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Deep learning automatic applicator-based MRI registration in image guided adaptive brachytherapy

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Objective

MRI based image-guided adaptive brachytherapy (IGABT) is the state of the art for treatment of locally advanced cervical cancer (LACC) [1]. To monitor implant stability, organ motion and its impact on delivered dose, routine control scans are taken before every second fraction delivered with the same implant.
A quantitative evaluation of the dosimetric changes between fractions due to anatomical variations, which can have significant dosimetric impact [2], can be achieved via rigid registration based on the applicator as a reference structure, as target and dose distribution are fixed to the applicator.
However, currently this is a manual and time-consuming process. Semi-automatic routines exist but rely on prior definition of landmarks. The required time investment prevents the evaluation of inter and intra-fraction motions of organs at risk in clinical routine.
The aim of this retrospective study was to automate this process. Therefore, we i) compared different structure-based rigid image registration algorithms to select the most suitable one for MR-IGABT, and ii) trained a neural network (NN) to predict the applicator structure to automate the registration process.

Patients and Methods

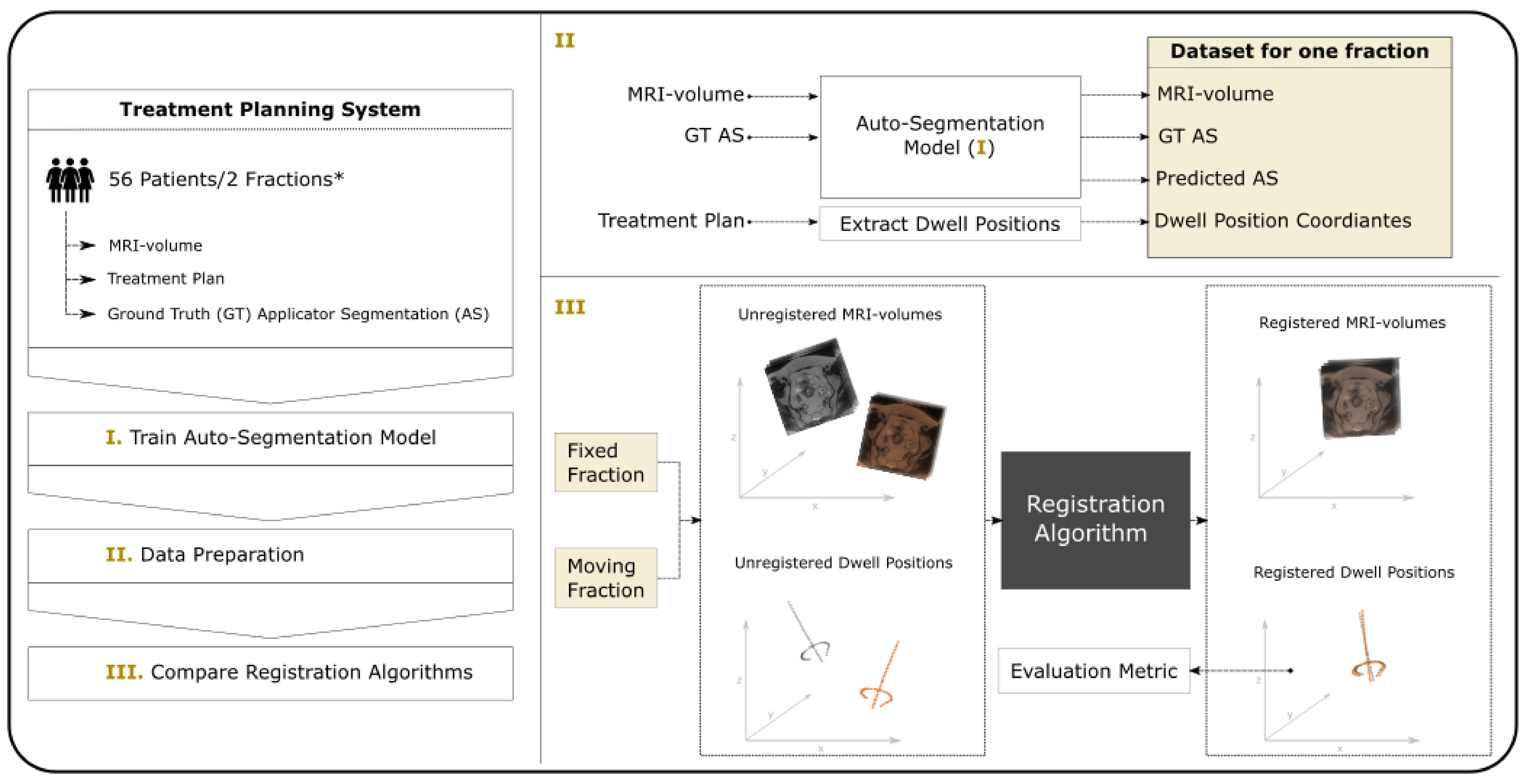

Figure 1 - For each patient in our cohort, two brachytherapy fraction treatment plans, and corresponding MRI-volumes were exported from the TPS. Ground-truth (GT) applicator segmentations (AS), which are usually not available in the TPS, were generated with an Elekta Applicator Slicer research plugin (Elekta, Venendaal). An auto-segmentation neural network was trained to predict the applicator structure in unseen MR-volumes. Finally, different applicator-based rigid image registration algorithms were compared, initially with GT, and eventually with predicted AS. The registration accuracy was evaluated by using the distance between dwell positions as a metric.

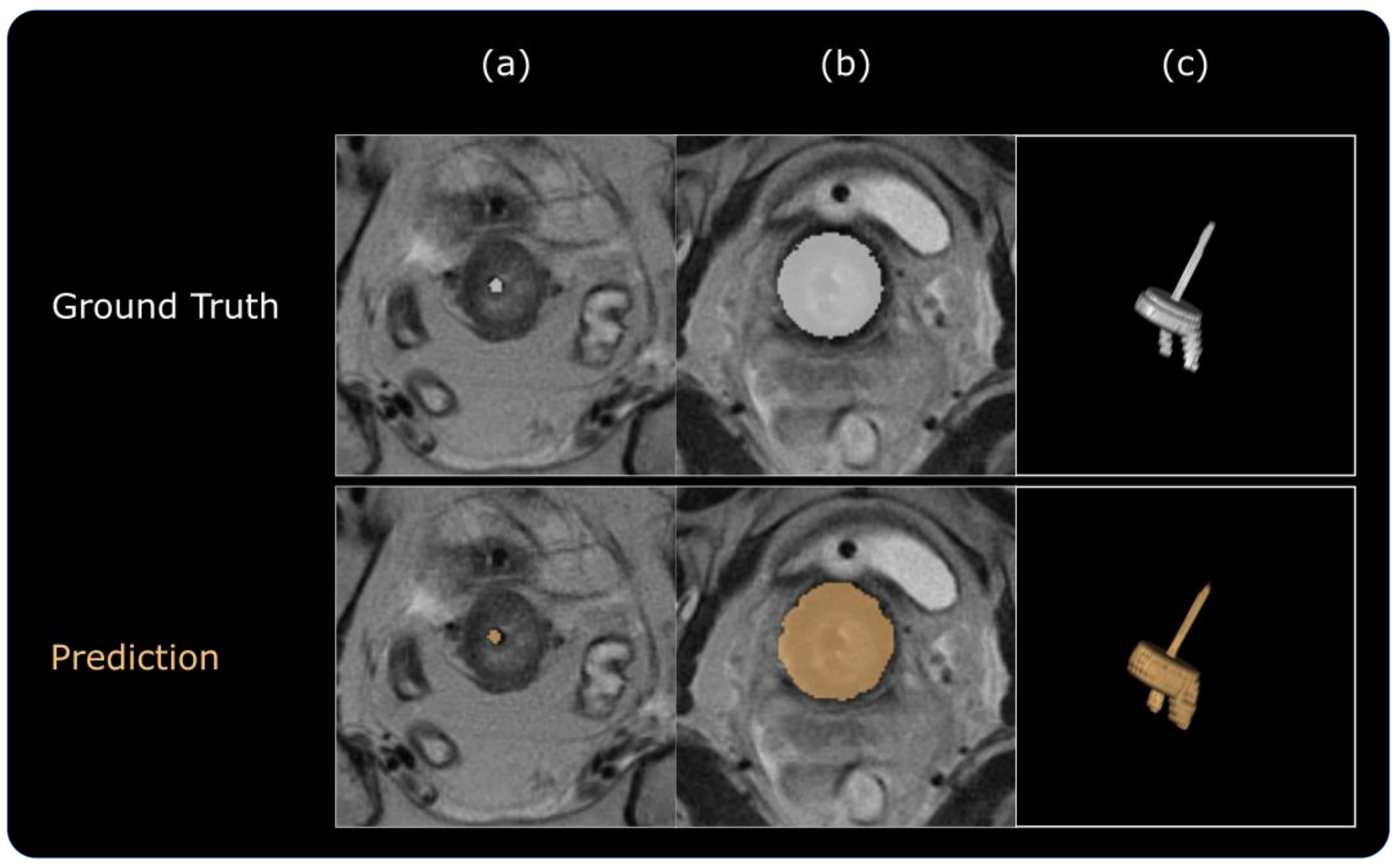

Figure 2 - Results of the auto-segmentation network from an example patient, and comparison with ground truth. Columns show (a) para-transversal slice through the tandem, (b) para-transversal slice through the ring of the applicator and (c) 3D rendering of the applicator structure.

Results

Segmentation and registration performance was evaluated on a test set of 10 randomly selected patients.
The mean DICE coefficient for the predicted applicator segmentations on the test set, using a 3D U-Net style architecture (UNETR), was 0.70 ± 0.07. Fig.2 shows the output of UNETR for an example patient in comparison with ground truth.

Five different rigid image registration algorithms were investigated:
“Default Rigid” (DR); used the full MRI-volumes and no applicator mask. “Applicator ROI” (AROI); used applicator masks to define valid sampling regions in MRI-volumes. “Applicator Mask” (AM); used no MRI and registered binary applicator masks directly. “Distance Map” (DM); used no MRI and registered distance maps generated from the applicator masks. “Prediction” (DM*); Same as DM but used predicted applicator masks from the NN.
The results of the different registration algorithms, evaluated on the test set are summarized in Fig.3. The best result was achieved by registering the distance maps generated from the ground truth applicator structures, resulting in an error of 0.7 ± 0.5 mm. Using the predicted applicator structures instead, the error was 2.7 ± 1.4 mm.

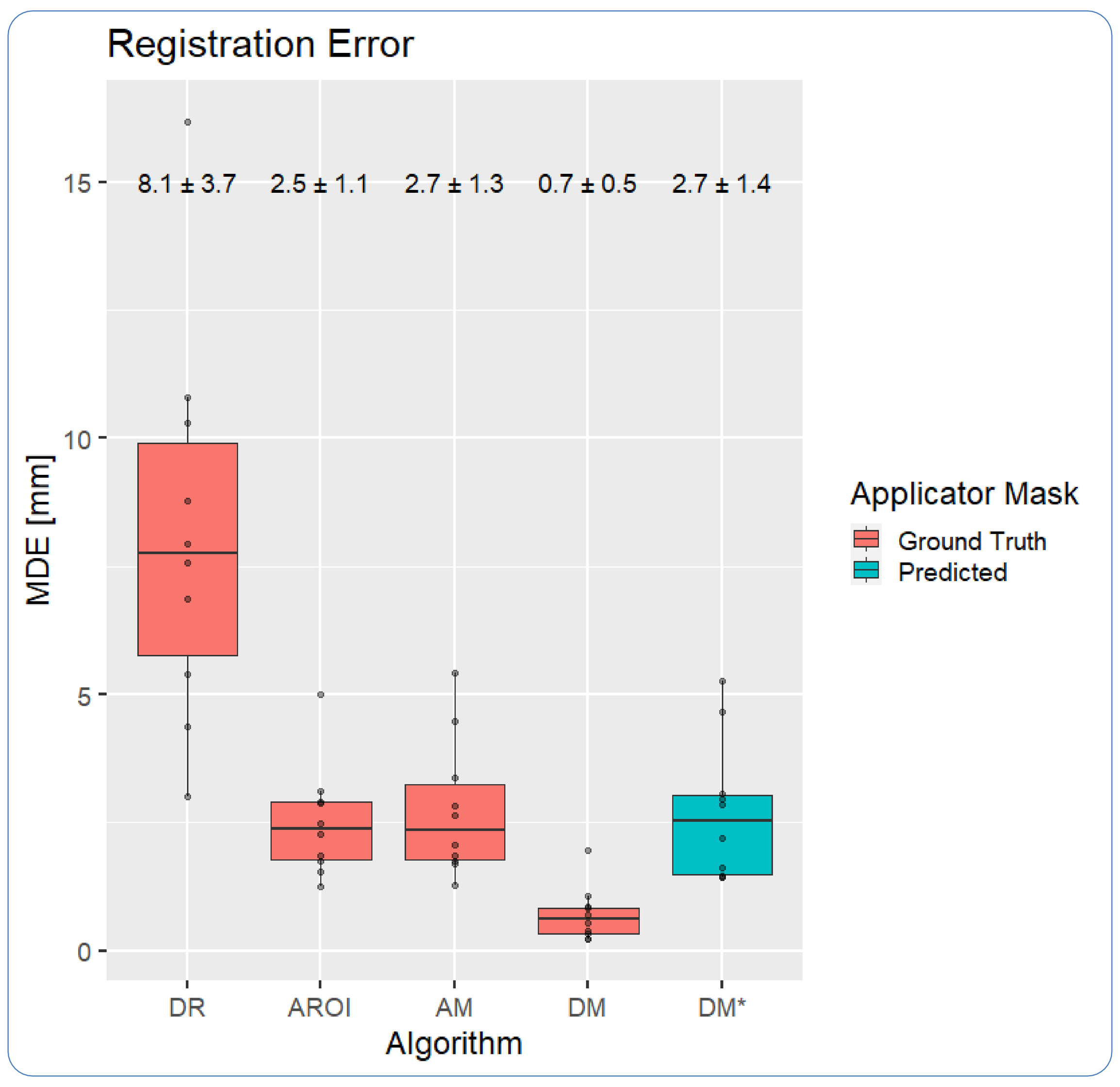

Figure 3 - Registration error for different algorithms. Each box shows the distribution of the Mean Distance Error (MDE - average distance between dwell positions in mm). Mean error and standard deviation are provided above.

Conclusion

The results of this study show that automatic applicator-based image registration for MR-IGABT could be achieved by combining classical image registration algorithms with modern deep learning methods.
It was shown that a registration error below 1 mm is achievable with our technique. Thus, using an improved version of the auto-segmentation network or similar approaches, would enable a fully automatic registration workflow.
Importantly, each inference on the model and the registration algorithm, takes less than 30 seconds on a standard computer. This represents a significant time improvement from current manual practices.
The presented model would be attractive as it could be used for different applicator and needle configurations. Such automation would represent an important step towards future applications for routine monitoring of organ motion during treatment and could help to reduce dosimetric uncertainties.

ADDITIONAL INFORMATION

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References

[1] R. Pötter et al.,Lancet Oncol., vol. 22, no. 4, pp. 538-547, 2021.
[2] N. Nesvacil et al., Radiother. Oncol., vol. 107, no. 1, pp. 20-25, 2013.

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