Organ motion for radiation therapy

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Laboratoire d'InfoRmatique en Image et Systèmes d'information

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Outline

- **Context: Organ motion modeling**

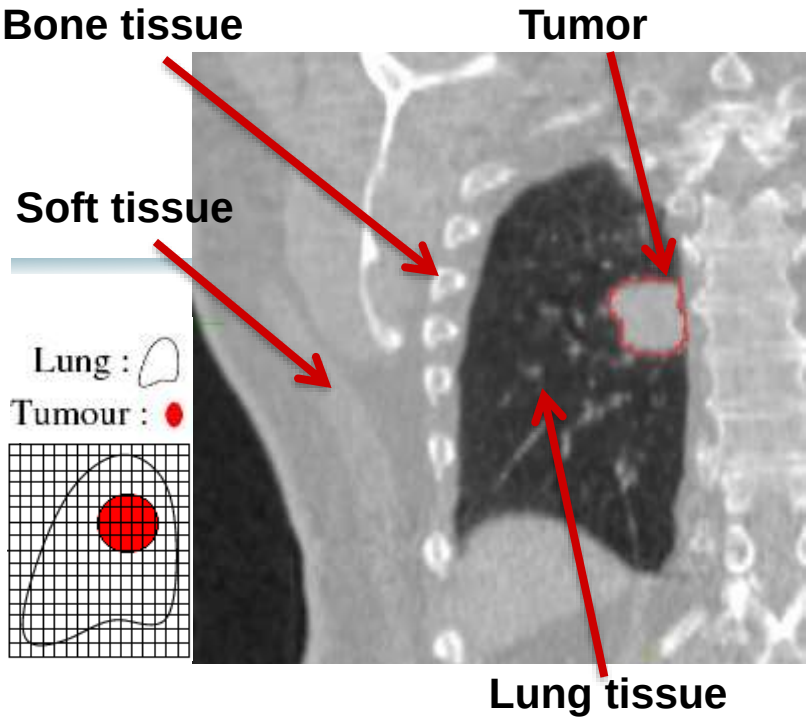
- Lung tumor motion tracking during radiation treatment

- 4D Dose calculation including organ motion

- Effects of the different breathing patterns on PET-based treatment verification and reconstruction

- **Conclusion and futur work**

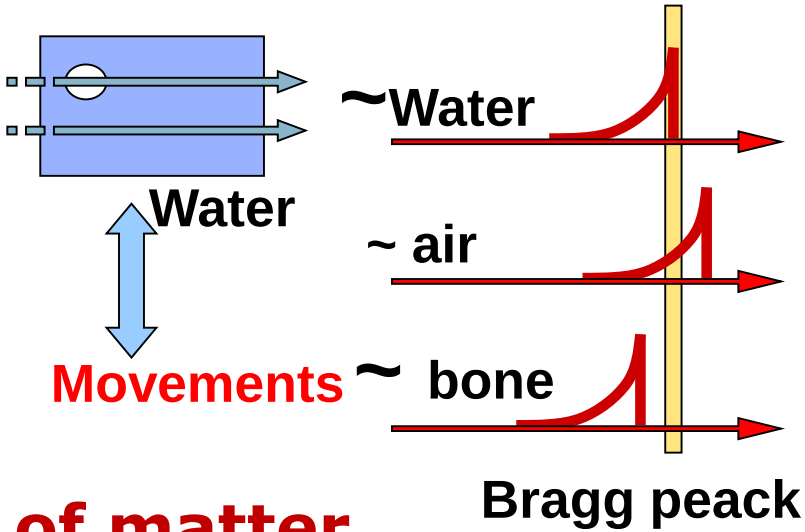
Context: moving organs



- **Ballistics problem:**
  - The position of the lung tumor
  - Calculate and optimize the dose delivery

➡ **Geometric data**

- **Specific problem of Hadrontherapy:**
  - Knowledge about the organs traversed by the beam
  - The position of the Bragg peak depends on the density of the matter traversed by the beam
  - Geometric data = insufficient !!!



➡ **Density of matter**

1- Imaging techniques: Target localisation techniques

- Imaging the tumour, if possible !!!
- Imaging of anatomical structures rigidly bound to the tumour (ex. bony landmarks)
- Detecting artificial fiducials implanted in or near the tumour (invasive, infection risk, pneumothorax...)

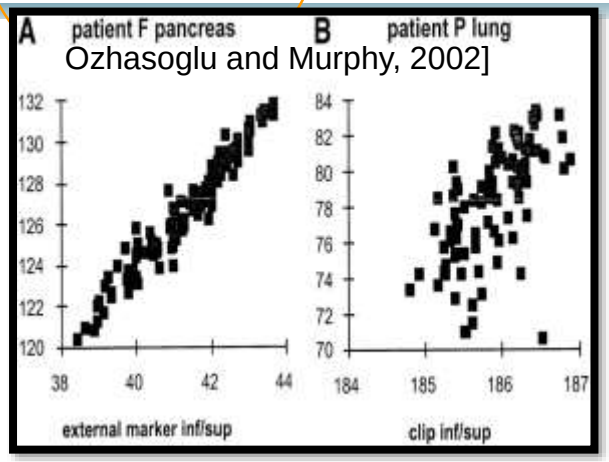
Techniques based on imaging → **assume a reproducible motion of the respiratory system.**

Existing solutions on tracking:

- Fiducial Markers
- CyberKnife system
- Online Pet Scan

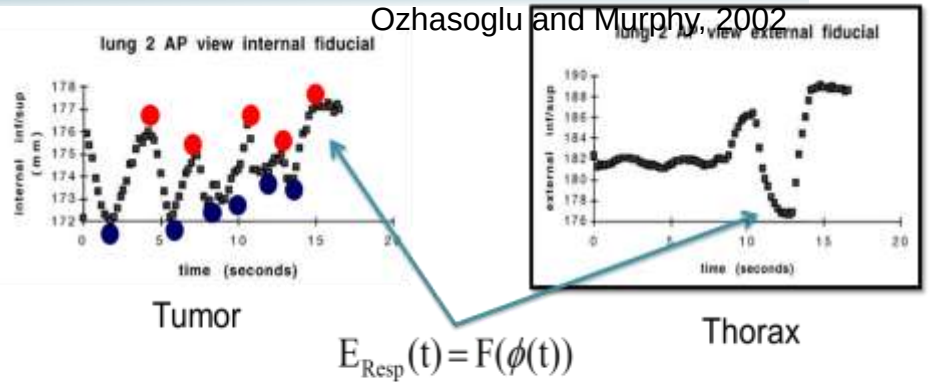
→ **intrusive or invasive**
the irradiation of the patient

Instalability and Non-reproducibility of the movements



Ozhasoglu and Murphy, 2002]

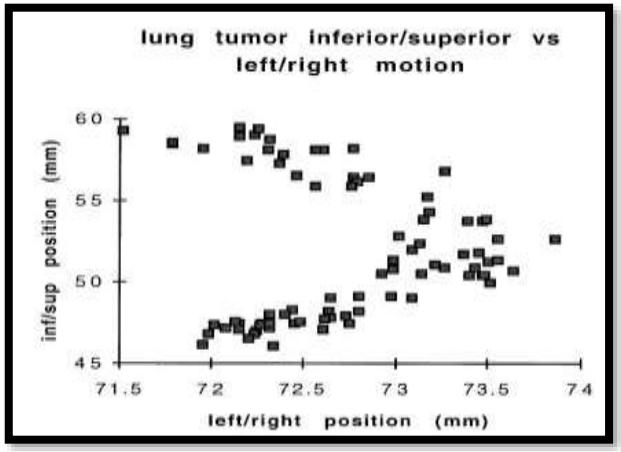
Correlation diaphragm movement vs pancreas and lung tumour



Ozhasoglu and Murphy, 2002

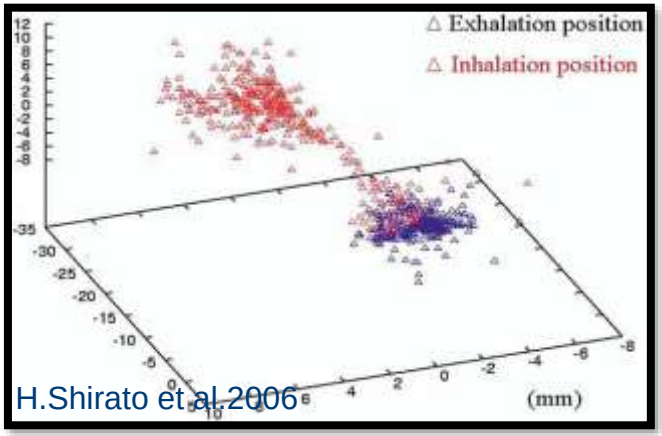
Respiratory instability

Correlation between internal motion lungs and external motion thorax



Lung tumor inferior/superior vs left/right motion

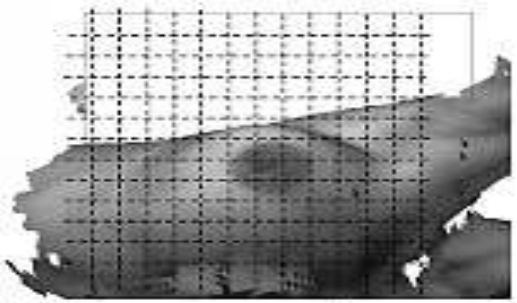
Non-reproducibility of the movements (chaotic?)



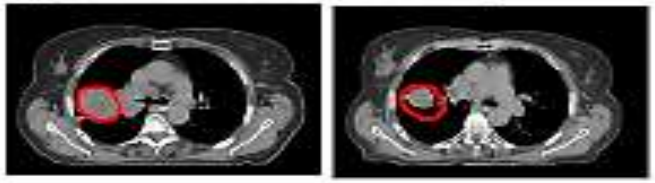
H.Shirato et al.2006

Internal marker : exhalation & inhalation positions

Breathing motion Inter/intra fractional uncertainties

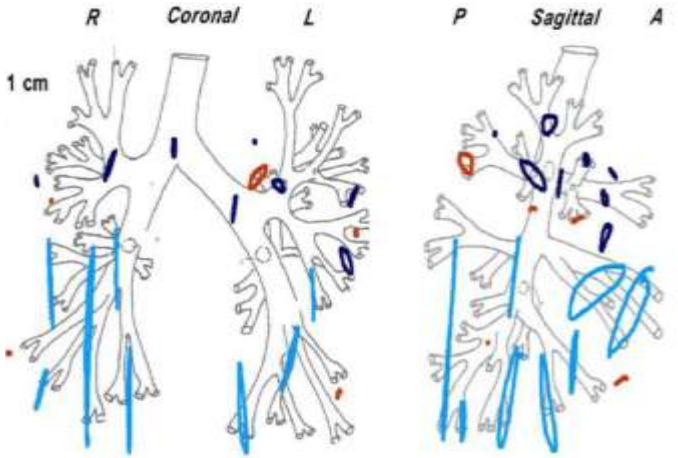


Guido et al.



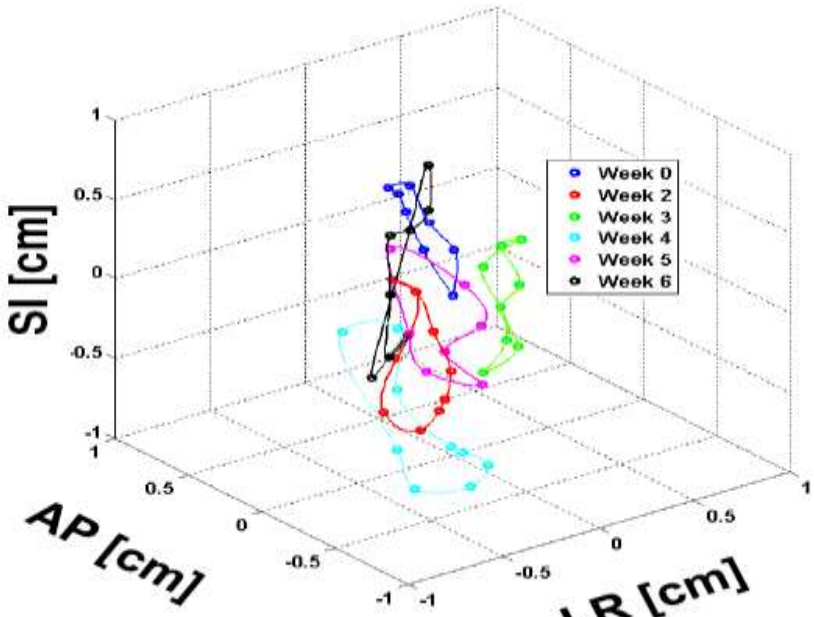
Inter-fractional setup errors and tumor shrinkage

Intra-fractional respiratory motion



Intra-fractional

- Variability in motion trajectory (**hysteresis loop**)
- Inter/intra-fraction changes in respiratory parameters (**baseline**, **amplitude** and **frequency**)

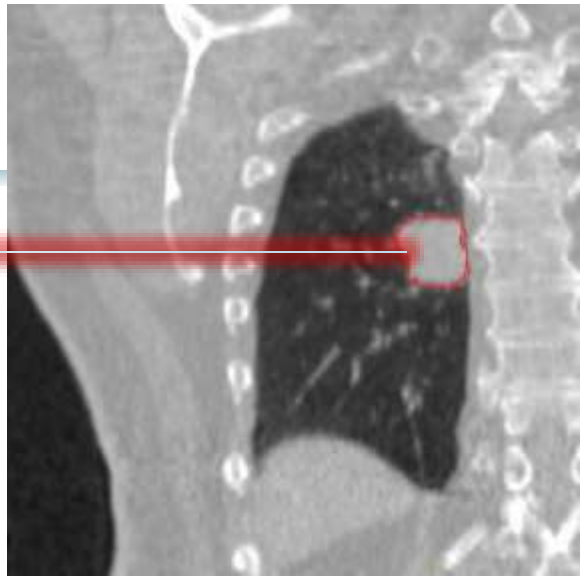


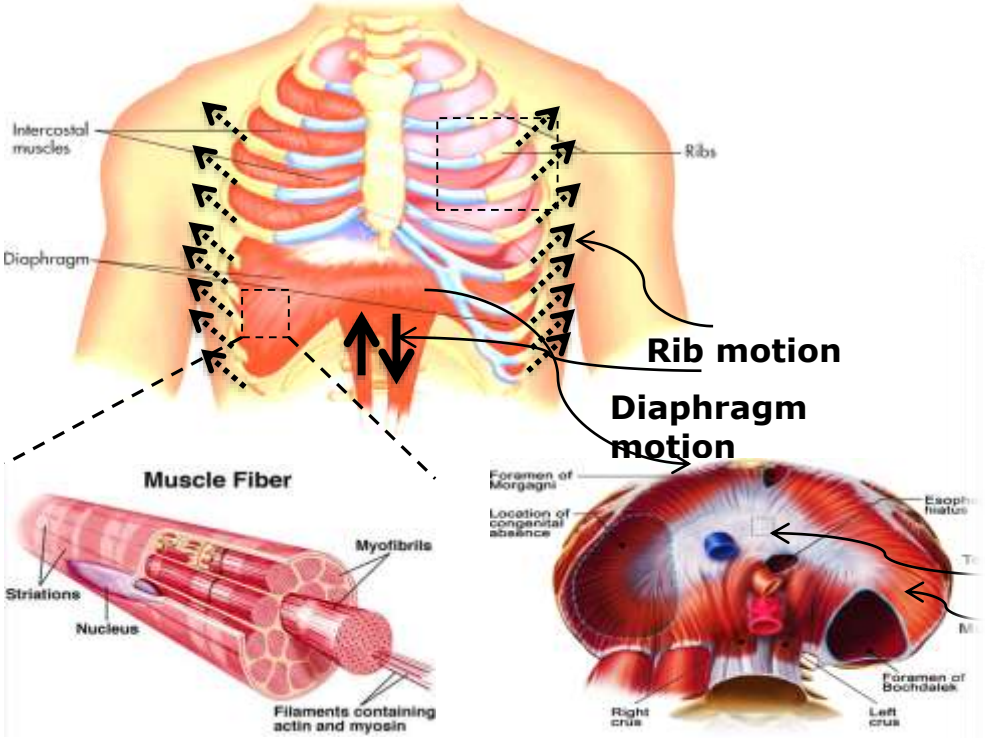
Inter-fractional

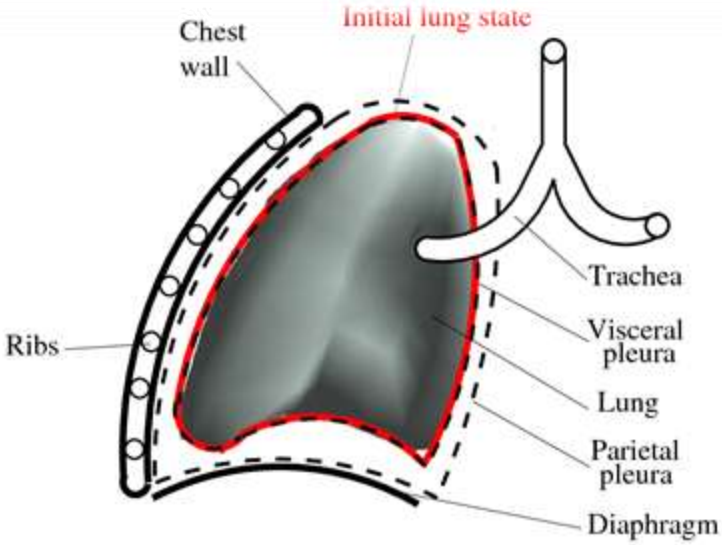
Anatomy of the respiratory system.

Breathing is non-reproducible

- Contraction of the diaphragm muscle.
- Intercostal muscles of the ribcage.



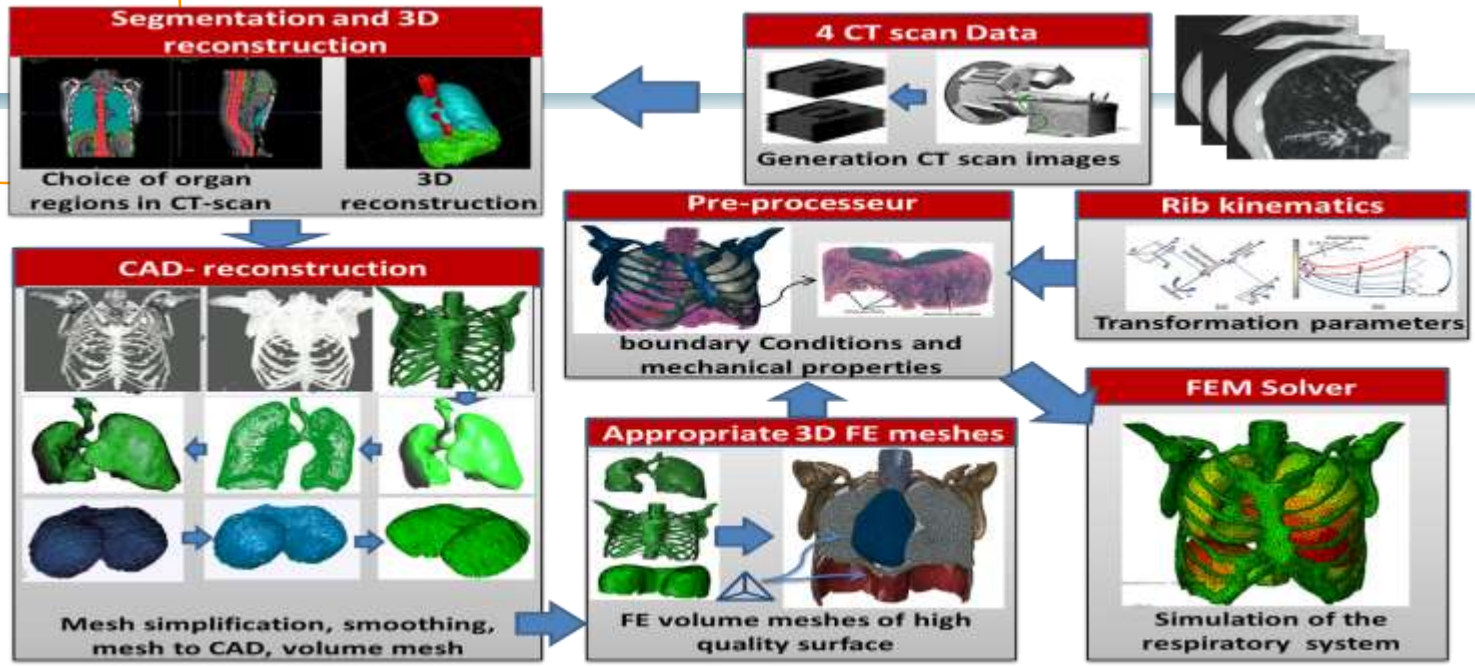




Diaphragm and Thorax

The breathing cycle is not regular,
Varies in amplitude and in phase from one cycle to another

From CT scan images to Biomechanical Simulation



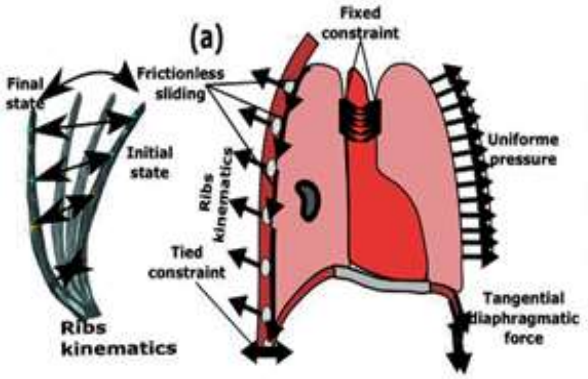
Pipeline Modeling based CAD modeling for FEM simulation

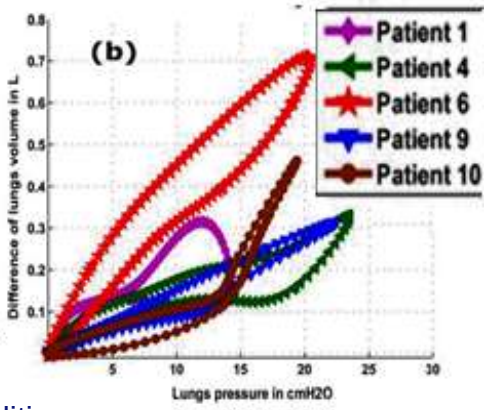
Approach based on the Biomechanical modeling allowing to:

- Take non reproducible aspects of lung motions into account
- Establish the biomechanical model from patients' geometrical ar physical data
- Be monitored by external sensors during the treatment
- Simulate a "virtual 4D-Scan"
- 4D dose distribution and online imaging control

Biomechanical patient-specific model of the respiratory system

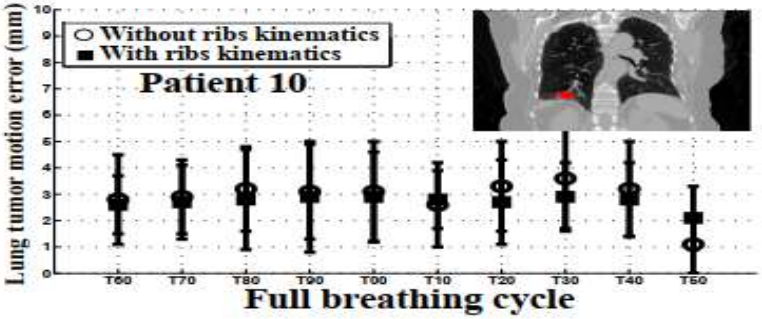
- Approch
  - Physiological and biomechanical patient-specific model of the respiratory system

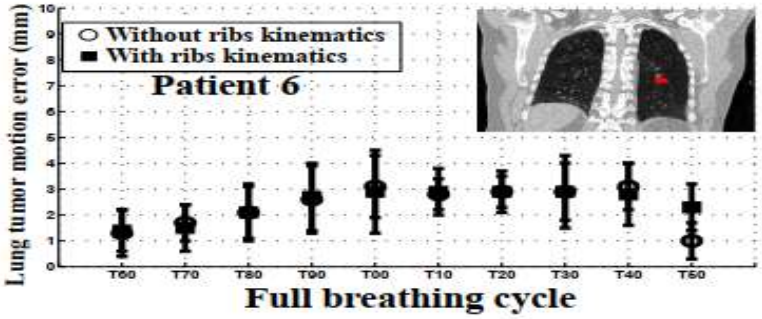




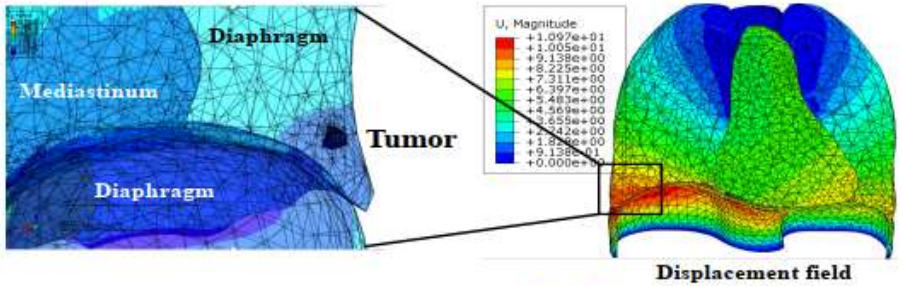
Boundary conditions

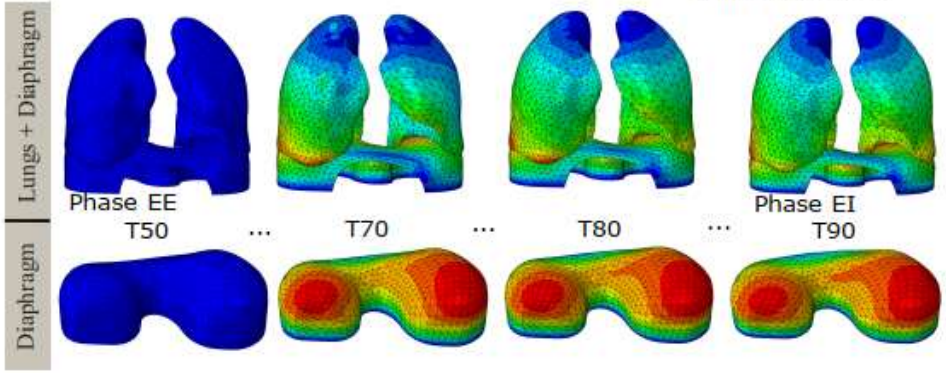
an average mean error less than $2.0 \pm 1.3mm$



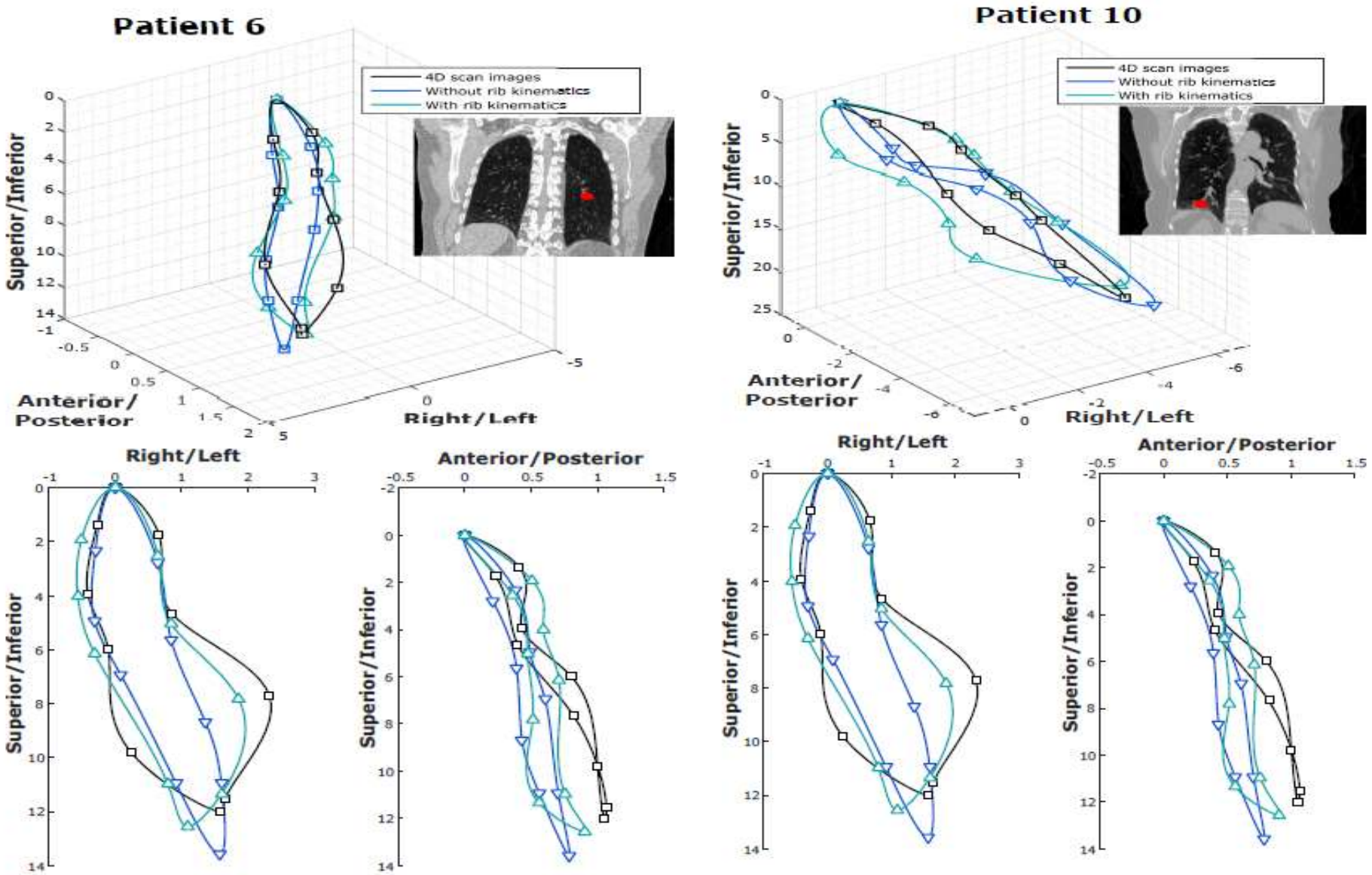


Ladjal et al. MICCAI 2017, IEEE TBME 2021





Experimental validation



Tumor trajectories identified in 4D CT scan images compared to the trajectory calculated from biomechanical FE simulation

Unified multi-physical model of the respiratory system

Biomechanical patient specific model

MICCAI 2017, CMB 2019, IEEE TBME 21

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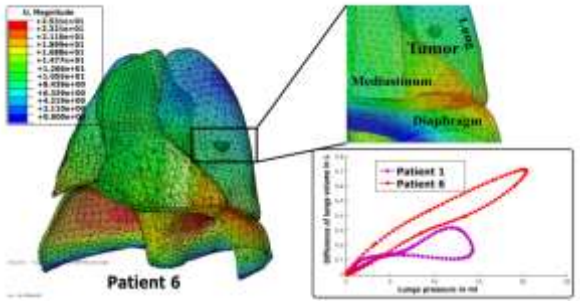
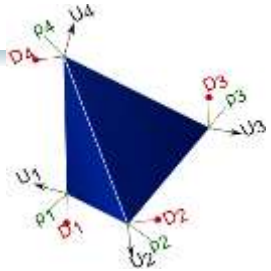
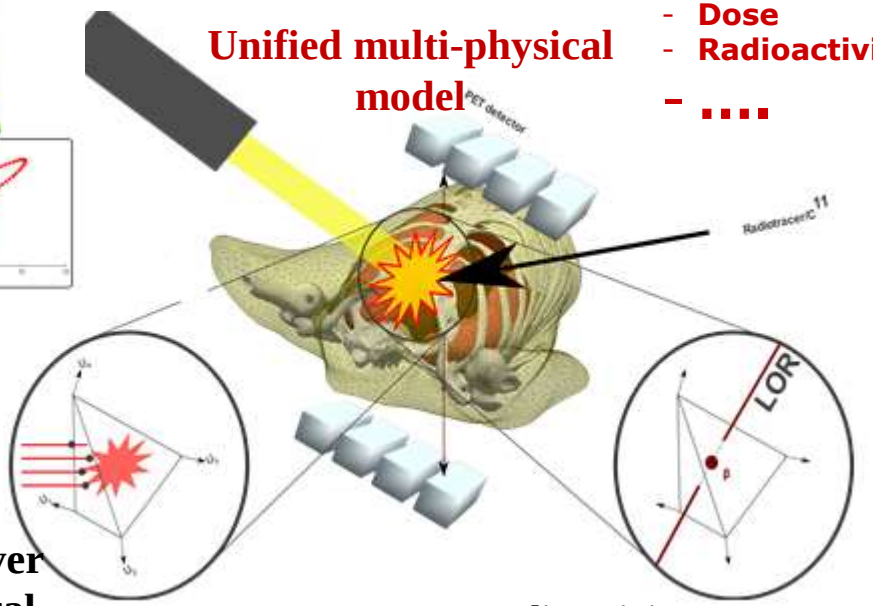


Tetrahedral structure

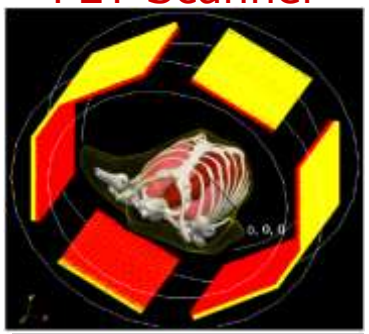
- Density
- Masse
- Displacements
- Dose
- Radioactivity
- ....



Unified multi-physical model



PET Scanner



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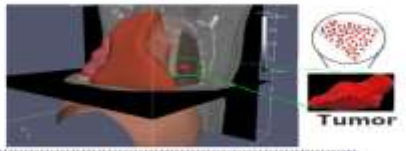
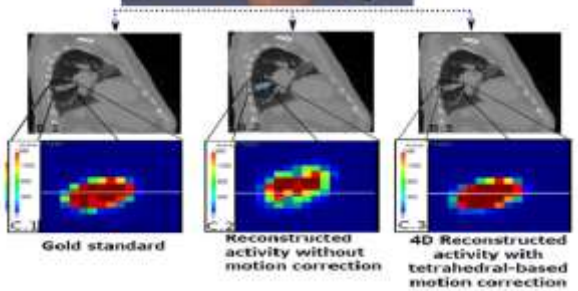
4D PET imaging

[JCARS14, PMB 15, IEEE ISBI 16]

Radioactivity reconstructed on tetrahedral elements





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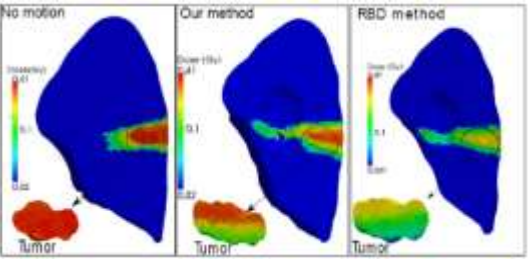
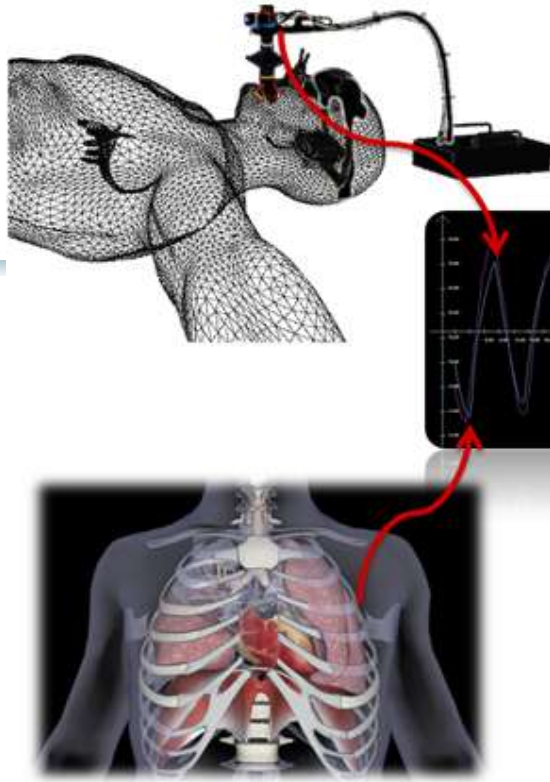
Dose accumulated over deforming tetrahedral

4D Dynamic dose distribution

IEEE ISBI 16, PMB 18



Conclusion and perspectives



Tracking different internal organs from external surrogates

Clinical validation of the model by external sensors

- Spiromter
- Thorax movement tracking (RPM markers)

Realistic anthropomorphic phantom
Lung Cancer LuCas (PSI)

- Experimental studies and pre-clinical validation based on realistic breathing anthropomorphic thorax phantom (LuCa "Lung Cancer")
- Contributing to the development of on-line control systems for Radio hadrontherapy (4D PET, Gamma prompt)
- Open for collaboration

Thank you for your attention