



HAL
open science

Multiparametric quantitative MRI with oxygen extraction fraction: Prospective characterization of soft tissue sarcomas, prediction of radiotherapy response and correlation with multiplex immunofluorescence

Benoît Allignet, Benjamin Laporq, Floriane Izarn, Amine Bouhamama, Frank Pilleul, Alexandra Meurgey, Gualter Vaz, Alexandre Beige, Marie-Pierre Sunyach, Waisse Waissi, et al.

► **To cite this version:**

Benoît Allignet, Benjamin Laporq, Floriane Izarn, Amine Bouhamama, Frank Pilleul, et al.. Multiparametric quantitative MRI with oxygen extraction fraction: Prospective characterization of soft tissue sarcomas, prediction of radiotherapy response and correlation with multiplex immunofluorescence. European Society for Magnetic Resonance in Medicine and Biology, Oct 2025, Marseille, France. <hal-05328811>

HAL Id: hal-05328811

<https://hal.science/hal-05328811v1>

Submitted on 23 Oct 2025

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire HAL, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



HAL Authorization

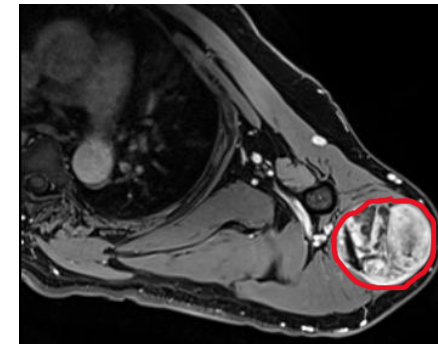
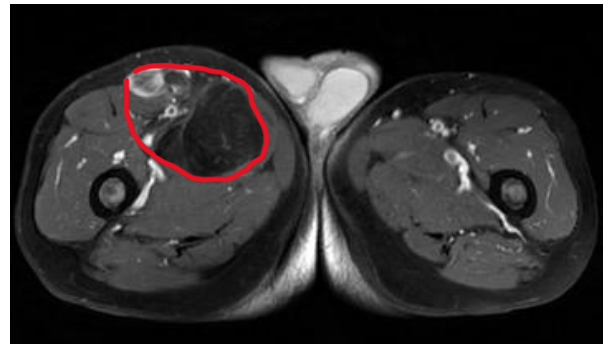
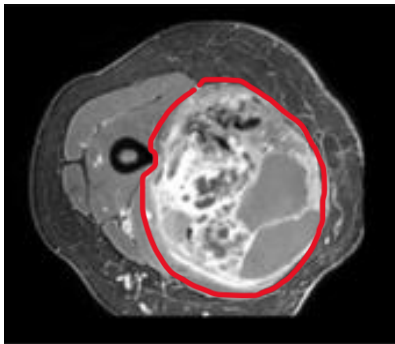
**Multiparametric quantitative MRI
with oxygen extraction fraction:
Prospective characterization of soft tissue sarcomas,
prediction of radiotherapy response and
correlation with multiplex immunofluorescence**

Benoît Allignet^{1,2}, Benjamin Leporq¹, Floriane Izarn³, Amine Bouhamama⁴,
Frank Pilleul⁴, Alexandra Meurgey⁵, Gualter Vaz⁶, Alexandre Beige²,
Marie-Pierre Sunyach², Waisse Waissi², Olivier Beuf¹

1. CREATIS, CNRS UMR 5220, Inserm U1294, INSA-Lyon, Université Claude Bernard Lyon 1
2. Radiotherapy Department, Centre Léon Bérard, Lyon, France
3. Medical Oncology Department, Centre Léon Bérard, Lyon, France
4. Radiology Department, Centre Léon Bérard, Lyon, France
5. Biopathology Department, Centre Léon Bérard, Lyon, France
6. Surgical Oncology Department, Centre Léon Bérard, Lyon, France

Introduction

- **Soft tissue sarcomas (STS)**
 - Rare heterogenous tumors
 - No predictive factor of response to preoperative treatment despite significant variations¹



Introduction

- **Hypoxia :**
 - Lack of oxygen in tissues
 - Important factor of radioresistance but unavailable in daily clinical practice
- **qMRI surrogate : relative oxygen extraction fraction (rOEF)¹**
 - Estimated by qBOLD method²
 - Positively correlated with hypoxia¹

1. Toth V., et al. *J. Neurooncol* 2013

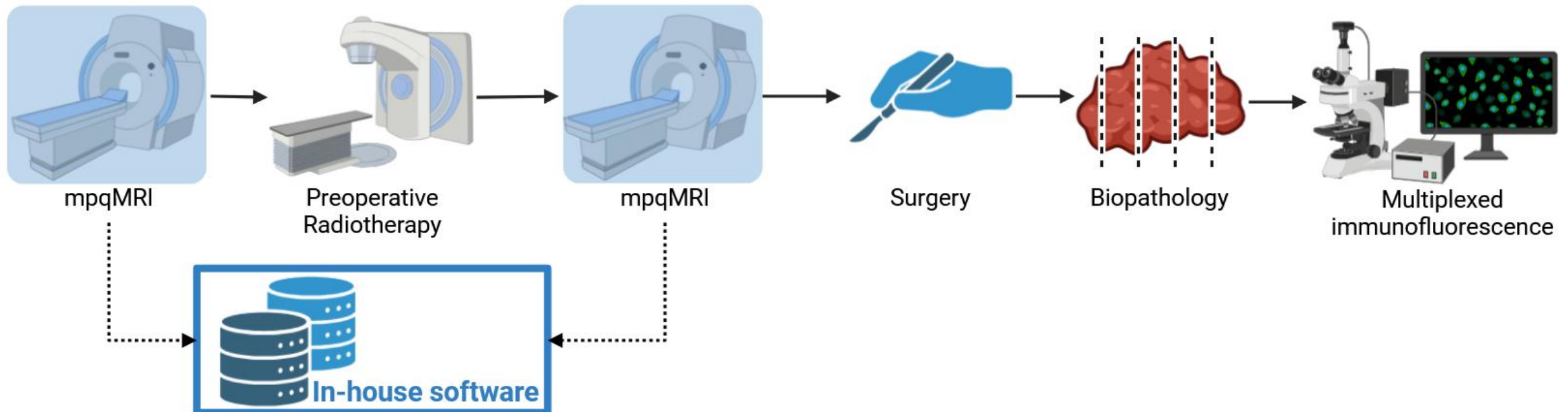
2. He & Yablonsky, *MRM* 2007

Objectives

- Evaluate the **feasibility, characterization** interest and **predictive** value
- Of a **multiparametric quantitative MRI (mpqMRI)** protocol
- Including quantification of **relative oxygen extraction fraction (rOEF)** without contrast agent injection.

Methods

- Interventional trial (NCT05684874, clinicaltrials.gov)
- Adult limb and trunk STS patients with indication of preoperative RT
 - n=16 per protocol, with n=6 located in thigh



Methods – Protocol

	CSE-MRI	T2 Mapping	DWI multi-b
MRI system	Siemens MAGNETOM Vida 3.0T		
Sequence	3D FLASH	2D TSE	WIP Diffusion
Field of view (mm³)	440 x 330 x 160		
Acquired voxel size (reconstructed) (mm³)	2.3 x 2.3 x 4.0 (1.15 x 1.15 x 4.0)		
Echo time (No. of echoes) (ms)	2.4-13.2 (10)	8-80 (10)	49
Echo spacing (ms)	1.2	8	-
Repetition time (ms)	15	5230	8100
Flip angle (°)	5	90-180	90
B-values (s.mm⁻²)	-	-	0, 20, 40, 60, 80, 100, 200, 400, 600, 800
Acquisition time	1 min 07 s	4 min 47 s	7 min 50 s

Methods – qBOLD

- Estimation of the relative oxygen extraction fraction (rOEF)¹

$$rOEF = \text{SaO}_2 - \text{SvO}_2 = \frac{R_2^* - R_2}{\frac{4}{3} \cdot \pi \cdot \gamma \cdot (\Delta\chi_0 \cdot Hct) \cdot B_0 \cdot rBV}$$

Pulse oxymeter



Difference of χ between oxygenated and deoxygenated Hb

Small vessel hematocrit, approximated as 75% macrovascular Hct (WBC)

Adapted from He & Yablonsky, MRM 2007

1. Toth V., et al. J. Neurooncol 2013

Methods – qBOLD

1- Multi-echoes gradient echo

Corrections: chemical shift and B0 macroscopic inhomogeneities

2- Multi-echoes spin echo

Correction: 1st echo discarded

$$r\text{OEF} = S_{aO2} - S_{vO2} = \frac{R_2^* - R_2}{\frac{4}{3} \cdot \pi \cdot \gamma \cdot (\Delta\chi_0 \cdot Hct) \cdot B_0 \cdot rBV}$$

3- Corrected « f » of the IVIM model (Bayesian inference)

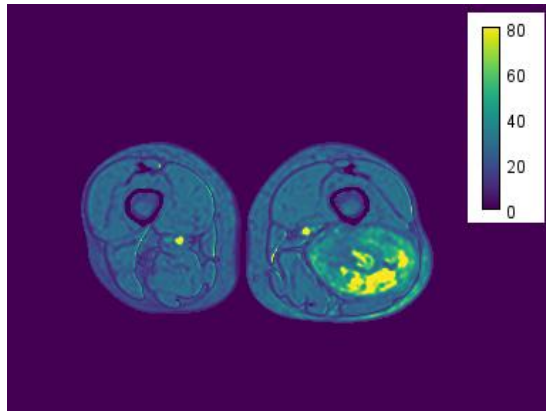
Corrections: T2, normalized by water fraction (1-PDF)

Adapted from He & Yablonsky, MRM 2007

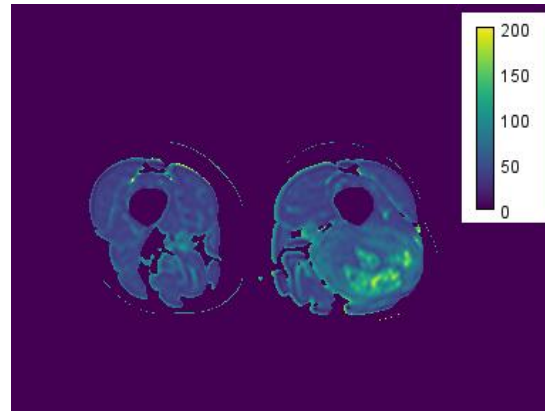
1. Toth V., et al. J. Neurooncol 2013

Results – Feasibility

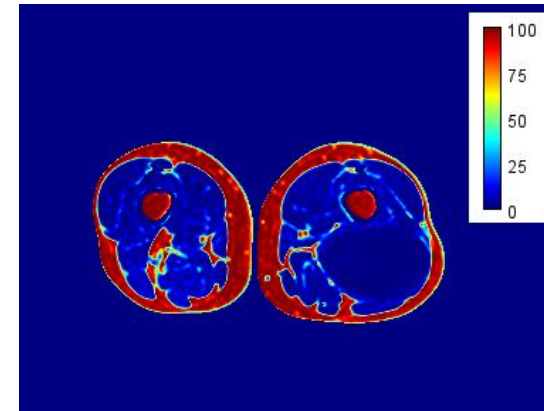
T2* (ms)



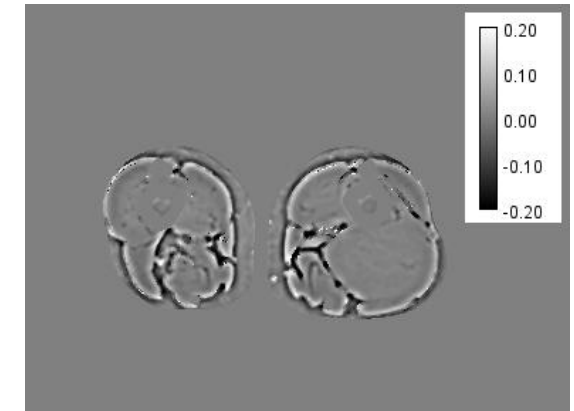
T2 (ms)



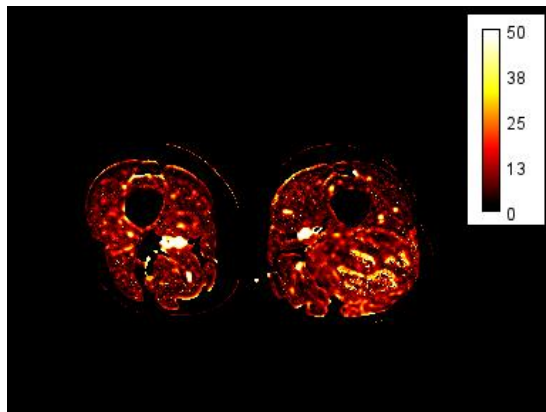
Proton density
fat fraction (%)



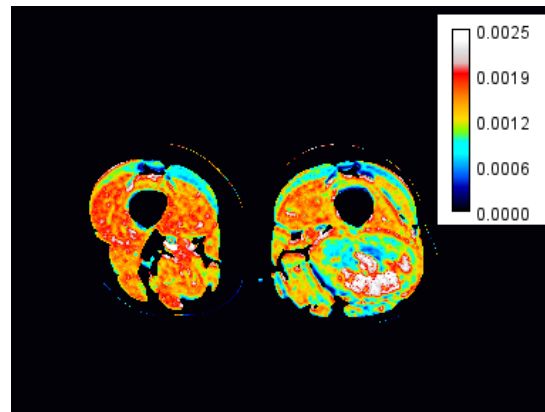
Magnetic susceptibility (ppm)



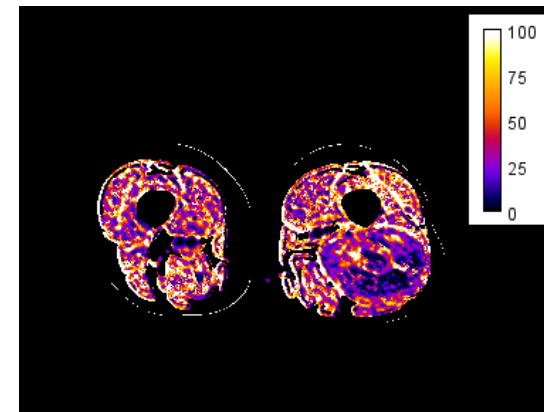
Relative blood volume (%)



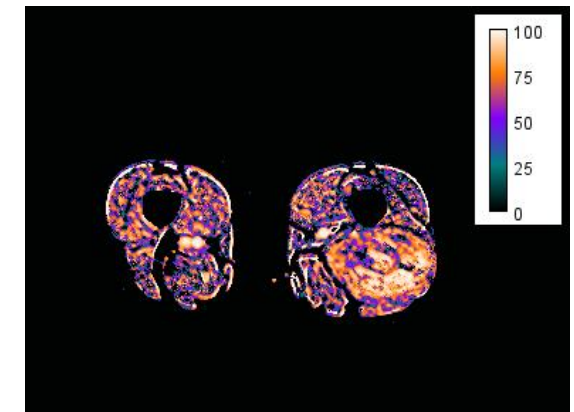
D_{slow} (mm.s⁻²)



rOEF (%)



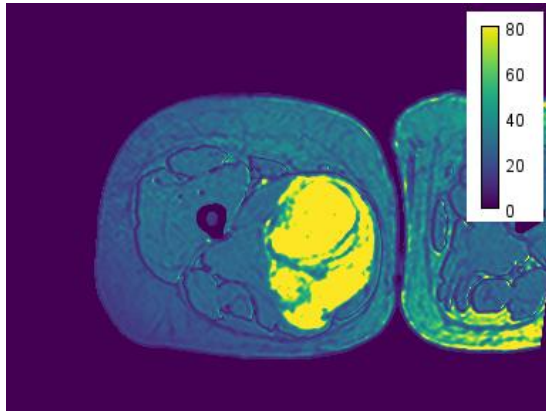
SvO2 (%)



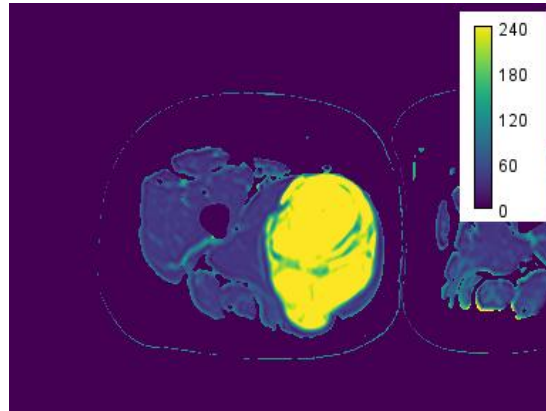
Sarcoma of the posterior compartment of the left thigh

Results – Feasibility

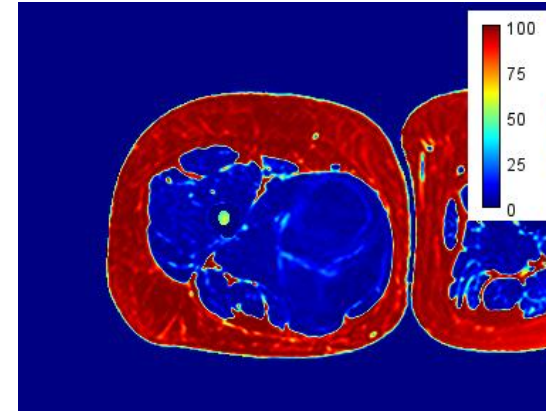
T2* (ms)



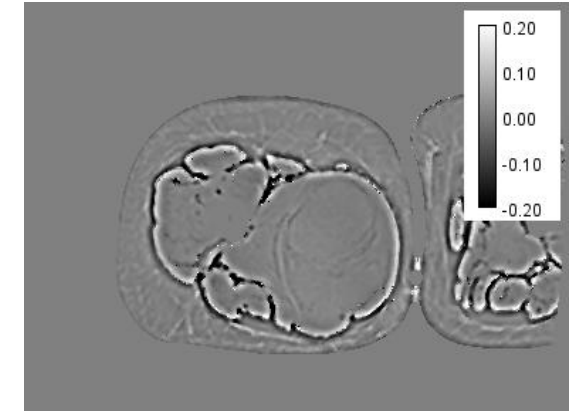
T2 (ms)



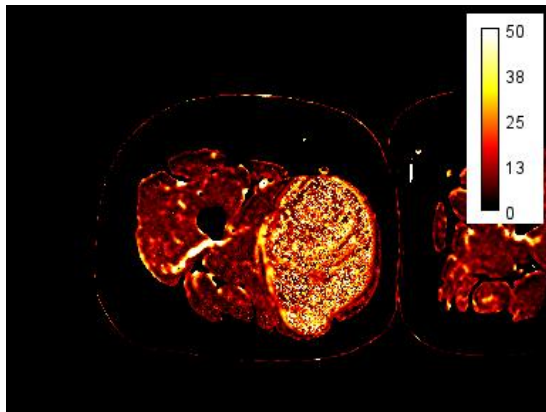
Proton density fat fraction (%)



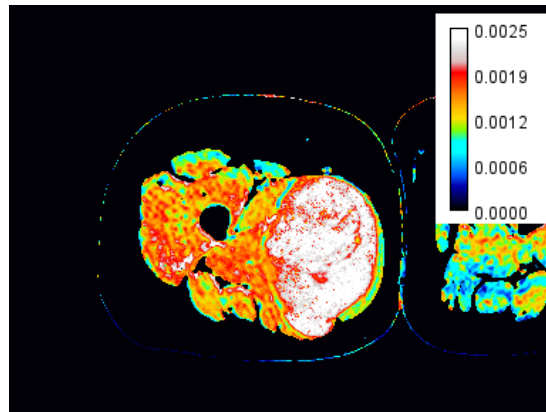
Magnetic susceptibility (ppm)



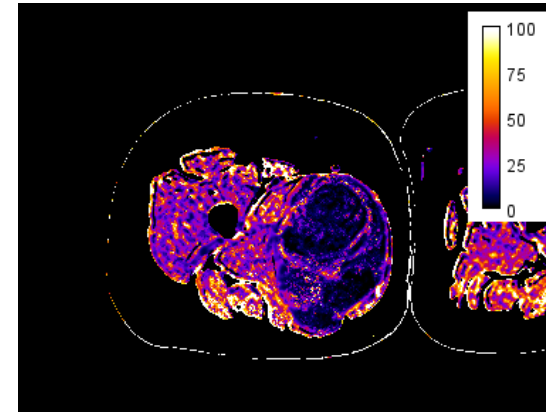
Relative blood volume (%)



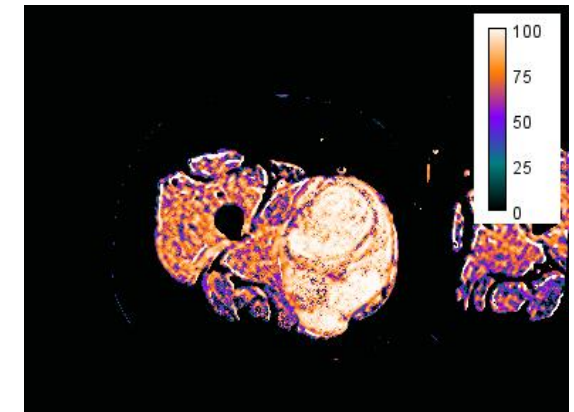
D_{slow} (mm.s⁻²)



rOEF (%)

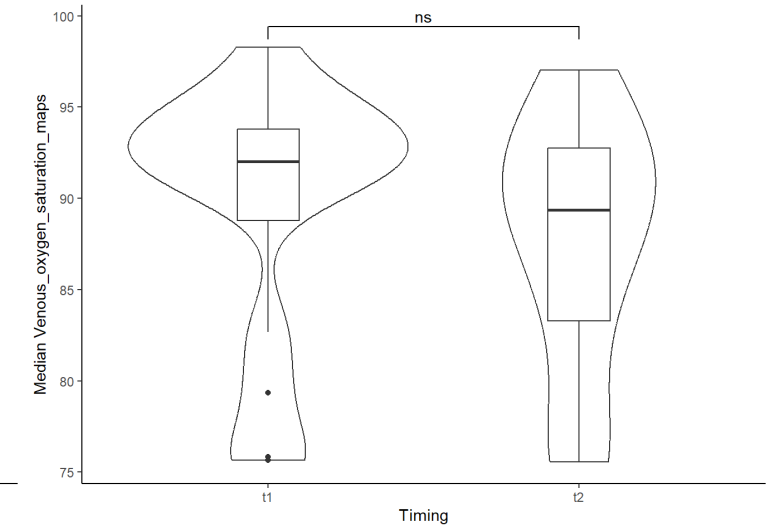
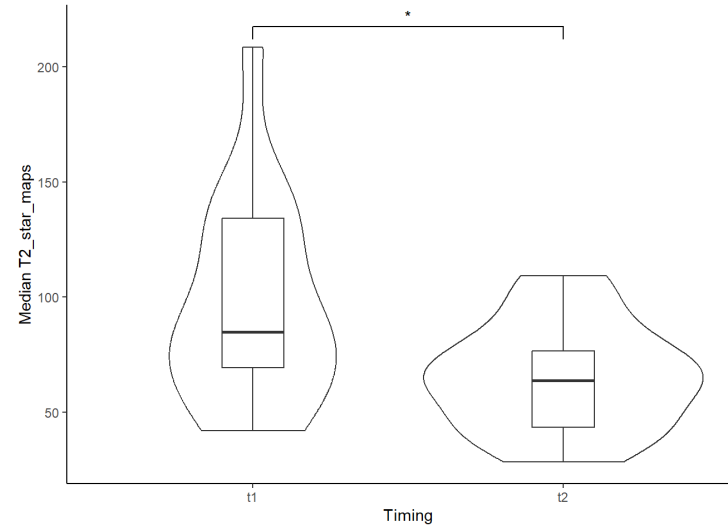
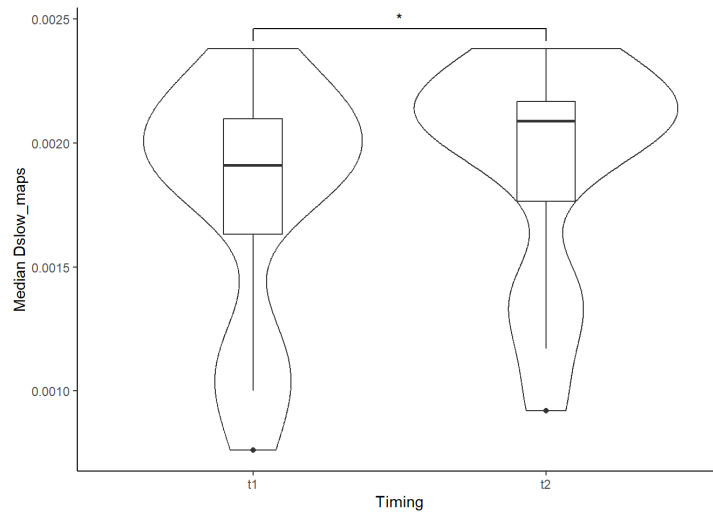


SvO2 (%)



Sarcoma of right thigh

Results – Pre-/post-treatment evolution



- ↑ ADC ($p < 0.001$) and Dslow ($p = 0.03$)
⇒ Lower cellularity

- ↓ of $T2^*$ ($p = 0.02$)
- Trend of ↓ of SvO2 ($p = 0.09$)
⇒ Lower oxygenation

Results – Quality assurance

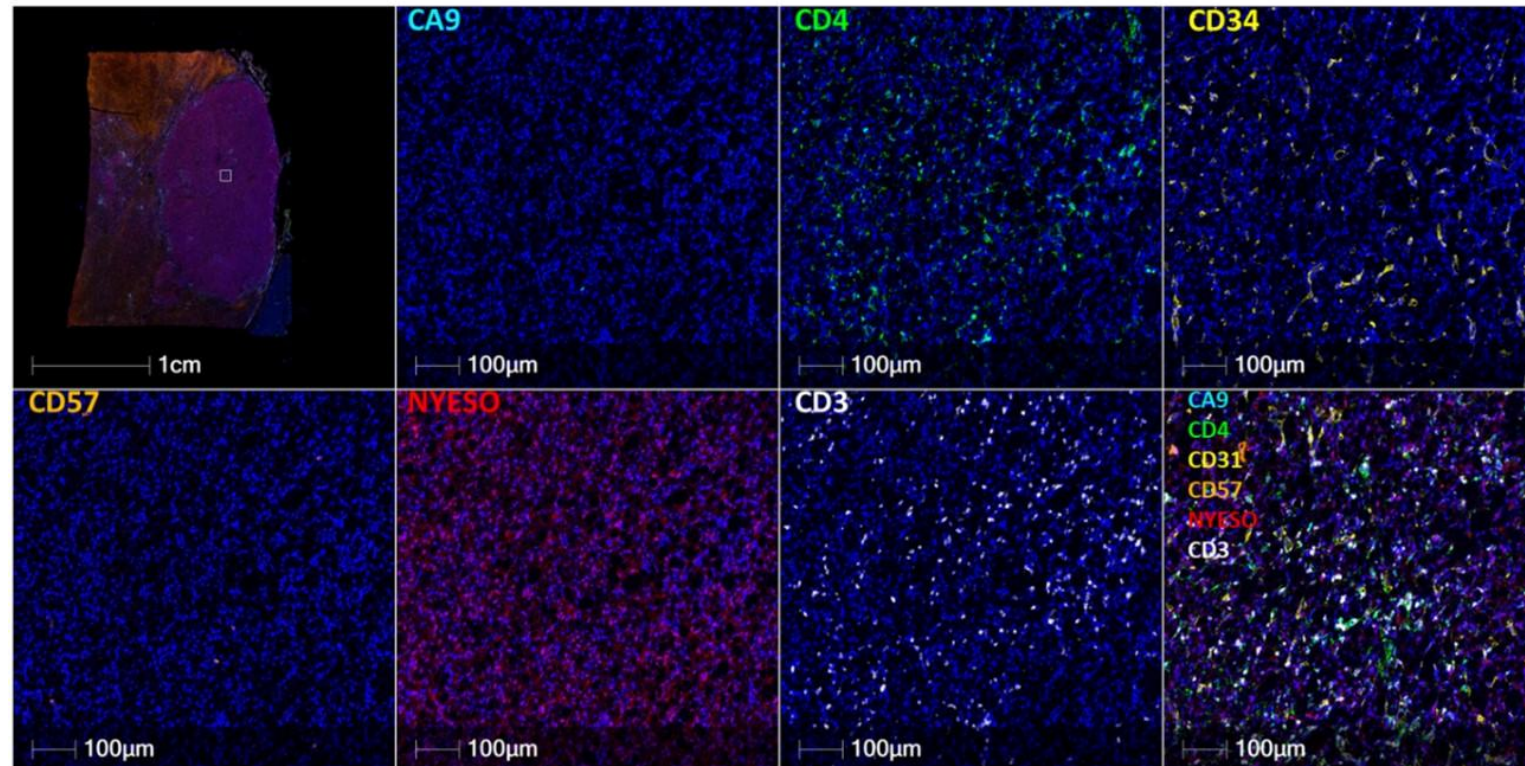
- Measure in **non-involved ipsilateral (irradiated) skeletal muscle**
- None of the parameters significantly varied
- Consistent with literature data
 - T2¹: 40 ms (IQR 37.7-42.6)
 - rOEF²: 36.4% (IQR 32.5-51.7)

1. Huang et al., *BMJ MuskeletDis* 2022

2. Wang et al., *JMRI* 2016

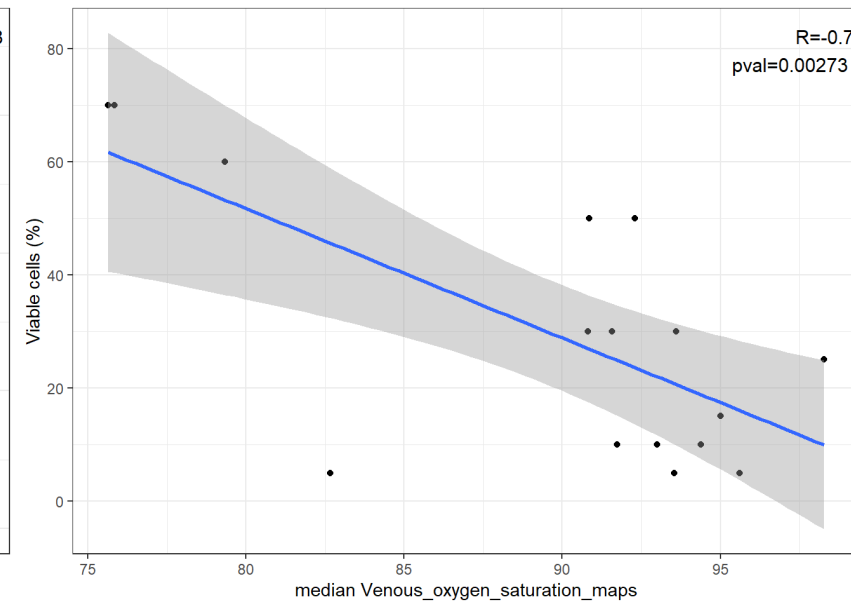
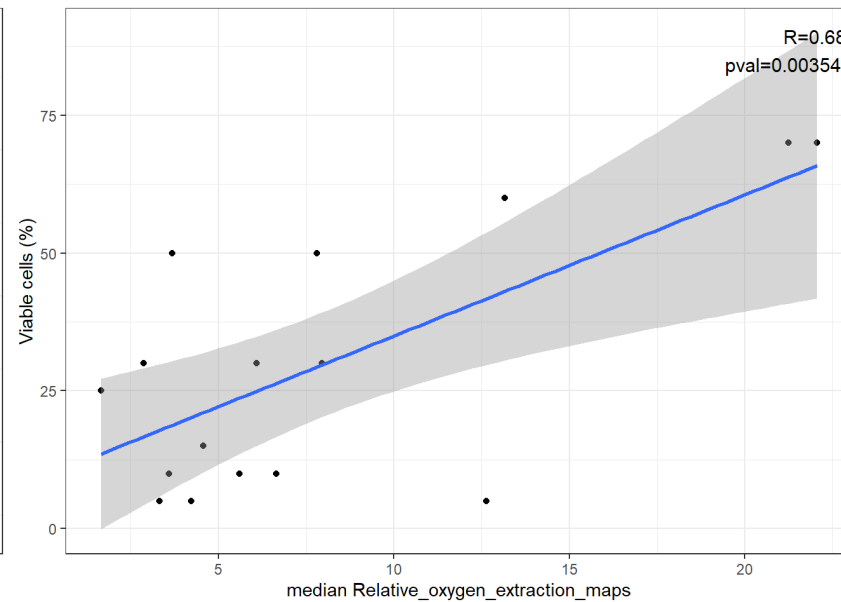
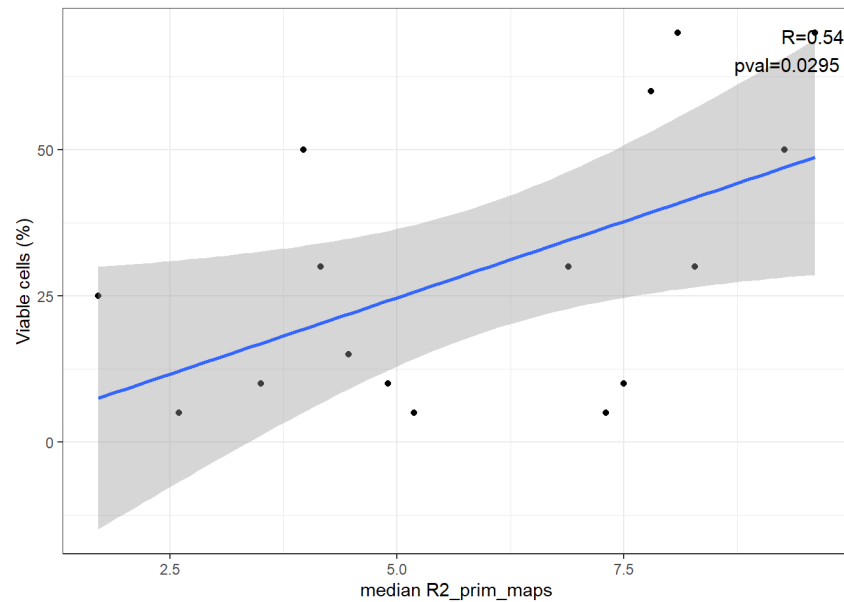
Results – Hypoxic status

- Tumors were **not hypoxic** (all pretreatment median rOEF <22%)
 - Confirmed by mIF (a single sample presented a density of CA9+ cells >3/mm²)



Results – Prediction (pretreatment)

- Pretreatment median **R2'**, **rOEF** and **SvO2** predictive of the percentage of remaining viable cells in surgical specimen



Discussion – Strengths

- **First available mpqMRI data in STS patients**
 - Various anatomical locations
- **Interventional trial**
- **Consistency with the literature**

Discussion – Limitations

- ***Median*** values
- **Potential confounding factors** that could influence $R2'$ and Hb dissociation curve
- To come : **analytical validation**
 - accuracy / reproducibility / repeatability

Conclusions

- In limb or trunk STS, an mpqMRI protocol evaluating rOEF is **feasible within usual clinical appointment slots**
- Some quantitative features being **potentially predictive of treatment response**
- **Opportunities:**
 - Other indications
 - Imaging biomarkers
 - Treatment personalization trials

Acknowledgements

- This project was financially supported by:
 - **Cancéropôle Lyon Auvergne-Rhône-Alpes (CLARA)** through its Emergence program as part of the Cancéropôle 2023-2027 certification awarded by the National Cancer Institute (INCa),
 - **Comité 42 de la Ligue Nationale Contre le Cancer**
 - **LabEx PRIMES** (ANR-11-LABX-0063).
 - **ITMO Cancer d'Aviesan** through the Ten-Year Strategy to fight cancer 2021-2030, on funds managed by **Inserm**.
- We thank the Plateforme d'Imagerie Biomédicale (**PIBio**) of Bordeaux for their calibration phantoms

Thank you for your attention

benoit.allignet@lyon.unicancer.fr

