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Technical note

The influence of the image registration method on the adaptive radiotherapy. A proof of the principle in a selected case of prostate IMRT

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ABSTRACT

Purpose: To analyse the influence of the image registration method on the adaptive radiotherapy of an IMRT prostate treatment, and to compare the dose accumulation according to 3 different image registration methods with the planned dose.

Material and methods: The IMRT prostate patient was CT imaged 3 times throughout his treatment. The prostate, PTV, rectum and bladder were segmented on each CT. A Rigid, a deformable (DIR) B-spline and a DIR with landmarks registration algorithms were employed. The difference between the accumulated doses and planned doses were evaluated by the gamma index. The Dice coefficient and Hausdorff distance was used to evaluate the overlap between volumes, to quantify the quality of the registration.

Results: When comparing adaptive vs no adaptive RT, the gamma index calculation showed large differences depending on the image registration method (as much as 87.6% in the case of DIR B-spline). The quality of the registration was evaluated using an index such as the Dice coefficient. This showed that the best result was obtained with DIR with landmarks compared with the rest and it was always above 0.77, reported as a recommended minimum value for prostate studies in a multi-centre review.

Conclusions: Apart from showing the importance of the application of an adaptive RT protocol in a particular treatment, this work shows that the election of the registration method is decisive in the result of the adaptive radiotherapy and dose accumulation.

1. Introduction

Adaptive radiotherapy (ART) has been described as a strategy to include patient variations during a course of radiotherapy that are due to anatomical changes or due to tumoral or biological changes. As a result, the actual delivered dose differs from the planned dose [1]. Image registration, which relates the points in one image to the points in another image are used to compensate for daily variations. Several algorithms have been described and used in clinical practice but their performance differs [2]. Image registration, which relates the points in one image to the points in another image are used to compensate for daily variations. Several algorithms have been described and used in clinical practice but their performance differs.

The objective of this study was to evaluate the use of an off-line, adaptive radiotherapy process in a selected IMRT prostate treatment. The aim was to accumulate the dose using 3 different registration algorithms and compare their respective results with the initial dose plan. This work therefore only tries to show the huge differences that can be reached in a particular case and, using validation systems of the registration, bring to light the importance of the image registration method employed. In any case, our major interest focused on the deformable image registration since the rigid registration is inadequate for the extracranial registrations.

2. Material and methods

Fig. 1 shows the overall workflow of the study. One prostate cancer intensity modulated radiotherapy (IMRT) treatment, which had 3 CT studies, was selected. Every CT represented a third of the total radiotherapy course. The patient was given enemas prior to simulation and daily during the course of radiotherapy and he was advised to have a comfortably full bladder during treatment. The prostate, rectum and bladder were manually delineated by the same radiation oncologist on each CT. A planning target volume (PTV) was created from a prostate

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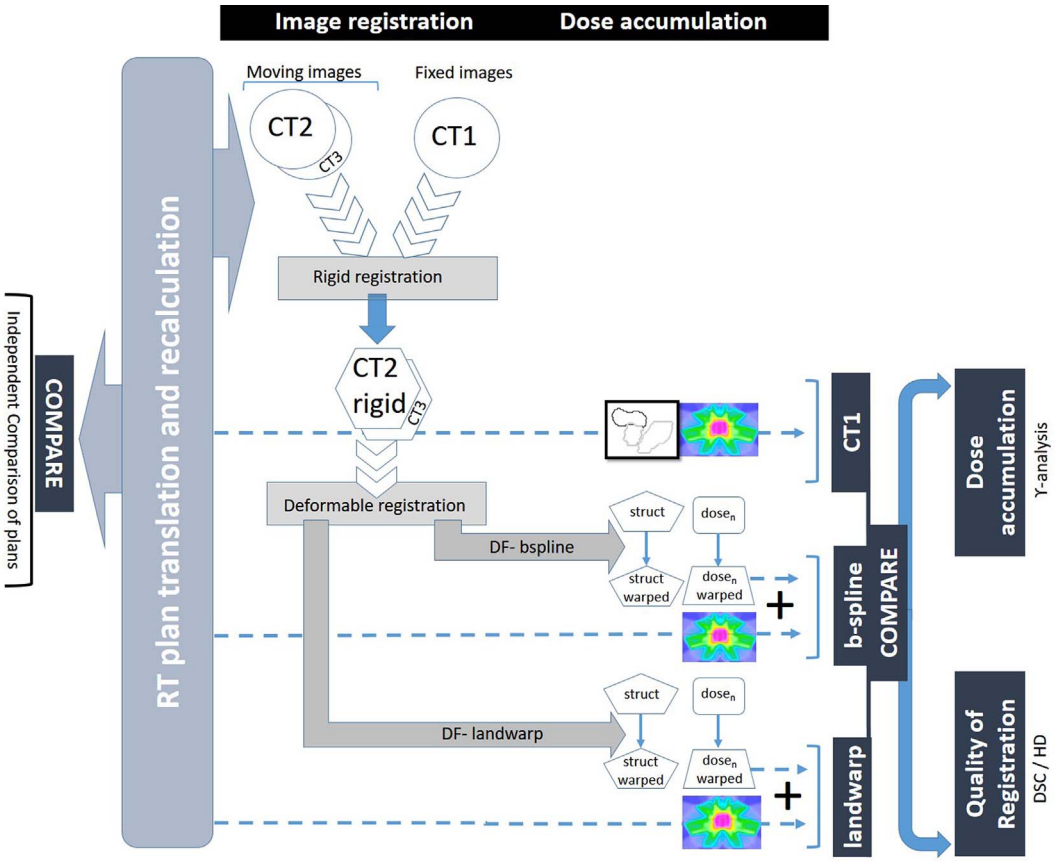

Fig. 1. Overall workflow of the study. CT1 was used to calculate an IMRT plan, which was translated to CT2 and CT3 taking into account isocentres, and to recalculate using the same monitor units. Each CT study was manually segmented. From these results, an independent comparison of the plans was carried out. After an initial rigid registration followed by deformable registration, using b-spline and landwarp algorithms, structures and doses were warped using the corresponding deformation fields (DF). Finally, two kind of comparisons were carried out, the quality of the registration and the dose accumulation, according to the registration algorithm and basal image study.

expansion. The first CT was used for planning 76 Gy, administered in 38 fractions, using XIO v.4.62.00.13 (Elekta AB, Stockholm, Sweden). The resulting IMRT plan was saved as a template and translated to other CT studies. The isocentre was placed using the spatial coordinates from the planning CT, the monitor units were kept exactly the same and the dose was recalculated for every CT study. Therefore every CT study had its own CT images, dose and structures, although the plan was the same between studies. Then, all this DICOM-RT information was exported to the 3D-Slicer package v.4.5.0-1 (www.slicer.org) using the SlicerRT module.

After carrying out the rigid registration, a large discrepancy was observed in the rectum and bladder position between the studies, which suggested that the first step should be the comparison of the DVHs of the different dose plans of each repeated CT independently in order to quantify the differences. This visual discrepancy was also confirmed numerically using the Hausdorff distance (HD) and Dice similarity coefficient (DSC) parameters during the rigid registration.

The next step was the registration of CT1 vs the other two CTs. All registrations used the first CT (CT1) as the reference volume, and subsequent CTs (CT2 and CT3) were taken as the moving volumes. The registration procedure has been described elsewhere [3,4]. In brief, after a rigid image registration (RIR) using the mutual information (MI) as the cost function, the moving volume was used for the initialization of the deformable image registration (DIR). Two parametric DIR algorithms were used: a B-spline algorithm with the mean squared error (MSE) as the cost function, and a landmark-based deformable algorithm (Landwarp 3D-Slicer module) which used the gaussian function as the Radial Base Function (RBF).

The deformation fields, from CT2 to CT3 toward CT1 that were created, were used to transform and warp the dose map. Warped doses were summed to the CT1 dose map and PTV, rectum and bladder dose-volume histograms (DVHs) were produced and compared between them and with the original one (CT1 alone). Finally the final dosimetry obtained after each registration and dose accumulation was compared with the initial dosimetry using the gamma index. The parameters for calculating the gamma index were: distance-to-agreement criteria was set to 3 mm; dose difference criteria was 3% defined as percentage of the reference dose value, in this case the global maximum value; and the dose threshold for gamma analysis was 10% of the maximum dose. The choice of parameters was not important because our purpose was the comparison of the results between the registration methods, although these parameters represent the clinical standards. The discrepancy in volume segmentations after deformation was also quantified by the 95% Hausdorff distance (95%HD), average HD, and the DSC.

3. Results

Fig. 2 and Tables 1 and 2 show the DVHs of the PTV, rectum and bladder for each of the three CTs scanned independently, without any registration. DVH discrepancies are evident, in particular for the rectum and bladder.

Fig. 3 and Tables 3 and 4 show the DVHs and DVH parameters of PTV, rectum and bladder, which compare the initial dose plan on CT1 with the dose accumulation plan after the rigid, deformable and deformable with landmarks registration of the 3 CTs. These comparisons were carried out taking into account only the structures contoured on CT1 while assessing, at the same time, the effect of dose accumulation according to the different image registration methods on these structures. Large differences were expected in these DVHs since important