CEMMTAUR :

CT synthEsis from Multicentric and Multisequence MRI daTA with qUality assessment for image-guided Radiotherapy

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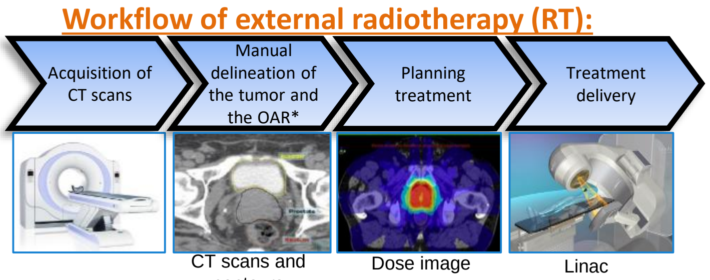
Scientific context

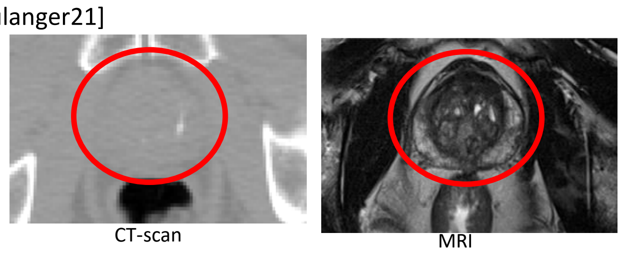
Cancer leading cause of death worldwide (10 million deaths in 2020), radiotherapy is one of the cancer treatment.

Workflow of external radiotherapy (RT):



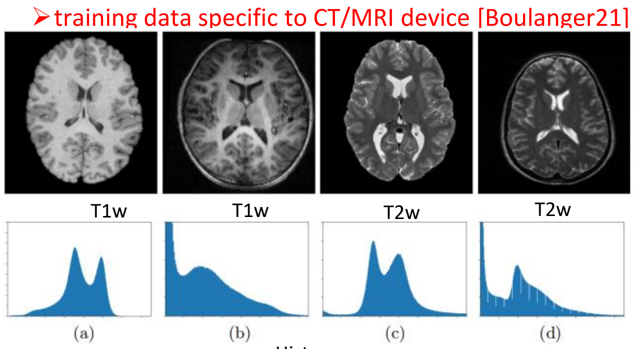
* OAR: Organs At Risk

- CT-Scan: reference imaging for dose planning in radiotherapy (RT)
  - poor contrast in soft tissues and ionizing imaging
  - imprecise delineation of the tumor and the organs at risk (OARs)
  - limiting the quality of the daily patient treatment positioning
- MRI: better soft tissue contrast compared to CT
  - but MRI do not provide electronic density information necessary for dose calculation
- State of art MR-to-CT synthesis: deep learning methods (DLM) [Boulanger21]



Limitation of DLM-based MR-to-CT synthesis:

- variety of image acquisition systems (manufacturers, calibration, acquisition parameters, magnetic field, etc.)
  - training data specific to CT/MRI device [Boulanger21]



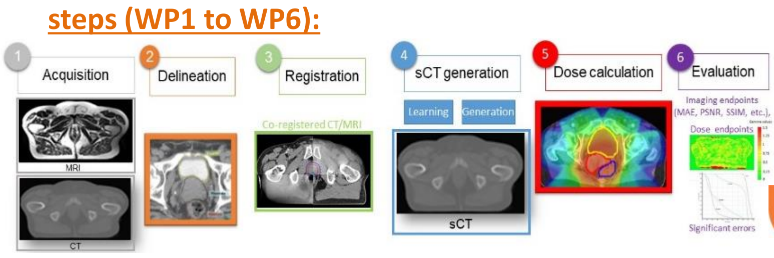
Histograms

Goals :

- Generation of synthetic CT (sCT) from MRI, based on DLM
- Development of a generic approach, a non-specific center/device, taking into account the variety of image acquisition systems
- accurate dose calculation from MRI (with sCT)
- Develop supervised and unsupervised learning

Workflow of the study (Work Packages):

Workflow of the study presenting the different steps (WP1 to WP6):



Data collection WP1

Image acquisition :

- Prostate and brain cancer: 3D CT, 3D MRI (T2, LavaFLEX) from Centre Eugène Marquis (CEM), Centre Régional de Lutte Contre le Cancer (CLCC) de Rennes.

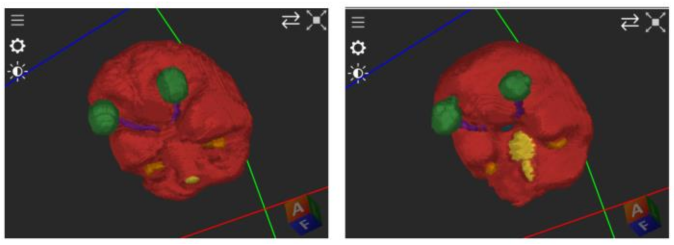
Centre Eugène Marquis RENNES

Segmentation and uncertainty WP2

Automatic segmentation (LS2N, Nantes)

- Anatomical regions: **prostate + OARs** (rectum, bladder) and **brain + OARs** (medulla, brainstem, pituitary gland, lens, eyes, retina, chiasm, optic nerve).
- Joint segmentation across different MR sequences (T1 and T2, LavaFLEX): exploit all data available.

- Stage (Amel Bakouche)
  - Segmentation with a U-NET under several mono / multi-modal scenarios for 6 OARs
  - First encouraging results on each modality (CT, MR)
  - Simple generalization method by training simultaneously the model on CT and MR images
  - Same label for symmetric organs gives better results
  - Scores still dependent on the size of the organ



Example of Ground truth (left) and prediction (right) for the Automatic segmentation of Brain OARS

Challenges yet to process:

- Structures not visible on CT for dose computation: build on unsupervised and weakly supervised domain adaptation [AlChanti21a] to transfer segmentation of soft tissues from MR to CT.
- Associate an uncertainty measurement to the predictions [Jimenez22].

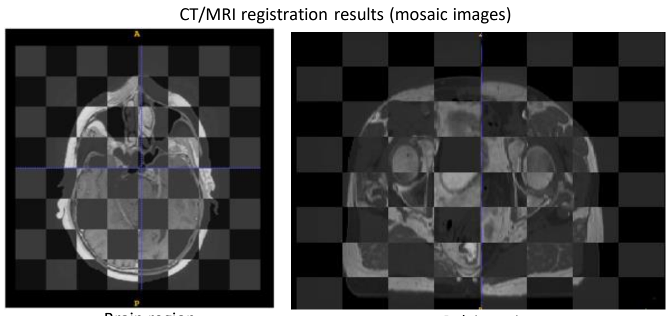
Multimodal image registration WP3

Image registration (LS2N and LTSI):

To match patient anatomy between CT and MRI

Method: a robust symmetric rigid registration [Rivest-Henault15] (metric, normalized cross-correlation; geometric transform, rigid), followed by structure-guided deformable registration to promote bone rigidity while allowing high-quality bladder and rectum deformable registration (metric, normalized mutual information with 64 bins; geometric transform, B-spline free-form deformation).

CT/MRI registration results (mosaic images)



Brain region   Pelvis region

Multicentric MRI-CT synthesis WP4

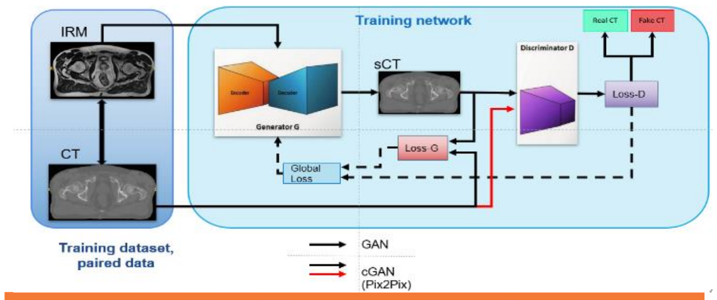
Preprocessing step (LTSI)

To standardize the database, several preprocessing steps were performed :

- thresholding technique,
- N4 bias field correction [Tustison10];
- histogram equalization,
- filtering by gradient anisotropic diffusion [Perona90]
- Cropping at 12cm under and above the barycenter of the prostate.

MR-to-CT generation (LTSI)

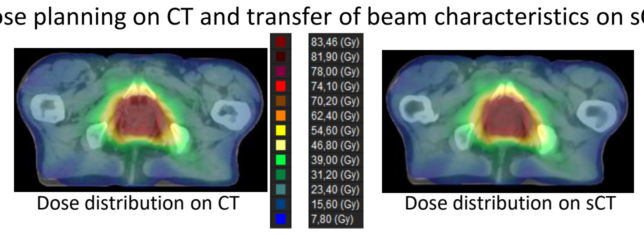
- MR-to-CT generation by 3D conditional GAN supervised & unsupervised context



Dose calculation WP5

Dose Calculation (LTSI):

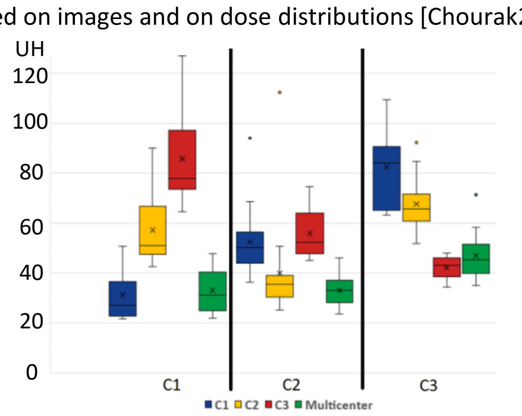
- Use of treatment planning system (TPS) Raystation (Raysearch) at Centre Eugène Marquis
- Dose planning on CT and transfer of beam characteristics on sCT



Evaluation WP6

Standardizing the sCT evaluation (LTSI)

- Imaging endpoints voxel-wise comparison (sCT vs CT): Mean Absolute Deviation (MAE), Mean error (ME), PSNR,
- Voxel-wise statistical test (Chen permutation test) will be applied on images and on dose distributions [Chourak21].



MAE results on external body: monocentric and multicentric supervised training comparison across centers. The boxplots illustrate the mean absolute error (MAE) results for when the learning was performed on a cohort: C1 (blue), C2 (yellow), and C3 (red) and the three centers (green) and the test was performed on C1 (row 1), C2 (row 2) or C3 (row 3).

- Dosimetric endpoints: voxel-to-voxel dose difference (between dose calculated on CT (reference and on sCT), dose-Volume Histogram (DVH) differences , Gamma-index analyses (comparison of dose distributions)

Publications in this project

[Tahri23] S. Tahri, B. Texier, C. Hémon, H. Chourak, A. Barateau, C. Lafond, … and J.C. Nunes, SFRO 2023.
[Texier23a] B. Texier, C. Hémon, P. Lekieffre, E. Collot, S. Tahri, A. Barateau, C. Lafond, … and J.C. Nunes, Multi-center CT synthesis by 3D cycle-GAN for prostate MRI-only radiotherapy, ISBI 2023.
[Texier23b] B. Texier, C. Hémon, E. Collot, P. Lekieffre, S. Tahri, H. Chourak, A. Barateau, C. Lafond, R. de Crevoisier, J. Castelli and J.C. Nunes, Evaluation of prostate synthetic CTs from MRI using 2D cycle-GAN with multicentric learning, ESTRO 2023.
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[Tustison10] Tustison NJ, Avants BB, Cook PA, Yuanjie Zheng, Egan A, Yushkevich PA, et al. N4ITK: improved N3 bias correction. IEEE Trans Med Imaging 2010; 29(6):1310–20.