

Automatic image registration performance for two different CBCT systems; variation with imaging dose

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Abstract. The performance of an automatic image registration algorithm was compared on image sets collected with two commercial CBCT systems, and the relationship with imaging dose was explored. CBCT images of a CIRS Virtually Human Male Pelvis phantom (VHMP) were collected on Varian TrueBeam/OBI and Elekta Synergy/XVI linear accelerators, across a range of mAs settings. Each CBCT image was registered 100 times, with random initial offsets introduced. Image registration was performed using the grey value correlation ratio algorithm in the Elekta XVI software, to a mask of the prostate volume with 5 mm expansion. Residual registration errors were calculated after correcting for the initial introduced phantom set-up error. Registration performance with the OBI images was similar to that of XVI. There was a clear dependence on imaging dose for the XVI images with residual errors increasing below 4mGy. It was not possible to acquire images with doses lower than ~5mGy with the OBI system and no evidence of reduced performance was observed at this dose. Registration failures (maximum target registration error > 3.6 mm on the surface of a 30mm sphere) occurred in 5% to 9% of registrations except for the lowest dose XVI scan (31%). The uncertainty in automatic image registration with both OBI and XVI images was found to be adequate for clinical use within a normal range of acquisition settings.

1. Introduction

The high uptake of kV imaging systems mounted on medical linear accelerators in recent years has placed tools for automatic image registration at the treatment console for routine use. These automatic matching algorithms have been shown to be accurate for matching 3D cone beam computed tomography (CBCT) scans to planning CT scans, on both the Elekta XVI system [1,2] and Varian OBI system [3,4]. There are some significant differences in how the two systems reconstruct 3D image sets, such as the handling of scatter and the sharpness of image reconstruction filters used. They also use different algorithms in their respective automatic registration software, ie – OBI uses a mutual information algorithm, whilst XVI uses a Chamfer algorithm for bone matching and a correlation ratio algorithm for the grey value match.

In a previous study [1], the accuracy of XVI automatic image registration is shown to have a dependence with imaging dose. This study looks at whether there is a similar relationship in the OBI system, and the impact of using images from both systems in a single automatic algorithm, in order to determine any differences in performance between the two systems.



2. Method

A CIRS model 801-P-B Virtually Human Male Pelvis phantom (Computerized Imaging Reference Systems, Inc., Norfolk, Virginia, USA) was used for all images. Cone beam images were acquired on both an Elekta Synergy (Elekta AB, , Stockholm, Sweden) and a Varian TrueBeam (Varian Medical Systems, Palo Alto, CA). For each, the phantom was set up and positioned using the CBCT system using a reference scan acquired on a GE Lightspeed RT scanner (GE Medical Systems, Waukesha, WI) with 1.25mm slice thickness. The initial phantom position was corrected in 6 degrees of freedom (DoF) on the Synergy using a Hexapod couch and 3 DoF on the TrueBeam.

Once positioned to within 0.5mm and 0.5° of the reference scan, a series of CBCT images were acquired on each system with mAs settings chosen to cover a range both above and below that used typically in clinical practice. The settings chosen were matched to be as similar as possible between systems. The exposure was varied from 68 mAs to 1360 mAs with XVI (5 settings), and from 132 mAs to 680 mAs with OBI (4 settings). The effective dose for each scan was calculated using published in-air dose/mAs factors for XVI and OBI [5].

The OBI images were imported into the XVI software, and then all 9 image sets were analysed against the initial reference CT scan. For each image set, an initial random translational offset was applied. Then the correlation ratio algorithm (grey value match) was run to register a mask region in 6 DoF. This mask encompassed the phantom prostate volume with an additional 5mm expansion. The registration result was subtracted from the initial known offset to provide the residual error of the registration algorithm. This process was repeated 100 times for each image set to simulate inter-fraction differences, using random initial offsets sampled from a 3D Gaussian distribution based on variations, observed clinically, in daily setup of prostate patients [6].

The mean of each image set's residual error was subtracted as it was assumed to be the systematic error in phantom positioning, accounting for initial positioning differences. The Target Registration Error (TRE) was determined as the maximum distance of a point on the surface of a sphere with residual translation/rotations to the initial sphere position [2]. A sphere of 30 mm radius was used to approximate the surface of the prostate. This was computed using dual quaternions to combine both translational and rotational components of the residual error and the distance denoted TRE_{30} [2].

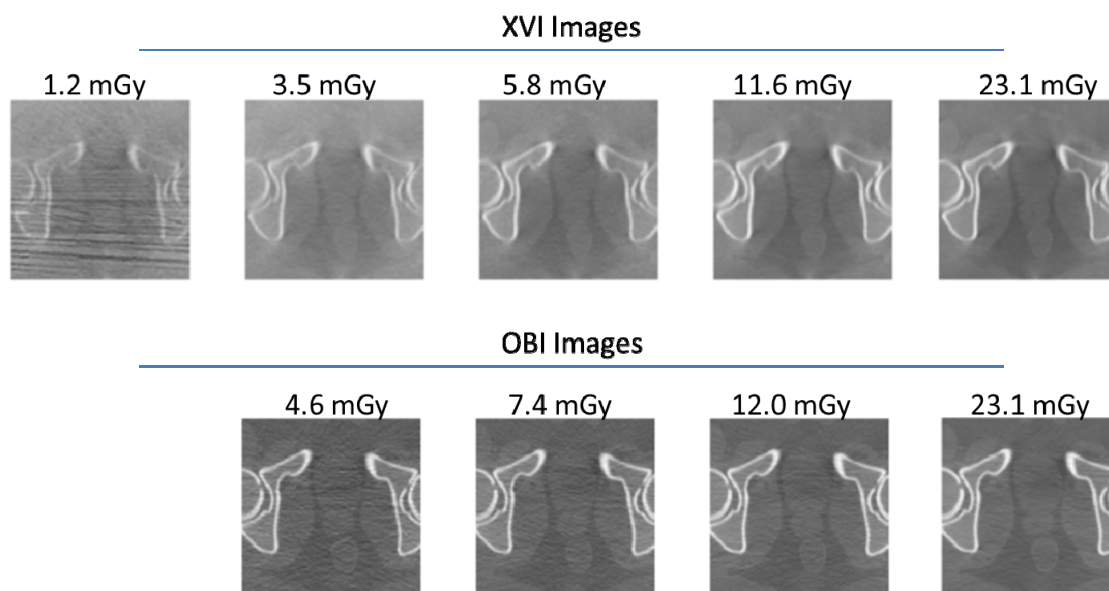


Figure 1 – Series of phantom CBCT collected for varying exposure. The top row shows XVI images and the bottom row shows OBI images. Exposure increases going from left to right.

3. Results

The image quality for the XVI and OBI images both deteriorated with decreasing dose, showing increased noise. For the lowest dose XVI image artifacts are observed which are likely due to photon starvation (Figure 1). Note that very low dose images could not be obtained with the OBI system to compare to the XVI system. Image quality comparisons between the systems are rather subjective due to the differing sharpness and noise present in each system's images. However, for images in the typical range of clinical doses (10-30 mGy), similar image quality was observed based on the ability to resolve anatomical landmarks in soft tissue such as the rectal wall. 5 mm diameter plugs in the phantom were only visible in scans of doses more than 23 mGy for both systems.

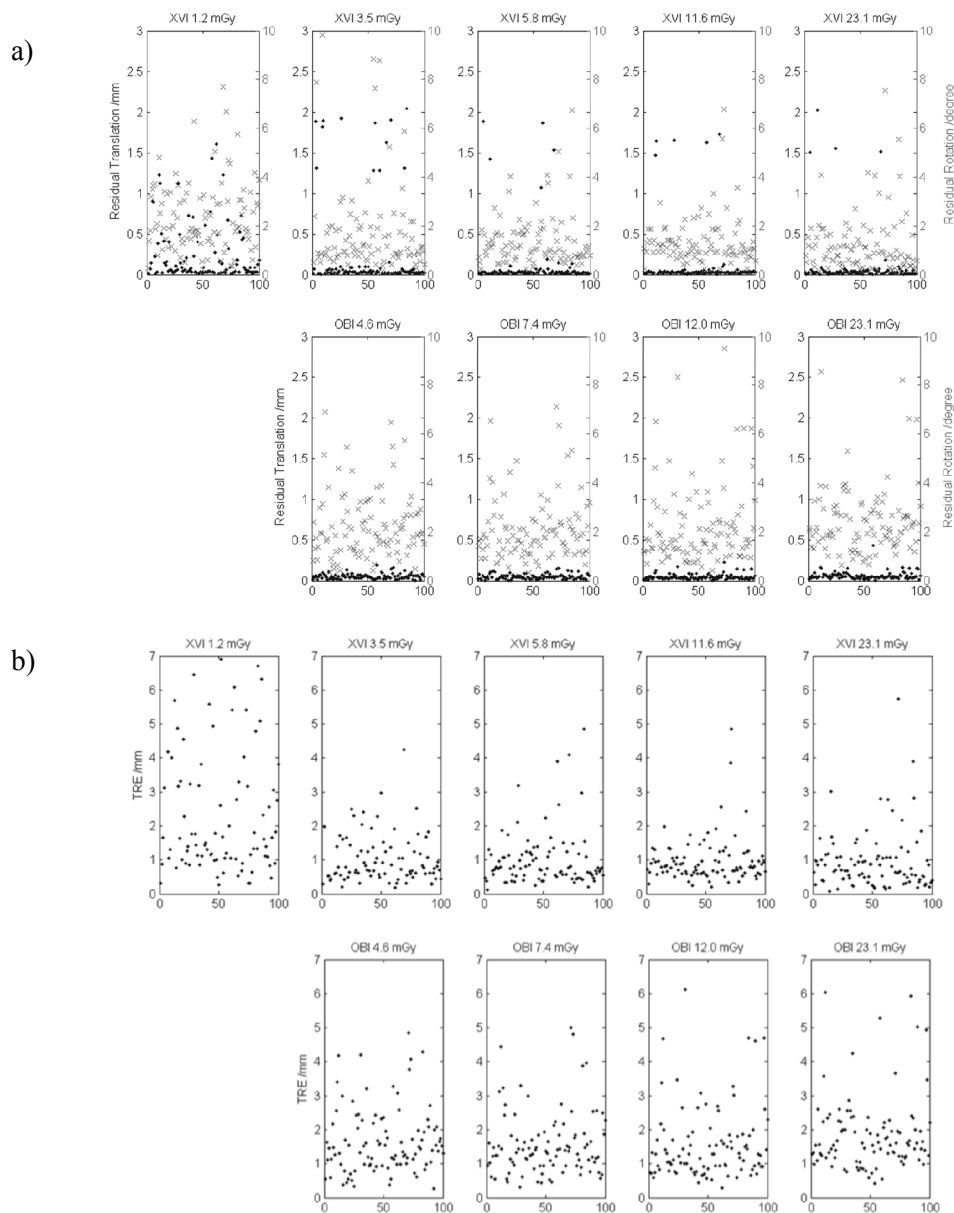


Figure 2 – a) Plots of residual translational error (dots) and residual rotational error (crosses) as 3D vector magnitude in the automatic image registration process for each image-set. b) Plots of TRE₃₀. Each plot shows the results of 100 repeat registrations

Registration performance with the OBI images was similar to that of XVI with residual translations $<0.5\text{mm}$ (1σ) (Figure 2a). OBI residual rotations were typically 1.2° (1σ) compared to 0.8° for XVI (Figure 2a). Over the clinical dose range, automatic registration provided similar residual error for both imaging systems. There was a dose dependence on residual translation and rotation errors for the XVI images, with both increasing for images with dose below 4 mGy, which correlated with the work of Sykes et al [2]. A similar dose dependence could not be investigated in the OBI results, because scans below 4 mGy could not be obtained.

The TRE_{30} in the clinical range was similar between the two imaging systems (Figure 2b). There was little difference in the range of TRE_{30} results across image sets except for XVI scans with dose less than 4 mGy where values increase. Using a pass/fail tolerance for any given automatic registration of $\text{TRE}_{30} = 3.6\text{mm}$, failures of the algorithm occurred in 5 - 9% of registrations except for the lowest dose XVI scan (31%). This indicates the algorithms can provide clinically suitable registrations more than 90% of the time, and also agrees with other results in the literature.

4. Conclusions

The uncertainty in automatic image registration with both OBI and XVI images was found to be adequate for clinical use, and similar between the systems, within the normal range of acquisition settings.

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