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FULL PAPER

Multimodal image registration for the identification of dominant intraprostatic lesion in high-precision radiotherapy treatments

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Purpose: The integration of CT and multiparametric MRI (mpMRI) is a challenging task in high-precision radiotherapy for prostate cancer. A simple methodology for multimodal deformable image registration (DIR) of prostate cancer patients is presented.

Methods: CT and mpMRI of 10 patients were considered. Organs at risk and prostate were contoured on both scans. The dominant intraprostatic lesion was additionally delineated on MRI. After a preliminary rigid image registration, the voxel intensity of all the segmented structures in both scans except the prostate was increased by a specific amount (a constant additional value, A), in order to enhance the contrast of the main organs influencing its position and shape. 70 couples of scans were obtained by varying A from 0 to 800 and they were subsequently non-rigidly registered. Quantities derived from image analysis and contour statistics were considered for the tuning of the best performing A.

Results: A = 200 resulted the minimum enhancement value required to obtain statistically significant

superior registration results. Mean centre of mass distance between corresponding structures decreases from 7.4 mm in rigid registration to 5.3 mm in DIR without enhancement (DIR-0) and to 2.7 mm in DIR with A = 200 (DIR-200). Mean contour distance was 2.5, 1.9 and 0.67 mm in rigid registration, DIR-0 and DIR-200, respectively. In DIR-200 mean contours overlap increases of +13 and +24% with respect to DIR-0 and rigid registration, respectively.

Conclusion: Contour propagation according to the vector field resulting from DIR-200 allows the delineation of dominant intraprostatic lesion on CT scan and its use for high-precision radiotherapy treatment planning.

Advances in knowledge: We investigated the application of a B-spline, mutual information-based multimodal DIR coupled with a simple, patient-unspecific but efficient contrast enhancement procedure in the pelvic body area, thus obtaining a robust and accurate methodology to transfer the functional information deriving from mpMRI onto a planning CT reference volume.

INTRODUCTION

In prostate cancer radiotherapy (RT), the use of multiparametric MRI (mpMRI) to detect dominant intraprostatic lesions (DILs) is gaining acceptance as a standard of care.^{1–3} It has been demonstrated that DILs are frequent sources of post-RT local failure and the benefit of an over-dosage with respect to the whole prostate is currently under investigation.⁴ Moreover, MRI allows an easier segmentation of the

prostate and in particular the identification of the boundary between prostate and rectum. Several studies showed that the integration of an MRI in an RT workflow leads to a decreased dose to the rectal volume, potentially allowing dose escalation protocols.^{5,6} On the other hand, despite the use of MRI-only planning is increasing in clinical use, CT is still the most common imaging modality for RT planning since it provides the primary information about electron

density, which is necessary for the dose calculation, but accurate segmentation is challenging due to insufficient tissue contrast. In this framework, image registration supports the fusion of these two types of information.

Several studies using rigid/affine multimodal image registration algorithm were reported.^{7–9} However, multimodal deformable image registration (DIR) is still a challenging task, due to the high dimensionality of the deformation and the non-linear relationship between the information contents of the images.¹⁰ These problems are exacerbated in case of large anatomical deformation between the images being registered, due to different patient position and different filling of hollow organs. Some studies evaluated the influence of using prostate MRI acquired in non-RT position (namely using non-flat couches), showing that the DIR enables to cope with different patient setups during image acquisition.^{11,12} However, an additional difficulty is given by different hollow-organ filling between scans, which is well-known to have a notable influence on prostate position and deformation.^{13,14}

In this feasibility study, a novel combination of anatomical information provided by morphological scans and image intensity-based information is reported, in the frame of multimodal DIR approach with explicit presentation of its relevant parameters, such as transformation function, similarity method, optimization function and regularization term. Images were modified by adding constant intensity values to the main structures influencing the position and shape of the prostate, in order to increase their contrast with respect to the surrounding soft tissue. The optimal contrast enhancing value that provided a significant improvement in image alignment was assessed.

METHODS AND MATERIALS

This study is part of a larger project granted by AIRC – Associazione Italiana per la Ricerca sul Cancro (project number IG-13218), namely a Phase II study aiming to investigate the feasibility of an extremely hypofractionated RT scheme with concomitant boost to the DIL for the treatment of low- to intermediate-risk prostate adenocarcinoma. The project was approved by institutional Ethics Committee on 20 February 2013 (Clinical trial identifier: NCT01913717).

Patient population

10 patients previously treated with RT for prostate cancer at the European Institute of Oncology in Milan (Italy) were retrospectively enrolled. The inclusion/exclusion criteria for the treatment are extensively presented in Timon et al.¹⁵ All patients gave written informed consent for the treatment and use of their anonymized data for research and educational purpose. The patients underwent a diagnostic mpMRI and a treatment planning CT scan. According to the Institutional protocol for RT of prostate cancer, patients are treated supine with knees slightly bent on dedicated support (CombifixTM, CIVCO Medical Solutions, Orange City, IA). Moreover, they are instructed to empty their rectum and to drink half a liter of water 30 min before the acquisition of planning CT and before each treatment fraction. The setup configuration for diagnostic mpMRI is usually different, with patients positioned supine with legs extended.

There are no strict requirements in MRI concerning the hollow organs, except of pharmacological hypotonization and a moderate filling of the urinary bladder. Five patients underwent mpMRI with the usual MR setup (patients 1, 2, 3, 8 and 9); for the remaining five patients the planning CT setup was reproduced during mpMRI acquisition. These subgroups of patients will be referred as *MR-setup* and *CT-setup*, respectively. In-plane image resolution is 1.27×1.27 mm in CT images and ranges from 0.89×0.89 to 1.34×1.34 mm in MR images. Slice thickness is 2.5 and 3.6 mm in CT and MR scans, respectively. Mean time between acquisitions is 26 days (range 0–113).

Segmentation

The prostate, the DIL and the prostatic urethra were identified by an expert radiologist on the mpMRI considering the T_2 weighted (T2W), diffusion weighted imaging and dynamic contrast enhanced automatically coregistered sequences. DILs identified on the mpMRI had a median volume of 2.0 cm^3 (range $0.1\text{--}3.8 \text{ cm}^3$). For two patients, two distinct foci were identified. An expert radiation oncologist contoured urinary bladder, rectum, femurs and pelvis bones on T2W images and CT scans for image registration and treatment planning purpose, respectively.

Image registration

Image registration was performed with the CT serving as fixed reference image and the T2W imaging as moving image. The scheme of the implemented process is shown in Figure 1.

An image pre-processing step was performed and composed of three stages. First, a rigid registration was performed with 3D-Slicer (www.slicer.org) using default registration parameters (Histogram bins: 30; Spatial samples: 10,000; Iterations: 1000, 1000, 500, 200; Learning rates: 0.01, 0.005, 0.0005, 0.0002; Translation scaling: 100).¹⁶ Since target structures, namely prostate and DIL, are scarcely contrasted with respect to the surrounding tissue, the rigid registration was applied taking into account the entire image. Then, as the cranio-caudal extension of MR scan was inferior to CT extension in our data set, CT scans were cropped in cranio-caudal direction in order to reduce the computational cost of the following DIR. Finally, the background was masked assigning an intensity value of -1000 to the voxels outside the body structure in order to remove the influence of couches and pillows on the registration procedure.

These pre-processed images served as input to contrast enhancement step, which was implemented in MATLAB (R2011a, TheMathWorks, Natick, MA). This crucial procedure was designed to trade-off the quality of the outcomes of the DIR procedure with a general applicability on pelvic image data sets, thus intentionally avoiding any patient-specific optimization. It was based on the selection of appropriate additional intensity values (A) to be added on specific structures segmented in CT and T2W scans. In particular, we investigated seven different combinations of contrast-enhancing values, which were obtained by adding $A = 0, 100, 200, 300, 400, 500$ and 800 to the intensity values of

Figure 1. Registration process scheme. The three steps constituting the implemented image registration algorithm are represented.

clinically relevant segmented structures. These were selected among the ones supposed to influence the prostate position in different image data sets; in particular, femurs and pelvis

bones were considered as surrogates accounting for the overall patient position mismatches and related prostate and organ at risk (OAR) displacements; urinary bladder and rectum were considered for their well-known effect on prostate position and shape.^{17–20} The additive intensity value was positive for all the selected structures; conversely for the rectum, which is surrounded by hyperintense soft tissues, the value was subtracted in T2W images. The so obtained data sets were provided as input to DIR step, which was performed using the Plastimatch (www.plastimatch.org) suite, an open-source software for image computation that carries out image registration as a function of customizable parameter sets.²¹ We implemented a multistage B-spline-based DIR procedure, using only one combination of parameters as a way to keep our approach independent from patient-specific registration parameter tuning. The DIR process consisted of four deformable stages, from coarse to fine registration, by means of a progressive reduction in B-spline grid tile; the optimizer was a limited-memory Broyden–Fletcher–Goldfarb–Shannon with simple bounds and optimization metric was the mutual information (MI). As large deformations are likely to occur, a regularization term was also introduced in the optimization process to limit the occurrence of discontinuities and folding.²² The complete list of Plastimatch registration parameters for different deformable stages is provided in Table 1. The DIR process was tested for all the imposed contrast-enhancement values, which we termed DIR-0 (*i.e.* considering the original scans without enhancement), DIR-100, DIR-200, DIR-300, DIR-400, DIR-500 and DIR-800, as a function of the increasing additive value. Therefore, seven DIRs were performed for each patient, thus obtaining 70 registration cases to be investigated.

Geometric validation

The determinant of the Jacobian matrix of the deformation vector field was used to analyse the smoothness of the transformation estimated by the deformable registration process. Irregular deformations were assessed considering the determinant of the Jacobian matrix of each voxel of the deformation field. A critical inspection of voxels corresponding to negative values

Table 1. Registration parameters http://plastimatch.org/registration_command_file_reference.html#registration-command-file-reference.

Deformable registration stage	I	II	III	IV
Registration transform	B-spline	B-spline	B-spline	B-spline
Optimization	lbfgsb	lbfgsb	lbfgsb	lbfgsb
Implementation	Plastimatch	Plastimatch	Plastimatch	Plastimatch
Metric	MI	MI	MI	MI
Max no. of iterations	50	30	20	10
Resolution	4 4 4	2 2 2	2 2 1	2 2 1
Grid spacing	20 20 12	8 8 6	5 5 5	5 5 5
Regularization	0.000005	0.0005	0.0005	0.005

lbfgsb, limited memory Broyden–Fletcher–Goldfarb–Shannon with simple bounds; MI, mutual information.

The different parameters are reported for each of the four implemented stages of the deformable image registration process. Extensive references are reported at: http://plastimatch.org/registration_command_file_reference.html#registration-command-file-reference.

was performed, since such areas correspond to singularities in the deformation field.²³

Since not visible in the CT images, the quality in the local registration of the DILs could not be evaluated directly. Therefore, we were forced to assess indirect indices to evaluate the performance of image registration. In order to take into account the relative gain provided by DIR with respect to rigid

image registration in terms of whole image overlap, we considered the residual normalized mutual information (Δ NMI) between the non-rigidly registered CT-MR scans with respect to the rigidly registered ones. NMI was calculated according to Studhelme *et al.*²⁴ Structure related indices were centre of mass distance (CMD), average Hausdorff distance (AHD), which is an expression of distance between surfaces and Dice Similarity coefficient (DSC), which expresses the overlap

Figure 2. Image intensity profiles are shown in correspondence of urinary bladder volume (green line, panels c and d), pelvic bones and femurs (blue line, panels e and f) and rectum (red line, panels g and h) for CT (panels c, e and g) and T2W MRI (panels d, f and h), at varying intensity enhancement values from 0 (namely original scans) to $A = 800$.

between two structures in a scale from 0 (no overlap) to 1 (perfect overlap).^{25,26} The statistical analysis was performed in MATLAB: statistical significance was asserted by analysis of variance (ANOVA) with *post-hoc* multiple comparison Tukey test after having verified the normality of the distribution using Jarque-Bera/Lilliefors test. For all tests performed, the threshold of significance is $p\text{-value} < 0.05$.

Subgroups analysis

Multiway ANOVAs were performed to investigate the influence of patient setup in the different scans on registration results, comparing the MR-setup and CT-setup groups. CMD, AHD and DSC were considered for all the structures together. The effects of different registration criteria and different OARs were considered as main influencing factors of the ANOVA.

Figure 3. Example of data set and results. For patient 1, axial and sagittal views of CT scan (a and c, respectively) and of MR scan (b and d) with segmented structures overlaid. On both scans, prostate is in light blue, urinary bladder in yellow, rectum in green, pelvis bones in blue, femurs in purple and outer contour in dark green. On MR scan, DIL is contoured in red. The modified scans with $A = 200$ are shown in (e) (CT) and (f) (MR). In (g and i), the result of rigid registration is shown. The different shape of bladder and rectum can be observed. In (h and j), the result of deformable registration obtained with DIR-200 is shown. DIL, dominant intraprostatic lesions.

RESULTS

In Figure 2, an example of the enhancing effect on image intensities is reported, showing three image intensity profiles in correspondence of urinary bladder, bones and rectum for CT and T2W MRI at varying enhancement values A.

In Figure 3 an example of original and modified scans, with segmented structures overlaid, and their rigid and non-rigid registration is shown.

The analysis of the determinant of the Jacobian matrix of the deformation fields showed that singularities were present in the 0.003% of voxels (median value, range 0–0.18%) of the deformation matrices. No statistically significant differences were found between different levels of applied enhancement values (p -value = 0.91, Kruskal-Wallis test). A point-by-point inspection revealed that all singularities corresponded to voxels within the urinary bladder or at the boundaries of the deformation field (first and last slices).

Residual normalized mutual information

Δ NMI was positive for all the tested combination of parameters. In particular, the relative increase of NMI in the non-rigidly registered respect to the rigidly registered images ranged from 6% for the original, unenhanced images to 7.2% for the highest enhancement value (DIR-800). The ANOVA highlighted that increasing over A = 200 did not result in a statistically significant increase of relative Δ NMI. In Figure 4, the *post-hoc* comparison is shown.

Structure-related parameters

In Figure 5, the boxplot representation summarizes the results obtained from structure-related indices. A statistical *post-hoc* analysis was performed for each structure to identify the bare minimum additive enhancement value, beyond which improvements in registration became statistically insignificant.

For right and left femurs, a statistically significant increase in DSC was found at DIR-500. Conversely, for right and left pelvis bones, no statistical significant differences were observed regardless the specific enhancement values. This is probably due to the fact that a satisfactorily pelvic bone alignment can be obtained by means of a simple rigid registration stage, thus exhibiting

Figure 4. *Post-hoc* analysis of residual information (Δ NMI). Relative Δ NMI obtained with non-rigidly registered images at increasing additional value A respect to the rigidly registered images is shown. Circles represent the mean value, lines extending from them represent the comparison interval. If the comparison intervals are disjoint, two group means are significantly different. The Δ NMI obtained for DIR-200 is significantly superior respect to the original images and to DIR-100, but not significantly different from results obtained at increasing additional value A.

negligible improvements introduced by the deformable stage at different enhancement values. Conversely, soft tissue structures exhibited noteworthy registration improvements. For example, mean DSC of urinary bladder raised from 0.59 in the DIR-0 to 0.8 in the DIR-100 and 0.92 in the DIR-200 (p -value = 0.01). For further increase over DIR-200, differences in DSC became non-statistically significant. The same behaviour was observed in the *post-hoc* analysis of AHD, with mean values of 3.8, 1.3 and 0.3 mm for DIR-0, DIR-100 and DIR-200, respectively. Similarly, the CMD index displayed improving mean values as a function of the level of contrast-enhanced deformable stage, with values of 8.5 mm for DIR-0, 4.0 mm for DIR-100 and 1.4 mm for DIR-200 (p -value = 0.01). For rectum, DIR-200 produced the best statistically significant results in terms of DSC (mean values 0.79 vs 0.69 in DIR-100 and 0.6 in DIR-0), AHD (0.8 mm vs 1.5 in DIR-100

Figure 5. Structure-related statistics. Boxplot representation of centre of mass distance (CMD, left panel), average Hausdorff distance (AHD, central panel) and Dice similarity coefficient (DSC, right panel), at varying image registration modalities, *i.e.* rigid (index R), non-rigid without additional contrast (index O) and non-rigid registration with increasing enhancement coefficient (indexes 100, 200, 300, 400, 500 and 800), considering all segmented structures. AHD, average Hausdorff distance; CMD, centre of mass distance; DSC, dice similarity coefficient.

Table 2. Mean and SD of the volumes of urinary bladder, rectum and prostate evaluated for CT and MR scans of 10 patients (CT and MR columns, respectively)

	CT		MR		Delta CT-MR			
					CT-setup		MR-setup	
	Mean (cm ³)	SD (cm ³)	Mean (cm ³)	SD (cm ³)	Mean (cm ³)	SD (cm ³)	Mean (cm ³)	SD (cm ³)
Urinary bladder	342.12	99.71	194.71	146.83	28.28	102.94	266.54	73.84
Rectum	66.54	16.31	62.17	29.07	5.30	34.94	3.44	16.69
Prostate	60.89	20.87	43.69	15.10				

In Delta CT-MR columns, the mean and SD of the difference between CT and MR volumes of urinary bladder and rectum are evaluated for the two patient subgroups.

and 2.6 mm in DIR-0) and CMD (2.8 mm vs 3.8 in DIR-100 and 6.7 mm in DIR-0). Prostate registration showed a statistically significant increase in mean DSC from DIR-0 (0.63) to DIR-300 (0.75) and a decrease in mean AHD from 1.3 mm in DIR-100 to 0.7 mm in DIR-300 (p -value = 0.02). Non-statistically significant improvements were found for CMD (6.9 mm in DIR-0, 3.2 mm in DIR-300).

Considering all the structures together, the highest statistically significance was obtained at DIR-200 with a mean DSC value of 0.83 (to be compared with 0.58 for rigid registration), mean AHD of 0.7 mm (vs 2.5 mm for rigid registration) and mean CMD of 2.7 mm (vs 7.4 mm for rigid registration).

Setup influence

In Table 2, statistics about contoured volumes are reported. The multiway ANOVA performed between CT-setup and MR-setup subgroups to test the effect of setup method, taking into account also the effects of different registration methods and organs at risk as main influencing factors, showed a statistically significant effect on DSC results (p -value = 0.0008) and a weak statistically significant effect on CMD (p -value = 0.018). In both cases, better results were obtained for CT-setup subgroup: mean DSC increased from 0.77 (MR-setup) to 0.80 (CT-setup) and mean CMD decreases from 3.8 mm (MR-setup) to 3.2 mm (CT-setup). The analysis of AHD, instead, did not show statistically significant differences between subgroups (p -value = 0.35). Subsequently, ANOVAs were performed within registration methods and results are shown in Figure 6. Larger statistically significant differences are obtained for DSC in correspondence of rigid and non-rigid registration with enhancement coefficient $A = 100$, where CT-setup subgroup obtained 7.4 and 5.7% higher mean DSC than MR-setup subgroup.

DISCUSSION

In this study, we investigated the application of a B-spline, mutual information-based multimodal DIR coupled with a simple, patient-unspecific but efficient contrast enhancement procedure in the pelvic body area. The rationale resides in the fact that the fusion of different imaging modalities allows coupling the information on the electron density of CT scans, which are required for dose distribution calculation in RT treatment planning, and the capability of mpMRI to show more clearly soft tissues and

structures, such as prostate boundaries and DILs, which are relevant for local dose-escalation strategies. In the presented method, input images are modified in order to increase the contrast of distinctive OARs, which particularly contribute to the position and shape of prostate with respect to surrounding soft tissues. In particular, bony anatomy (namely femur and pelvis bones) was considered to align the pelvis position, whereas soft tissues surrounding the prostate (namely urinary bladder and rectum) were considered to refine the alignment of prostate. The intensity enhancement value underwent a specific analysis in order to estimate the optimal value for granting the highest quality in image registration. A subanalysis of CT-setup and MR-setup subgroups was presented, although the limited number of patients in the subgroups weakened its statistical significance. However, our findings should be considered as hypothesis-generating and might be further confirmed in large-scale studies. The difference between CT and MR volumes highlights that the preliminary instruction to patients significantly influenced the urinary bladder volume, as the mean difference between CT and MR scans is very low for the CT-setup subgroup (28 cm³). Conversely, this was not true for rectum volume. Moreover, due to the lack of soft tissue contrast in CT scans, prostate segmentation resulted in an overestimation of the prostate volume in CT with respect to MR of about 40%, in agreement with published data.^{5,6,27}

The assessment of the image registration quality indices (DSC, CMD and AHD) obtained after rigid and deformable registration with image contrast enhancement showed notable reduction in average values dispersion and number of outliers. This suggests that the incorporation into a CT-based treatment planning process of MRI derived information may lead to significant improvements in prostate localization and targeting.

Recently, the introduction of the endorectal coil-based MRI for the improvement of spatial resolution and signal-to-noise ratio in prostate imaging induced several research groups to investigate various registration algorithms, including narrow band and thin plate splines.^{28–30} Different algorithms were tested for the mono-modal registration, including finite element method, thin plate splines, principal component analysis and the propagation phase was performed rigidly or non-rigidly.^{31–33} Rivest-Hénault et al presented a method for CT-MR registration in pelvis scans.

Figure 6. Setup influence statistics. Mean (circles) and SD (whiskers) of DSC (a), CMD (b) and AHD (c) for all segmented structures are shown for subgroups of patients with similar and different setup between CT and MR acquisition, at varying imageregistration modalities, i.e. rigid and non-rigid at increasing additional parameter A. The corresponding p -values resulting from ANOVA between CT-setup and MR-setup groups are also shown.

They considered both the anatomical guidance and image similarity criterion in two separate steps: they used structure segmentation, including prostate, to create binary images that served as an input for the registration phase based on anatomical guidance and then refined this result in a registration stage based on intensity information.³⁴ However, some uncertainties exist in the segmentation of prostate in CT, particularly at the apex.^{35,36} For this reason, in our study, we decided not to introduce *a priori* knowledge about the prostate contour but to infer

its position and shape from adjacent structures. Conforming to this observation, Zhong et al³⁷ recently implemented an MR-CT DIR workflow based on adaptive finite element method-based refinement of the displacement vector field obtained with a commercial B-spline-based algorithm in a region surrounding the prostate. In our study, the registration process was driven by both the anatomical information of OARs and the information deriving from intensity values in the images, simultaneously. Images were modified by adding a constant value to the voxels

of the segmented structures, in order to enhance their contrast with respect to surrounding soft tissues, while maintaining the peculiar tissue variability. We integrated such a simple and easy-to-implement contrast enhancement method in image registration procedure in the pelvic body area still obtaining acceptable registration results. The effectiveness of other tools or contrast enhancement methods, more or less sophisticated, might be investigated in further studies. The optimal additional value was determined by a tuning test, evaluating intrinsic parameters of the registered images and quantities derived from image analysis. The bare minimum additive enhancement value was chosen both in order to minimize the contingent influence of manual delineation on the performance of the registration algorithm and to maximize the influence of peculiar tissue variability. Best results were obtained in correspondence of DIR-200, with a relative percentage enhancement of 64% in CMD, 74% in AHD and 42% in DSC, with respect to rigid registration. Mean DSC for prostate at DIR-200 was 0.77. It is interesting to note that, as the mean volume ratio of prostate segmentation in MR and CT scan is 0.72 in this study, according to Yacoub et al the maximum mean DSC achievable for this organ is 0.84.³

In Figure 3, the difficulties in appropriately matching the position of rectum and bladder using a rigid registration, due to their different filling and extension, are well depicted. The DIR process is able to recover these differences, as testified by the improved superimposition of corresponding contours, and consequently deform the prostate contour as appropriate. We are well aware that the main conceptual drawback of this issue is that the quality of the transferred lesion to the CT cannot be directly evaluated. Therefore, the correctness of the registration in its entirety was considered as a surrogate of the missing metric.

It is probable that the quality of manual delineation affects the performance of the DIR and it could be evaluated in a further study. However, since the images are modified by adding a constant value to the voxels of the segmented structures, the peculiar differences between voxel intensities are maintained and discontinuities and unevenness in the segmented region can still be appreciated and taken into account during the image registration. Thus, the uncertainty due to the variation in manual contouring is mitigated. Further confounding factors might be changes in patient weight/body habitus during care path due to time distance between scans and/or additional therapies such as chemotherapy and hormone-therapy. However, these investigations are beyond the purpose of this feasibility study. An intensity-based algorithm that optimizes the MI was chosen to perform

image registration. This similarity criterion is more sensitive to common information between images rather than to absolute intensity values. Moreover, in order to smooth the registration results and to limit folds and tears that can occur in a DIR, in particular if large deformations take place, a multigrid and multistage algorithm was implemented and a regularization term was used in the image registration process.^{22,38,39} As observed, all singularities correspond to voxels within the urinary bladder, when large differences in urinary bladder volume between scans are present, or at the boundaries of the deformation field (first and last slices). Therefore, the resulting deformations are considered adequate, although a higher value of regularization might be considered for future application.

The implemented registration algorithm is fully automated. The only operator time-consuming step is the segmentation of structures required for the registration. However, the registration algorithm was intended for off-line registration, so computational time issues are not a key concern.

CONCLUSION

Our study indicated that the proposed multimodal DIR method is generic in the sense that it works for different anatomies. The simple, patient-unspecific but efficient contrast enhancement procedure proposed might be easily implemented in commercially available image registration software with script-based integration options. Better results are achieved for both the rigid and the implemented DIR if the registered scans are acquired with similar setup, even if poor statistical significance was obtained. The implemented method is robust with respect to initial setup of the patient, as acceptable accuracy is obtained for subgroups of patients with varying setup in the MR scan. Contour propagation according to the vector field resulting from DIR-200 allows the delineation of dominant intraprostatic lesion on CT scan and its use for high-precision RT treatment planning.

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