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Original research article

Accuracy in automatic image registration between MV cone beam computed tomography and planning kV computed tomography in image guided radiotherapy

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ABSTRACT

Aim: To verify the accuracy of automatic image registration (IR) between the planning kilo voltage computed tomography (kV CT) and megavoltage cone beam computed tomography (MV CBCT) datasets using phantom and patient images.

Background: The automatic IR between MV CBCT and planning kV CT is a fast solution for performing online image guided radiotherapy (IGRT). The IR accuracy has to be verified periodically as it directly affects patient setup accuracy.

Materials and methods: The automatic IR accuracy was evaluated using image quality phantom acquired with different kV CT slice thickness, different MV CBCT acquisition MUs and reconstruction slice size and thickness. The IR accuracy was also evaluated on patient images on different anatomical sites such as brain, head & neck, thorax and pelvis. The uncertainty in the automatic registration was assessed by introducing known offset to kV CT dataset and compared with the registration results.

Results: The result with the phantom images was within 2 mm in all three translational directions. The accuracy in automatic IR using patient images was within 2 mm in most of the cases. 3 mm planning kV CT slice thickness was sufficient to perform automatic IR successfully within 2 mm accuracy. The MV CBCT reconstruction parameters such as slice thickness and slice size had no effect on the registration accuracy.

Conclusion: This study shows that the automatic IR is accurate within 2 mm and provides confidence in performing them between planning kV CT and MV CBCT image datasets for online image guided radiotherapy.

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1. Background

Advanced conformal radiotherapy delivery techniques, like the intensity modulated radiotherapy (IMRT) and volumetric modulated arc therapy (VMAT), have become routine in radiotherapy centres. These techniques require high accuracy in patient treatment positioning and alignment with respect to the treatment fields. Image guidance system utilising cone beam computed tomography reconstruction had contributed to achieve high precision in patient treatment positioning.[1–4] Megavoltage cone-beam computed tomography (MV CBCT) is one of the commercially available IGRT systems[5–7] using megavoltage X-rays of the treatment beam from the linear accelerator (linac). The retractable amorphous silicon flat-panel detector mounted on the linac is used to acquire the 2D projection images at different gantry angles around the patient on the treatment couch and reconstruct 3D volumetric MV CBCT image which provide both soft tissue and bony structure information. The system provides software tools for automatic and manual registration of the MV-CBCT and (kilo Voltage) kV CT images acquired for patient treatment planning and calculate the patient position 3D translation offsets from which couch corrections can be made. Introduction of online image guidance in the patient treatment verification has increased the patient's time on treatment couch, which has the potential to induce patient intra-fraction movement, hence the preference to have a faster image guidance solution. The automatic registration, which uses mutual information to establish correspondence between the two image sets, helps to speed up the alignment process.[8] In our radiotherapy department, we perform online image guidance with automatic image registration between the acquired MV CBCT and reference planning kV CT and visually inspect the results before applying the couch correction. The clinical implementation of the automatic image registration requires evaluating the uncertainties associated with it, as registration failures may result in very large errors.

2. Aim

The aim of this study is to verify the accuracy of automatic image registration between the planning kV CT and MV CBCT datasets in phantom with different CBCT acquisition and reconstruction parameters and with different planning CT slice thickness used clinically and in patient images at different sites.

3. Materials and methods

3.1. MV CBCT system

The Medical high energy linear accelerator, Siemens Oncor Expression^{TM} equipped with the retractable imaging guidance (IG) system, (OPTIVUE 1000ST^{TM}, Siemens Medical solutions Inc., Concord, CA) used for MV planar and MV CBCT imaging, is attached to the gantry at the counter-part of the head of the linear accelerator, as shown in Fig. 1. The IG system consists of flat panel detectors which have the sensors of amorphous silicon (a-Si) photo diodes that are deposited on a glass substrate with a scintillator coating. The pixels have a pitch of 400 μm and there are 1024 × 1024 pixels covering a 40 × 40 cm^2 area. The entire imaging system operates under SYNGO^{TM} based COHERENCE^{TM} therapist workspace, which communicates to the control console, the linear accelerator, and a local patient database. The workspace contains applications allowing for automatic acquisition of projection images, image reconstruction, CT-to-CBCT image registration, and couch position adjustment. Each projection of the CBCT acquisition is corrected for defective pixels, as well as for pixel-to-pixel offset and gain variations before 3D reconstruction.

Fig. 1 – The Siemens Oncor Expression linear accelerator equipped with OPTIVUE imaging system.

3.2. Phantom

The image quality phantom (Siemens Medical Solutions, Concord, CA), as shown in Fig. 2, is a cylindrical acrylic shell of diameter 20 cm with four solid water sections positioned axially within the shell. These sections are used to assess the MV CBCT image quality and geometric accuracy. Section 1 is purely made of solid water of thickness 4 cm without any inserts and used to check image uniformity, noise and artefacts. Sections 2 and 4 consist of 5 circular inserts of 8 different density materials with diameter 2, 1, 0.7, 0.5 and 0.3 cm used to check low and high contrast resolution. Section 3 contains 11 bar groups and each bar group contains 5 air bars to evaluate spatial resolution. The sections 2 and 4 are of thickness

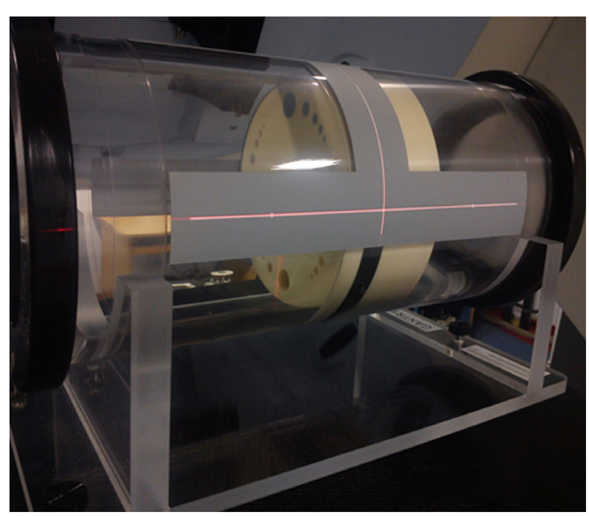

Fig. 2 – Image quality phantom.