phys. 2012; 83(1):5-11 [3] Sénégas et al. ISMRM. 2008; #2567. [4] Buerger et al. Med Imag Anal. 2011; 15:551-564.