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Original paper

Commissioning and validation of commercial deformable image registration software for adaptive contouring

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ABSTRACT

Purpose: To report the commissioning and validation of deformable image registration(DIR) software for adaptive contouring.

Methods: DIR (SmartAdapt®v13.6) was validated using two methods namely contour propagation accuracy and landmark tracking, using physical phantoms and clinical images of various disease sites. Five in-house made phantoms with various known deformations and a set of 10 virtual phantoms were used. Displacement in lateral, anterio-posterior (AP) and superior-inferior (SI) direction were evaluated for various organs and compared with the ground truth. Four clinical sites namely, brain (n = 5), HN (n = 9), cervix (n = 18) and prostate (n = 23) were used. Organs were manually delineated by a radiation oncologist, compared with the deformable image registration (DIR) generated contours. 3D slicer v4.5.0.1 was used to analyze Dice Similarity Co-efficient (DSC), shift in centre of mass (COM) and Hausdorff distances $Hf_{95\%/avg}$.

Results: Mean (SD) DSC, $Hf_{95\%}$ (mm), Hf_{avg} (mm) and COM of all the phantoms 1–5 were 0.84 (0.2) mm, 5.1 (7.4) mm, 1.6 (2.2) mm, and 1.6 (0.2) mm respectively. Phantom-5 had the largest deformation as compared to phantoms 1–4, and hence had suboptimal indices. The virtual phantom resulted in consistent results for all the ROIs investigated. Contours propagated for brain patients were better with a high DSC score (0.91 (0.04)) as compared to other sites (HN: 0.84, prostate: 0.81 and cervix 0.77). A similar trend was seen in other indices too. The accuracy of propagated contours is limited for complex deformations that include large volume and shape change of bladder and rectum respectively. Visual validation of the propagated contours is recommended for clinical implementation.

Conclusion: The DIR algorithm was commissioned and validated for adaptive contouring.

1. Introduction

The application of Deformable Image Registration (DIR) in the field of Adaptive radiotherapy (ART) has been on the rise in the recent past [1]. Particularly, there are two major applications of DIR for ART, viz adaptive re-contouring and deformable dose accumulation (DDA). Although, there have been a lot of controversies and mixed opinion regarding the use of DIR for DDA, its use for adaptive contouring is generally acceptable among the community now [2]. This is mainly due to the fact that the validation process for the adaptive contouring is simple while it is too complex for dose accumulation, for example, validation of adaptive re-contouring can be done based on the landmark tracking or by contour propagation, while the dose accumulation needs complex dosimeters which will track the dose voxel to voxel [3].

The ART process and the clinical application of DIR are relatively new to the hospital radiation oncology physicists in our country, who has to commission these software tools, while implementing the ART in their departments. Traditionally to commission a TPS, we would refer IAEA TRS 430 [4], or AAPM practice guidelines [5] which include both dosimetric and non dosimetric tests. These documents recommend that each of these processes and the software must be commissioned before clinical implementation. However, validation/commissioning of DIR is complex due to the lack of the processes that have not been documented systematically at the time of this work and writing manuscript [6]. It is also quite challenging when the deformable phantoms are not available in the hospital. In addition, standard guidelines from professional societies were missing at the time of the present study, which made the validation procedure more complex.

A literature survey reveals that there are various methods to validate the DIR for the purpose of adaptive re-contouring. Traditionally,

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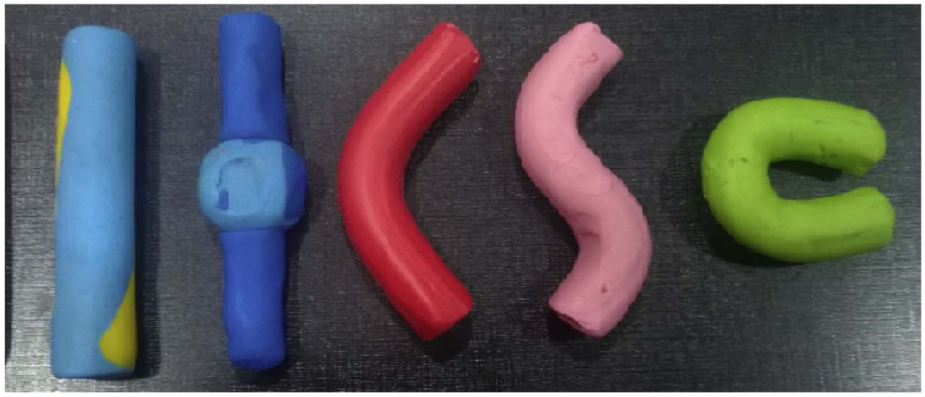

Fig. 1.1. Phantom – 4, Clay models of different shapes.

image subtraction method was used, wherein a reference image was deformed using a reference DVF, to produce a test image [7]. The reference and the test image will be registered by means of DIR which results in test-DVF. The reference and the test DVF is then compared by means of image subtraction method. The image subtraction method compares the intensity difference between the images. A limitation of this method is that the neighbouring voxels which have the same intensity may belong to different organs are aligned to each other. Alternatively, reference and test DVF also can be compared [8]. The limitation of the above methods is that the reference DVF may not include the anatomically realistic deformations.

Later on, land mark based approach method was used by most of the researchers [9] to evaluate the DIR errors. In this method, large number of landmarks > 1000 points will be used to match and quantify the error. Although the quantification of the DIR error is significantly improved in this method, it has an inherent limitation, wherein, in the regions, with similar image features, the visual verification may not work as compared to the regions with the significant change in the image features [10].

Another most commonly used method is the contour comparison [11] between the manual drawn and DIR adapted contours. The advantage of this method is that the visual inspection can act as a tool to validate the DIR generated contours, however this method cannot be used reliably to validate the dose deformation.

Finally, the most comprehensive method to validate the contour and the dose deformation is the voxel-to voxel analysis [12]. As on date, out of all the methods stated above, voxel-voxel based analysis is the most reliable validation method both for adaptive contouring and dose deformation.

When we have acquired DIR, in our department, we also have faced a lot of difficulties. This study was therefore initiated to validate our commercially procured DIR algorithm before clinical implementation for adaptive contouring. We have carried out the validation using both landmark tracking and contour propagation methods using physical/virtual phantom and clinical images in a systematic and comprehensive manner. We therefore, have decided to report the results of these validation tests carried out as part of commissioning of our commercially procured DIR algorithm before clinical implementation for ART.

2. Material and methods

2.1. DIR software

The DIR software tested in this study was SmartAdapt® which is the DIR application in Varian's Eclipse™ treatment planning system v13.6 (Varian Medical Systems Inc., Palo Alto, CA). This application employs a modified demons-based DIR algorithm. All the tests in the present study used only the user settings of the DIR algorithm, no change in the algorithmic parameters were introduced. This application is capable of adaptive re-contouring and not deformable dose accumulation. Hence it was decided to carry out validation only for the adaptive re-contouring.

Two methods of validation were carried out viz, contour propagation accuracy and landmark tracking. The contour propagation accuracy was carried out using physical phantom and clinical images of various disease indications such as brain, head and neck (HN), prostate and cervix, while the land mark tracking was done using virtual phantom HN images.

2.2. Physical phantoms

Five in-house made phantoms with various known deformations were used for this analysis. The known deformations were ranged from simple to complex. The first phantom was a cylinder of different diameter in axial direction, while the second phantom had cylinders of the same diameter with varying heights, in cranio-caudal direction. Third phantom consisted of cylinders with known deformations in both axial and in cranio-caudal direction. Fourth phantom consisted of clay models of various shapes (Fig. 1.1) while the fifth phantom consisted of clay models of varying shapes with change in volume, direction and density (Fig. 1.2). In Phantom 5, some clay objects were used as reference between the images while others had known deformations introduced between the CT acquisitions (Fig. 1.2). The first phantom consisted of various cylinders of diameter 1.4 cm, 1.8 cm, 2.4 cm, 3.3 cm, 4.1 cm and 5.4 cm. The magnitude of the deformation ranged from -0.6 cm to 3.0 cm in axial direction. Second phantom had various lengths such as 2.5 cm, 3.5 cm, 4.5 cm, 5.5 cm and 6.5 cm. The magnitude of variation during image registration varied from -3 cm to 4 cm in cranio-caudal direction. CT scans were obtained for each phantom with a slice thickness of 1.25 mm followed by DIR registration. Various combinations of registration were carried out. Contours were delineated for each phantom set which were propagated to the registered images.

2.3. Synthetic/virtual phantoms

A set of 10 virtual phantom image sets which were freely downloadable from deformable image registration evaluation project [13] were used for this analysis. A detailed description of these phantom images and the download link is available https://sites.google.com/site/dirphantoms/virtual-phantom-download. A short description is as follows: Each phantom was derived from a pair of kVCT volumetric image sets of HN patients. The first images were acquired prior to the start-of-treatment and the second were acquired near the end-of-treatment. Research algorithms were used to auto-segment and deform the start-of-treatment (SOT) images according to a biomechanical model. Various other deformations such as change in head, mandible position, and weight loss were simulated in SOT images to resemble the end-of-treatment (EOT) images. Further, a thin-plate splines algorithm was