Digital Twins for biologically adaptive MR-guided radiotherapy
Supervisory Team: Dr Andreas Wetscherek, Division of Radiotherapy & Imaging (ICR); Professor Wayne Luk, Department of Computing (Imperial); Dr Katharine Aitken, Department of Radiotherapy, (Royal Marsden NHS) and Dr Shaista Hafeez, Department of Radiotherapy, Royal Marsden NHS)
Project Summary: This project addresses unmet clinical and technological needs in radiotherapy of abdominal tumours (liver, pancreas and kidney), which undergo significant respiratory motion. To improve patient outcomes and to understand radiobiological effects in short-course radiotherapy, we will use quantitative MRI (qMRI) to measure tissue properties that are sensitive to treatment response or predictive of outcomes. Current qMRI implementations on the MR-Linac, however, suffer from poor repeatability. We will build a comprehensive framework to overcome the current limitations of qMRI on the MR-Linac and to enable biologically adaptive radiotherapy. Collaborating across the international MR-Linac consortium, we are collecting qMRI raw data throughout the treatments of patients. At project start we will have access to data from multiple treatment fractions of at least 50 patients. In Dr Wetscherek's MRI in Radiotherapy group at ICR, the student will learn the basics of MRI and signal simulations. In Stage 1 the student will develop a realistic system model of the MR-Linac (digital twin), based on ground truth measurements of the exact magnetic field distributions, which will be implemented using vendor-neutral pulse sequence programming (Pulseq, gammaSTAR). Stage 2 will focus on integrating the system model into the KomaMRI simulator. The student will develop digital twins of patients, which hold information on tissue properties and their uncertainty, including motion patterns, for the abdominal anatomy. In Stage 3, having demonstrated the benefits of the digital twin approach, the student will work closely with Prof Luk's Custom Computing group at Imperial College to accelerate the framework towards implementation in clinical treatment workflows, including real-time updates of the qMRI tissue parameters and their uncertainty. In addition to working closely with Prof Luk's group at Imperial and Dr Wetscherek's group at ICR, the student will regularly attend clinical audit meetings led by Dr Aitken (gastro-intestinal oncology) and Dr Hafeez (genitourinary oncology) to develop a thorough understanding of patient pathways, treatment workflows and challenges of MR-guided radiotherapy. We envision a 3-months secondment at the Centro de Imágenes Biomédicas at the Pontificia Universidad Católica de Chile to work with Pablo Irarrazaval's group on the open-source KomaMRI simulator.
Literature references Low DA, Fallone BG, Raaymakers BW. MRI-Guided Radiation Therapy Systems. Semin Radiat Oncol. 2024 Jan;34(1):14-22. doi: 10.1016/j.semradonc.2023.10.009. Westley RL, Biscombe K, Dunlop A, *et al*. Interim Toxicity Analysis From the Randomized HERMES Trial of 2- and 5-Fraction Magnetic Resonance Imaging-Guided Adaptive Prostate Radiation Therapy. Int J Radiat Oncol Biol Phys. 2024 Mar 1;118(3):682-687. doi: 10.1016/j.ijrobp.2023.09.032. Chuong MD, Lee P, Low DA, *et al.* Stereotactic MR-guided on-table adaptive radiation therapy (SMART) for borderline resectable and locally advanced pancreatic cancer: A multi-

center, open-label phase 2 study. Radiother Oncol. 2024 Feb;191:110064. doi: 10.1016/j.radonc.2023.110064.

Siva S, Bressel M, Sidhom M, *et al*. Stereotactic ablative body radiotherapy for primary kidney cancer (TROG 15.03 FASTRACK II): a non-randomised phase 2 trial. Lancet Oncol. 2024 Mar;25(3):308-316. doi: 10.1016/S1470-2045(24)00020-2.

Ali M, Mooi J, Lawrentschuk N, *et al*. The Role of Stereotactic Ablative Body Radiotherapy in Renal Cell Carcinoma. Eur Urol. 2022 Dec;82(6):613-622. doi: 10.1016/j.eururo.2022.06.017.

Wetscherek A, Stieltjes B, Laun FB. Flow-compensated intravoxel incoherent motion diffusion imaging. Magn Reson Med. 2015 Aug;74(2):410-9. doi: 10.1002/mrm.25410.

Tijssen RHN, Philippens MEP, Paulson ES, *et al*. MRI commissioning of 1.5T MR-linac systems - a multi-institutional study. Radiother Oncol. 2019 Mar;132:114-120. doi: 10.1016/j.radonc.2018.12.011.

Kooreman ES, van Houdt PJ, Keesman R, *et al.* Daily Intravoxel Incoherent Motion (IVIM) In Prostate Cancer Patients During MR-Guided Radiotherapy-A Multicenter Study. Front Oncol. 2021 Aug 13;11:705964. doi: 10.3389/fonc.2021.705964.

Goodburn R, Bruijnen T, Lecoeur B, *et al*. Gradient system characterization of a 1.5 T MR-Linac with application to 4D UTE imaging for adaptive MR-guided radiotherapy of lung cancer. Magn Reson Med. 2025 Jul;94(1):28-40. doi: 10.1002/mrm.30505.

Bano W, Holmes W, Goodburn R, *et al.*. Joint radial trajectory correction for accelerated T2* mapping on an MR-Linac. Med Phys 2023. doi: 10.1002/mp.16479

Castillo-Passi C, Coronado R, Varela-Mattatall G, Alberola-López C, Botnar R, Irarrazaval P. KomaMRI.jl: An open-source framework for general MRI simulations with GPU acceleration. Magn Reson Med. 2023 Jul;90(1):329-342. doi: 10.1002/mrm.29635.

Zhang Z, Genci M, Fan H, *et al*. Accelerating MRI Uncertainty Estimation with Mask-Based Bayesian Neural Network. 35th IEEE International Conference on Application-specific Systems, Architectures and Processors. Hong Kong; 2024. p. 107-115. doi: 10.1109/ASAP61560.2024.00030

Lecoeur B, Barbone M, Gough J, *et al*. Accelerating 4D image reconstruction for magnetic resonance-guided radiotherapy. Phys Imaging Radiat Oncol. 2023 Aug 20;27:100484. doi: 10.1016/j.phro.2023.100484.

Freedman JN, Gurney-Champion OJ, Nill S, *et al*. Rapid 4D-MRI reconstruction using a deep radial convolutional neural network: Dracula. Radiother Oncol. 2021 Jun;159:209-217. doi: 10.1016/j.radonc.2021.03.034.

Key words:
1. Magnetic Resonance Imaging
2. Artificial Intelligence
3. MR-Linac
4. Digital Twins
5. High-performance Computing
6. MR-guided Radiotherapy

Project suitable for a student with a background in: Computer Science, Physics, Engineering, Mathematics, Statistics, Epidemiology