MR-only radiotherapy planning with ART-Plan™ Annotate and Pseudo-CT

White paper

THERAPANACEA

Reinventing cancer care through AI

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Introduction

Computed tomography (CT) is currently the gold standard for radiotherapy (RT) planning. As a patient's anatomy changes throughout the treatment process, the initial treatment plan computed on a CT may no longer reflect the actual dose that is being delivered to the target and organs at risk (OARs) of tumor spread. Repeated imaging, such as cone-beam computed tomography (CBCT), commonly used for patient positioning purposes, can facilitate plan adaptation decisions. However, little discrimination between soft tissues is obtained from the CT and CBCT images, since tumour and the organs at risk have similar attenuation coefficients. In addition, CBCT images suffer from several image quality deficiencies (e.g. scatter) that prevent direct dose calculations.

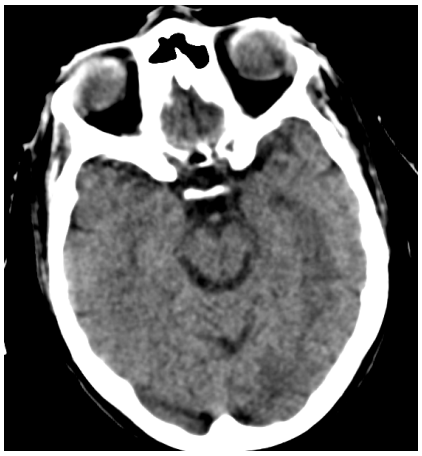
Thanks to its better soft-tissue contrast, magnetic resonance imaging (MRI) is widely used as a supplement to the CT imaging for a better delineation of the tumor and OARs. Additional benefits of MRI over CT include the usage of non-ionizing radiation and the ability to derive more information on tumor activity and therapy response.

Despite all benefits, to date, radiotherapy cannot be planned on MR images alone, as they do not provide the tissue electron density information needed for dose calculations in a treatment planning system (TPS). To bridge this gap, TheraPanacea is proposing an MR-only workflow. This new workflow will help radiation oncology practitioners overcome the limitations of the MR/CT hybrid workflow and, ultimately, reduce the overall treatment cost, workload, and patient exposure to ionizing radiation.

As part of the MR-only workflow, ART-Plan™ now includes a tool for pseudo-CT generation from MR images. The aim is to provide the electron density information for dose calculations with the same accuracy as that of CT images, all without the need of additional CT images.

MRI

pCT



CT

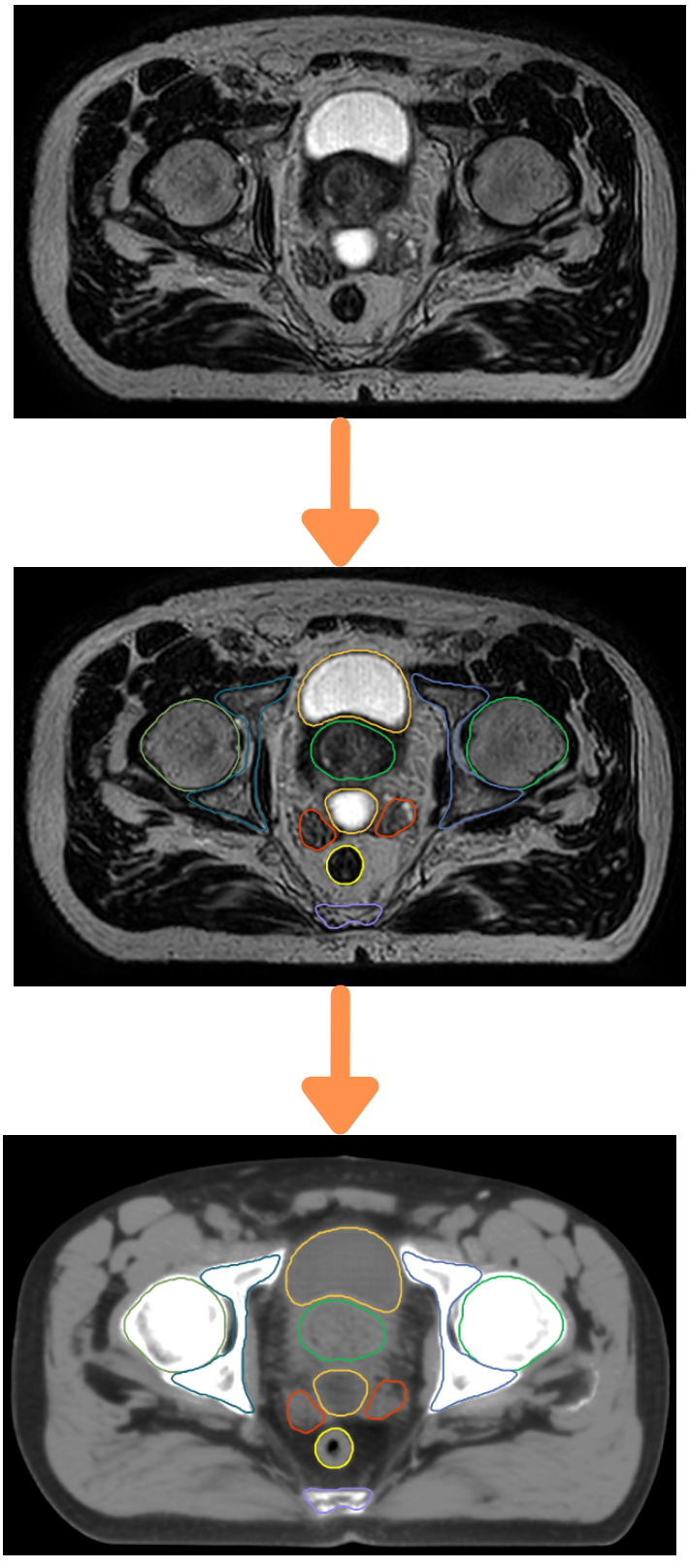
Key Advantages of MR only Radiotherapy Planning

- Better soft tissue contrast for improved delineation
- Reduced registration errors
- Reduced Patient exposure to ionizing radiation
- Reduced overall Treatment cost

Experience MR-only Workflow in your Clinic with ART-Plan™

Here is how ART-Plan™ can help improve the radiotherapy workflow thanks to its new module for MR-only Radiotherapy.

Through the new pseudo-CT module, the user will be able to simplify their current workflow for both the planning and replanning phases, as they will not only avoid the need for different images (MR and CT) as well as the need for multi-modal registration.



Delineate OARs on MR images

Thanks to its better soft-tissue contrast, magnetic resonance imaging (MRI) is widely used as a supplement to CT imaging for better delineation of tumors and OARs. In addition, more information on tumor activity and therapy response can be derived from MR sequences.

Generate an MR-based pseudo-CT

Generate tissue electron density for dose calculation from pseudo-CTs. All without the need of multi-modal scans and registration.

Plan your treatment

Save time, reduce costs and optimize patient scheduling for better use of departmental resources.

MR Annotation by ART-Plan™

Brain T1

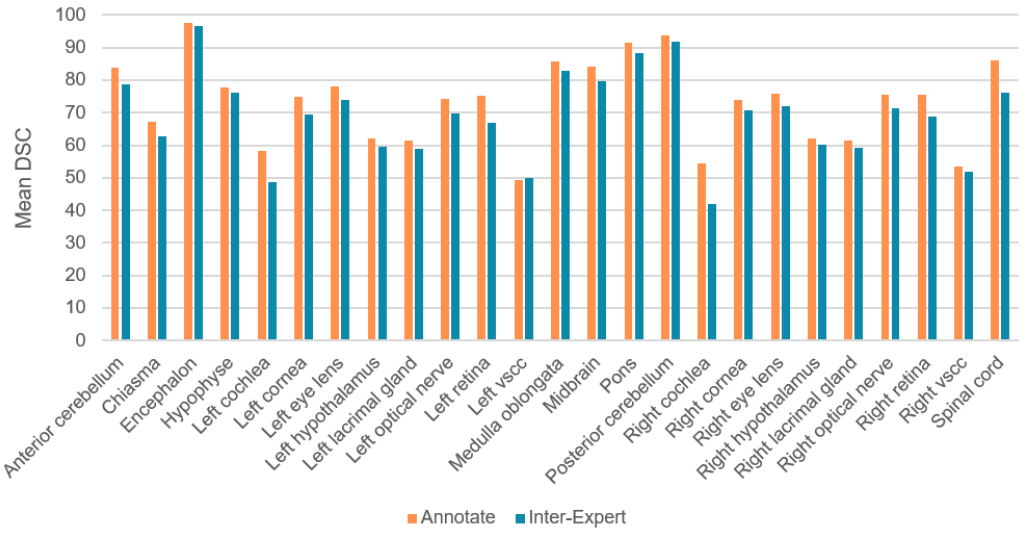
OARs*

Anterior Cerebellum
Cochlea
Cornea
Encephalon
Eye Lenses
External Contour
Hippocampus
Hypothalamus
Lacrimal Glands
Medulla Oblongata
Midbrain
Optic Chiasm
Optical Nerves
Pituitary Gland (Hypophysis)
Pons
Posterior Cerebellum
Retina
Spinal Cord
Vestibular Semicircular Canals (VSCC)

Performance Assessment

Several clinical departments have carried out evaluation studies to validate the MR Annotation performance on different anatomies. The results of these studies demonstrate that the auto-segmentation algorithm of the Annotate module provides clinically acceptable contours for the concerned structures on an MR images of a patient.

MR T1 Brain study aimed at evaluating the inter-expert variability through the calculation of DICEs (DSC) between contours done manually by different experts and Annotate.



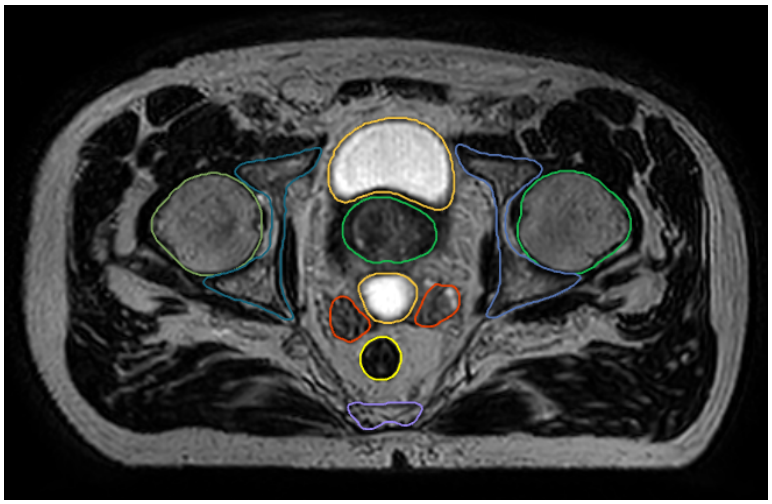
All mean DCS (%) of the new Annotate's MR Brain structures were found to be equal to or superior to inter-expert variability.

*Guideline: EPTN consensus-based guideline for the tolerance dose per fraction of organs at risk in the brain (2018)

Pelvis T2

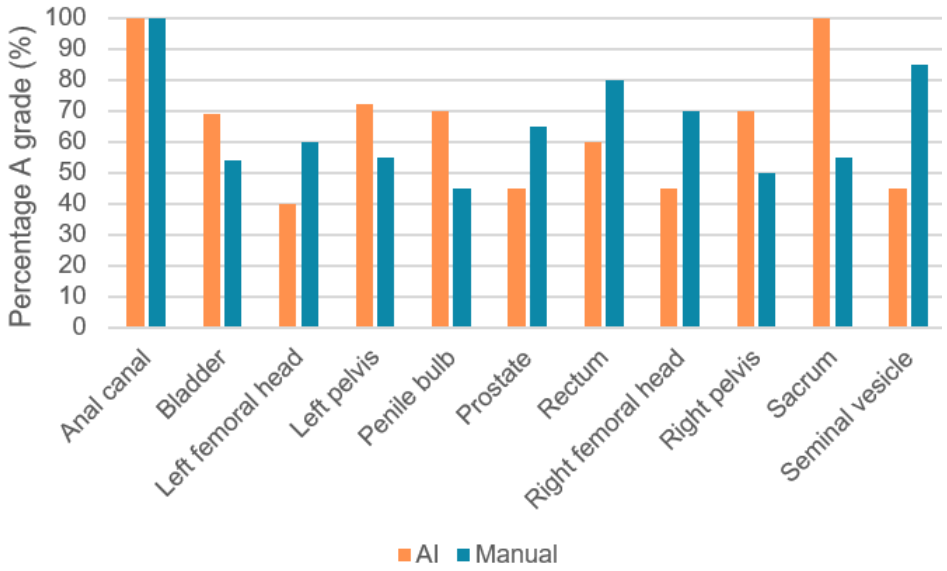
OARs*

Anal Canal
External Contour
Femoral Heads
Penile Bulb
Prostate
Rectum
Urinary Bladder
Sacrum
Seminal Vesicle



Performance Assessment

MR Annotation performance of Annotate T2 Pelvis model has been demonstrated using quantitative and qualitative evaluations involving experts rating contours from A to C**. Overall clinical acceptability after aggregating blinded evaluations coming from two independent experts for the combined categories (A+B) was 98% for ART-Net® and 95% for EC.



Percentage of structures evaluated as A (i.e. considered clinically acceptable) per organ (AI (AC) vs Clinical Reader (EC))

Dice coefficients (mean = 84.70%) are higher than the ones usually reported in the literature and the blinded clinical evaluation yielded slightly higher acceptability for the AI contours than for EC, at a fraction of the time (around 30 seconds as compared to 15 minutes for the expert).

*Guideline: ESTRO ACROP guideline, Salembier et al. (2018)
** A : the contour is acceptable for clinical use without any modification; B : the contour would be acceptable for clinical use after minor modifications/corrections; C : the contour requires major modifications or even expert's contouring from scratch prior to clinical use.

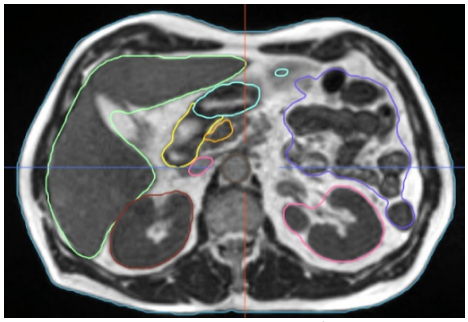
Abdomen & Pelvis Truefisp

Pelvis OARs

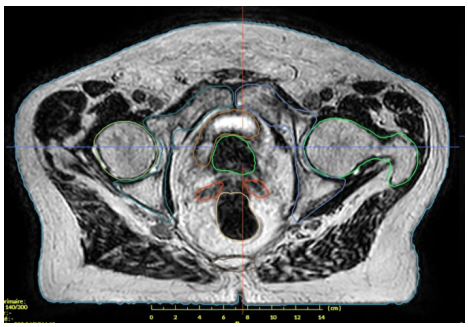
Anal Canal
External Contour
Femoral Heads
Penile Bulb
Prostate
Rectum
Seminal Vesicle
Sigmoid Colon
Urinary Bladder

Abdomen OARs*

Aorta (Abdomen)
Duodenum
External Contour
Inferior Vena Cava
Kidneys
Large Bowel
Liver
Pancreas
Stomach



Abdomen TrueFisp



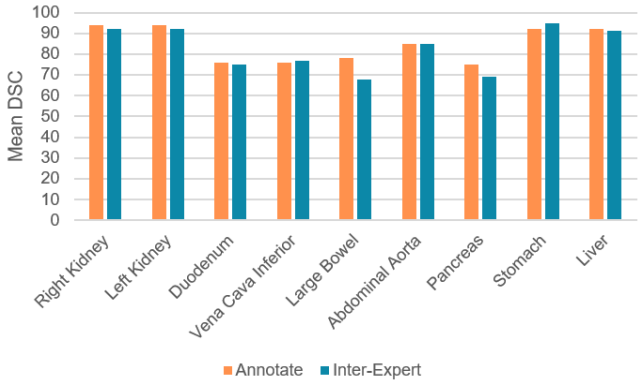
Pelvis TrueFisp

Performance Assessment

Abdomen TrueFisp

MR Annotation performance of Annotate TrueFisp Abdo model has been demonstrated using a quantitative study. DSC have been calculated for different organs and compared against the DSC between experts.

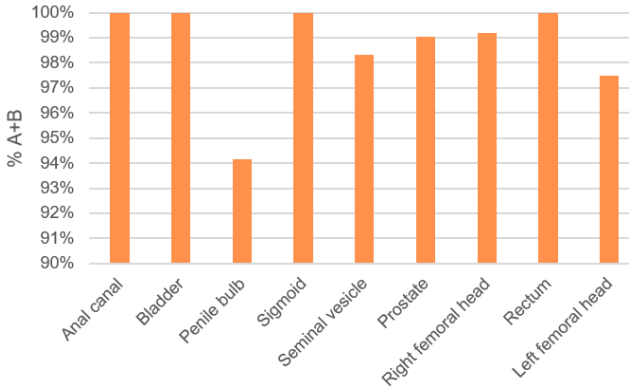
For all organs, Annotate has demonstrate expert-like performance. In fact, for 6 out of 9 organs, Annotate has outperformed the clinical experts, showing its ability to help in the standardization of the delineation practice.



Pelvis TrueFisp

MR Annotation performance of Annotate TrueFisp Pelvis model has been demonstrated using a qualitative study involving experts rating contours from A to C**.

The table opposite shows how for all organs Annotate has obtained A or B for at least 94% of the cases. These results demonstrate that the automatic contours provided by Annotate are not only accurate but also require little to none improvements by clinical experts, further reducing the time needed for the delineation process.



*Guideline: RTOG Jabbour et al (2014), RTOG Kong et al (2011)
** A : the contour is acceptable for clinical use without any modification; B : the contour would be acceptable for clinical use after minor modifications/corrections; C : the contour requires major modifications or even expert's contouring from scratch prior to clinical use.

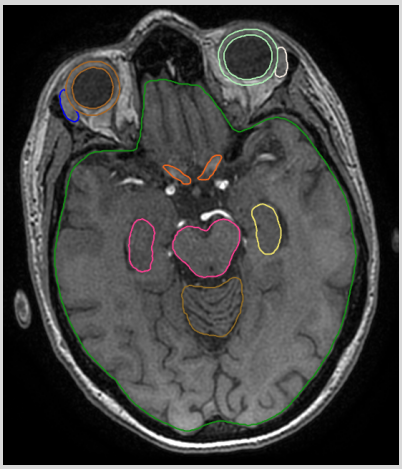
Pseudo-CT generation for the Brain

ART-Plan Pseudo-CT uses T1 MR sequences to generate a synthetic-CT (sCT) image of the brain. A clinical study was performed to evaluate the dose accuracy of this innovative self-supervised generative adversarial neural networks synthetic-CT generation, from diagnosis MR images, for MRI-only workflow for intensity modulated radiation therapy (IMRT) of brain gliomas.

T1w-MRI and planning CT images were retrospectively collected for a cohort of patients for the dosimetry evaluation. Pseudo-CTs were generated using ART-Plan. The absolute differences in DVH-parameters for PTV (D2, D50, D95 and D98) and for OARs (Dmax and Dmean) were calculated. Dose distributions were in addition compared with 1%1mm and 2%/2mm local and global gamma index criteria.

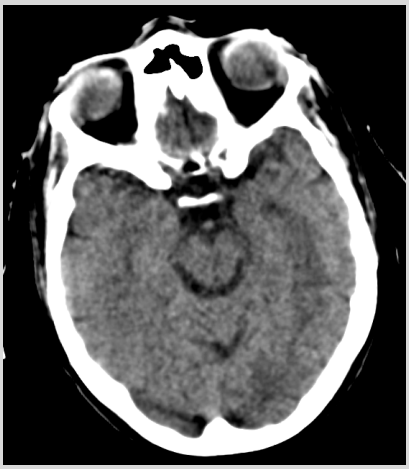
	sCT/CT
1%/1mm Gamma Index Pass Rates (N=25) [%]	
Local 10%	93.9 ± 1.9 (88.0 - 96.4)
Global 20%	97.6 ± 1.1 (94.4 - 100.0)
Global 50%	98.0 ± 1.3 (95.8 - 100.0)
2%/2mm Gamma Index Pass Rates (N=25) [%]	
Local 10%	98.7 ± 0.6 (97.4 - 99.5)
Global 20%	99.8 ± 0.2 (99.4 - 100.0)
Global 50%	99.7 ± 0.3 (99.1 - 100.0)
DVH Absolute Differences (N=27) [Gy]	
PTV D2%	0.05 ± 0.04 (0.00 - 0.16)
PTV D50%	0.05 ± 0.05 (0.00 - 0.19)
PTV D98%	0.06 ± 0.09 (0.00 - 0.46)

This work successfully evaluated a self-supervised DL based software for sCT generation that allows for superior alignment of training data and makes it possible to train a generative model even with diagnostic MRIs, bypassing the need for patients to be in treatment position on the MRIs. Dosimetric differences were minimal and clinically insignificant for both PTVs and OARs. The results show that using ART-Plan for MRI-only planning can be feasible to use for RT planning of brain tumours.



MRI

pCT



CT*

*A rigid registration was performed between MR and CT images using ART-Plan SmartFuse

Pseudo-CT generation for the Pelvis

ART-Plan Pseudo-CT uses T2 or TrueFisp MR sequences to generate a synthetic-CT (sCT) image of the pelvis.

A multi-centric study was performed to evaluate the dose accuracy of ART-Plan's artificial intelligence based pseudo-CT generation tool to assess the potential of MRgRT for pelvic cancer care.

A cohort of patients were selected for this evaluation, with T2w and TrueFISP MRIs. Planning CTs were deformably registered to the MRIs for each patient. Treatment plans were optimized on the warped planning CT (wCT) with a clinical TPS fulfilling all clinical criteria and recalculated on the pCT for image and dosimetric evaluation.

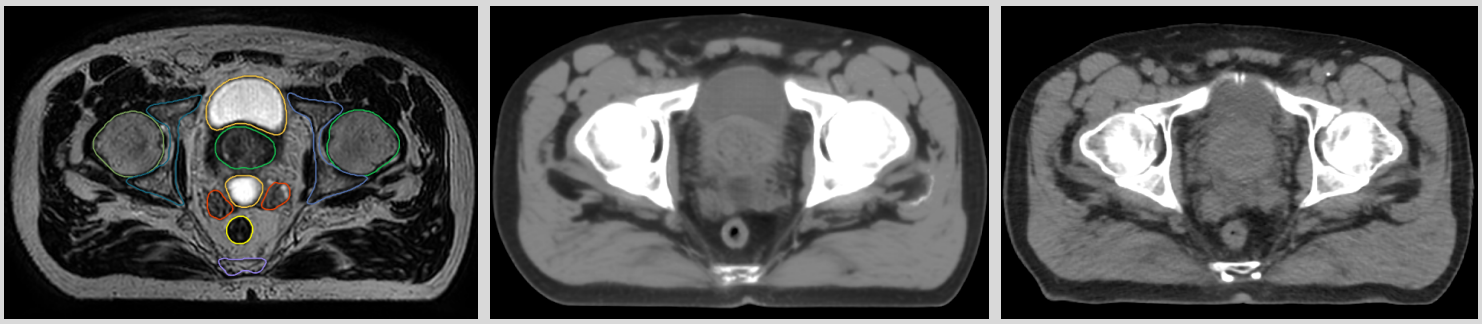
For the analysis, wCTs and pCTs were compared based on:

- DVH-parameters (D2%, D50%, D95%, D98% and Dmean) for the PTV and CTV, and
- Dose distributions compared with global gamma criteria.

Summary of the passing acceptance criteria

Local 10%	Criteria	Results
T2w MRI	DVH < 2% (PTV/CTV)	< 1.94%
	DVH Individual Pass Rates	100%
	Median Gamma Index (2%/2mm)	98.5%
	Median Gamma Index (3%/3mm)	99.9%
TrueFISP	DVH < 2% (PTV/CTV)	< 1.22%
	DVH Individual Pass Rates	100%
	Median Gamma Index (2%/2mm)	99.8%
	Median Gamma Index (3%/3mm)	99.9%

This multi-centric evaluation demonstrated the possibility of using Annotate's pseudo-CT for treatment planning in terms of dosimetric measures. Tested on T2 and TF sequences, Art-Plan has shown to produce results that meet the acceptance criteria derived from clinical practice and literature review.



MRI pCT CT*

*A deformable registration was performed between MR and CT images using ART-Plan SmartFuse

Conclusion

The Pseudo-CT by ART-Plan™ enriches ART-Plan™ and makes possible the generation of pseudo-CT images from MRI for MR-only planning in the use case of conventional Linac and MR-Linacs alike.

The AI models to generate pseudo-CTs from MRI are used to create full 3D electron density maps, which are then converted into pseudo-CT images in HU values thanks to the use of calibration curves imported by each center.

Using the Annotate module, the user is able to benefit from the AI-assisted contours of OARs for both the brain and pelvis anatomies. With the SmartFuse module, the user is able to perform registrations using the pseudo-CTs as target or source images and export to other applications compatible with the DICOM format for further use.

A zero-click (batch) solution is also made available enabling the use of the auto-segmentations done by ART-Plan™ without manipulating of ART-Plan™, as soon as a CT or an MR is pushed into the solution.

The key benefits of the pseudo-CT by ART-Plan™ can be classified as follows:

- **Combined information:** enables to bridge the gap between MR and CT by combining the high soft tissue contrast of the MR images for OARs and target delineation with the possibility of generating tissue electron density information needed for dose calculations.

- **Gain of time:** Facilitate fast, automated, and easy plan adaptation with limited user intervention thanks to the batch solution, the integration of the pseudo-CT, Annotate and SmartFuse all in one software.

- **Elimination of registration errors:** no need for multi-modal registration and avoidance of residual errors.

- **Facilitate patient scheduling:** no need for imaging slots on different machines since all that is needed is a MR-scan.

- **Cost reduction:** avoidance of financial issues such as bundled reimbursement schemes not awarding the use of additional imaging during a patient's radiotherapy treatment.

- **Managing treatment plans over time:** Thanks to SmartFuse, dynamically track and adapt to the impact of patient changes to treatment plans.

References

- C. Veres et al., ESTRO 2022, *Dosimetric evaluation of AI-based synthetic CTs for MRI-only brain radiotherapy*
- I. Coric et al., ESTRO 2022, *Dosimetric evaluation of dose calculation uncertainties for MR-only treatments of pelvic MRgRT*
- *P.* Fenoglietto et al., ESTRO 2022, *Clinical evaluation of self-learning GAN based pseudo-CT generation software for low field pelvic MR*
- *G.* Gungor et al., ESTRO 2022, *AI-based OAR delineation in brain T1w-MRI: Overcoming Inter- and Intra-observer variability*
- N. Newman et al., ESTRO 2022, *Clinical evaluation of organs at risk automatic-segmentation for T2-weigthed MRI*

Our Partners

At TheraPanacea, we work with a range of partners across the medical field to keep improving our products.

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