Patient-specific biomechanical model for the prediction of lung motion from 4-D CT images: Dosimetry and PET Imaging

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Workshop ClaRyS project Defis Imaging 2016

Laboratoire d'**I**nfoRmatique en **I**mage et **S**ystèmes d'information

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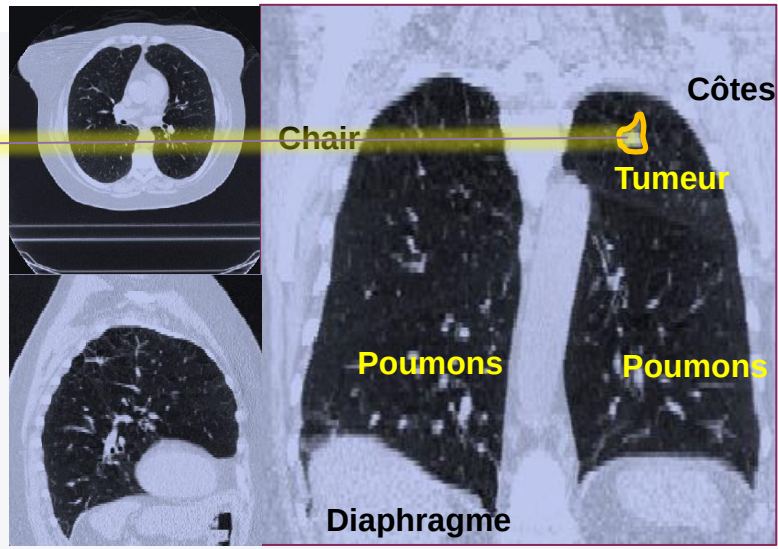
11/02/2016

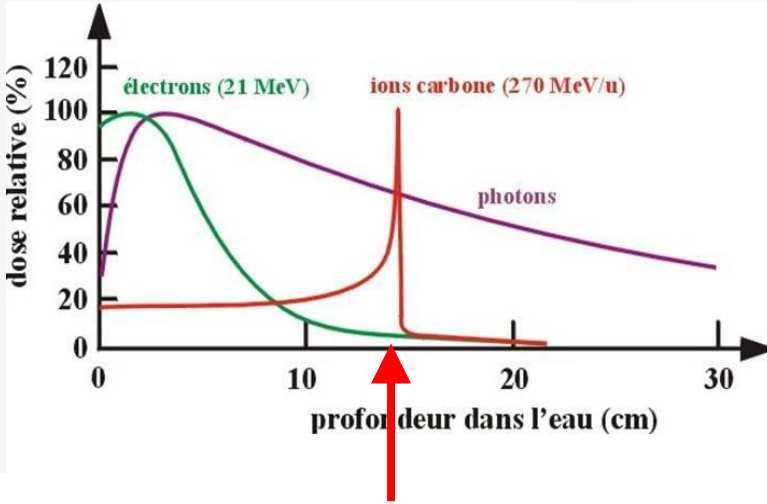
Hadron thérapie: organes en mouvements

Radio/Hadron thérapie



- **Problème de la balistique**
  - Connaître la forme et la position de la tumeur
  - Calculer, optimiser et contrôler la dose d'irradiation

- **Problème spécifique en hadronthérapie**
  - Données géométriques = insuffisantes
  - Densité de matière



Peack de Bragg

Organes en mouvements

STRATÉGIE IDÉALE

Diminution des marges d'irradiation par:

- **Détermination de la position tumorale**
- **Anticipation du mouvement tumorale**
- **Repositionnement du faisceau**
- **Adaptation de la dosimétrie, prenant en compte la nouvelle configuration**

Organes en mouvements

LOCALISATION DE LA CIBLE PAR L'IMAGERIE

- l'imagerie de la tumeur elle-même,
- l'imagerie des structures anatomiques rigidement liés à la tumeur (par exemple, repères osseux),
- la détection des marqueurs implantés dans ou à proximité de la tumeur (invasif, risque d'infection, …)
- le suivi des organes de substitution (« surrogates ») se déplaçant en synchronisme avec la tumeur.

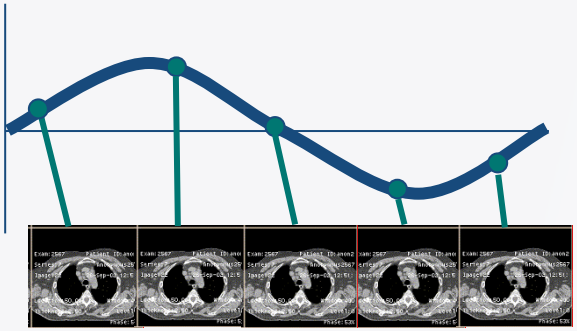
Organes en mouvements

APPROCHES USUELLES

- **Optimisation des marges d'irradiation (contention externe, …)**

Grande quantité de tissus sains irradiés

- **Blocage respiratoire, ABC**
  - **Blocage respiratoire passif**
  - **Blocage du faisceau**



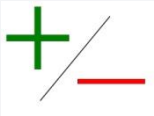
Problème des instabilités respiratoires : position de la tumeur considérée identique pour un instant précis du cycle respiratoire

- **Suivi de tumeur par analyse d'image**

Organes en mouvements

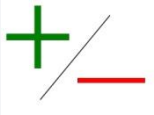
APPROCHES USUELLES

- **Suivi de tumeur par marqueurs**



Position de la tumeur connue à chaque instant
Méthode invasive
Densité de matière?

- **Suivi de tumeur utilisant cyberknife**
  - **Images acquises pendant le traitement**

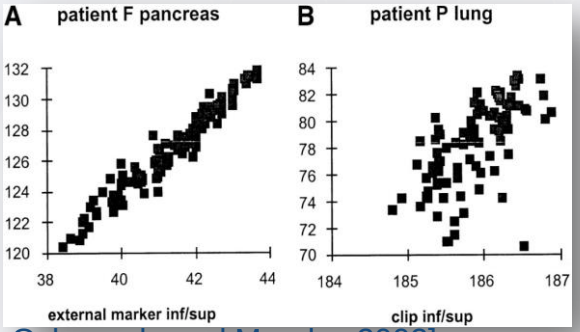


Position de la tumeur connue à chaque instant
Irradiation permanente du patient
Temps de traitement : 30 à 90mn

Toutes ces méthodes présentent des inconvénients

Pas de prise en compte du mouvement complexe des tumeurs
Méthodes invasives
Pas de connaissance de la variation de densité de matière

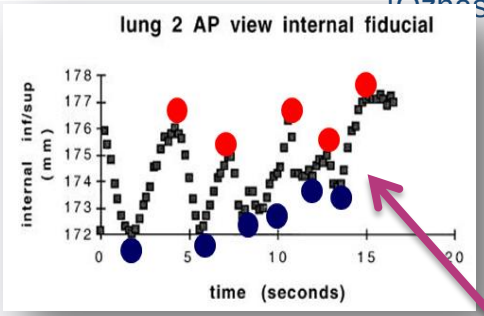
Instabilité respiratoire: Non reproductible et chaotique

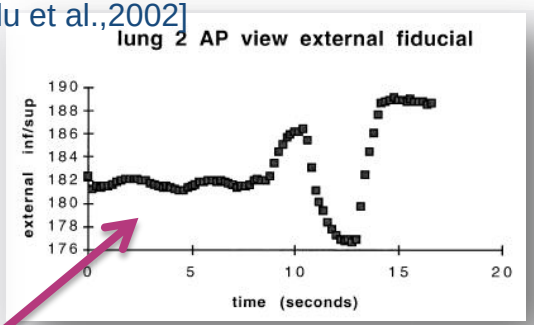


Ozhasoglu and Murphy, 2002]

Corrélation mouvement diaphragmatique vs tumeur du pancréas et des poumons

[Ozhasoglu et al.,2002]

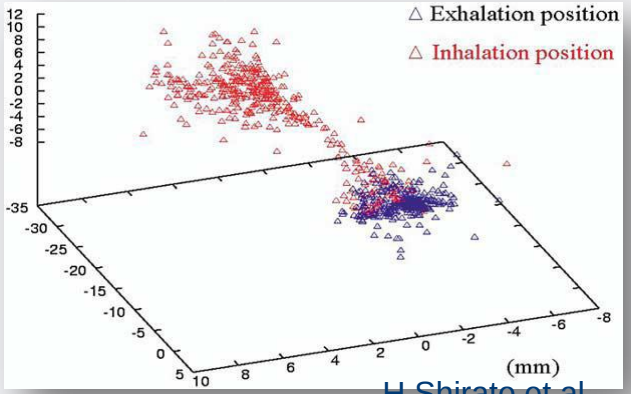




La tumeur **Thorax**

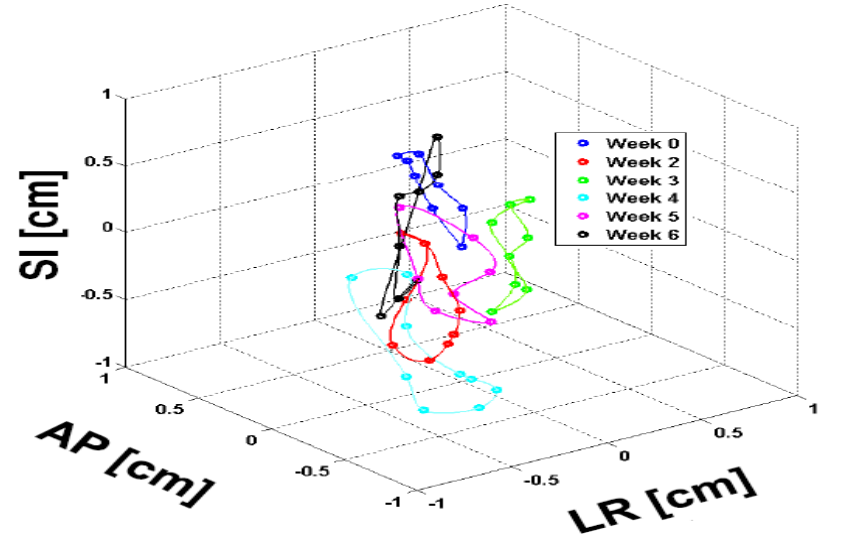
$$E_{Resp}(t) = F(\phi(t))$$

Estimation de $E_{Resp}(t)$ par l'évaluation de $\phi(t)$



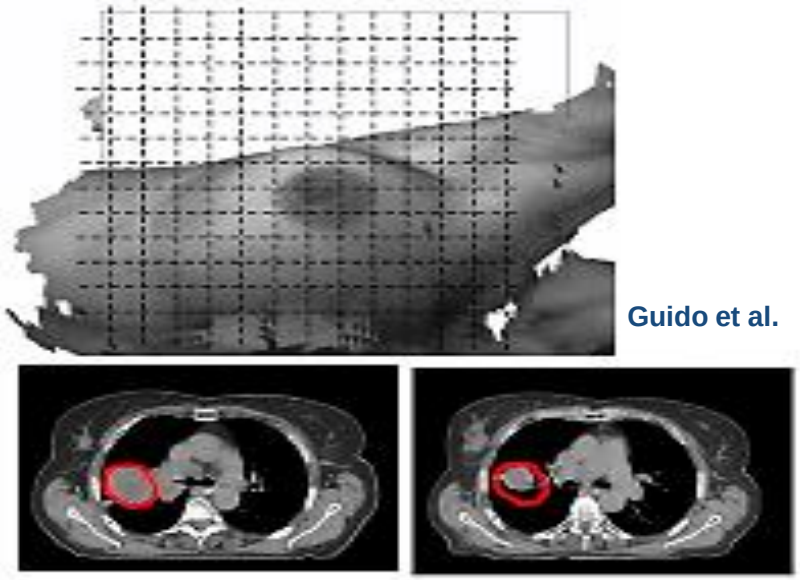
H.Shirato et al.

Position des marqueurs internes Inspiration max Vs Expiration max



Trajectoires hystérisises

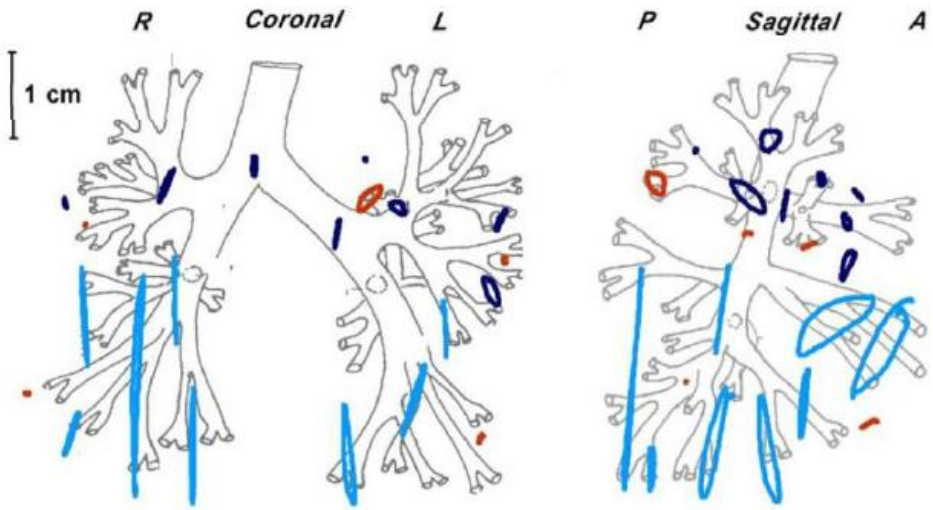
Incertitudes liées au mouvements intra-fraction et inter-fraction

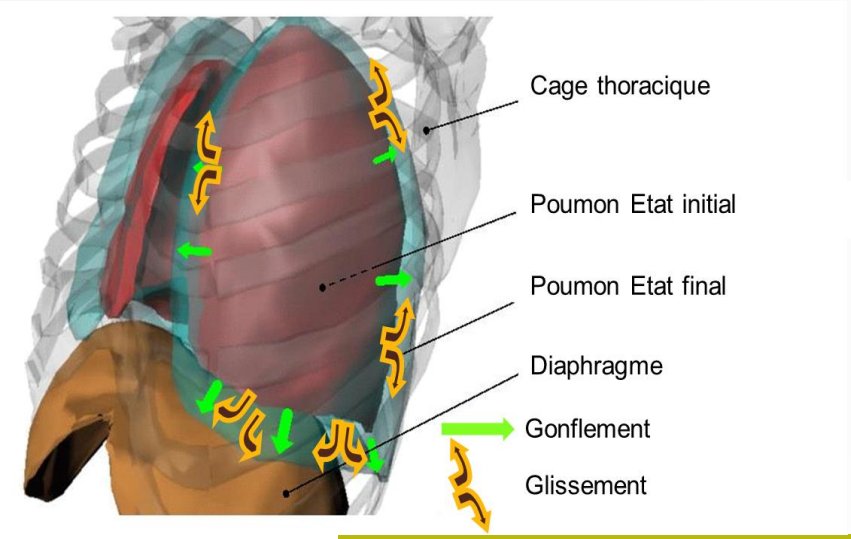


Guido et al.

Inter-fractional setup errors and tumor shrinkage

Intra-fractional respiratory motion



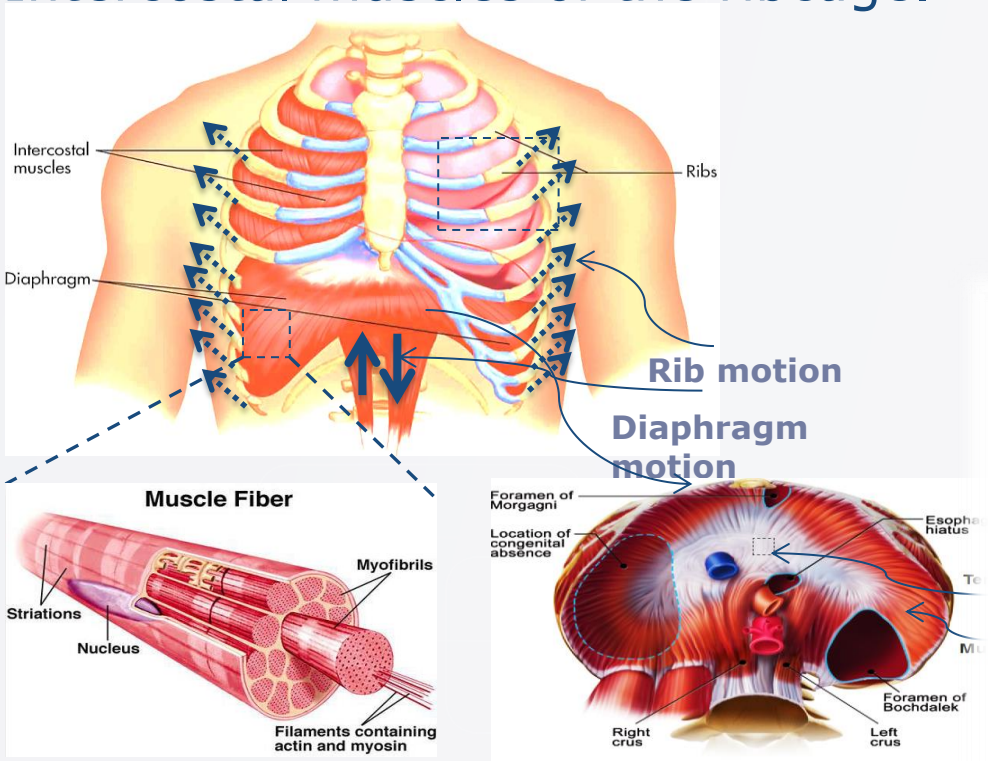


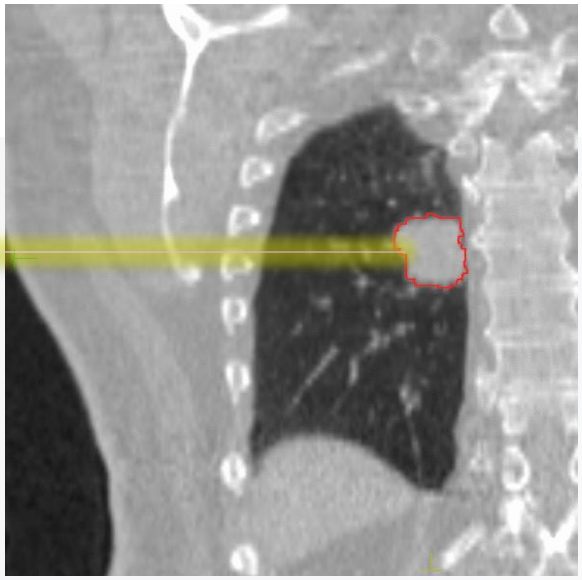
Intra-fractional

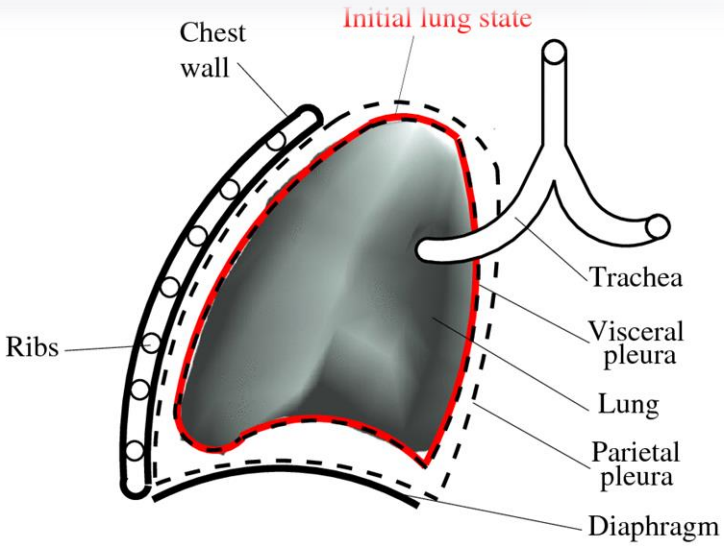
Anatomy of the respiratory system.

Breathing is non-reproducible

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







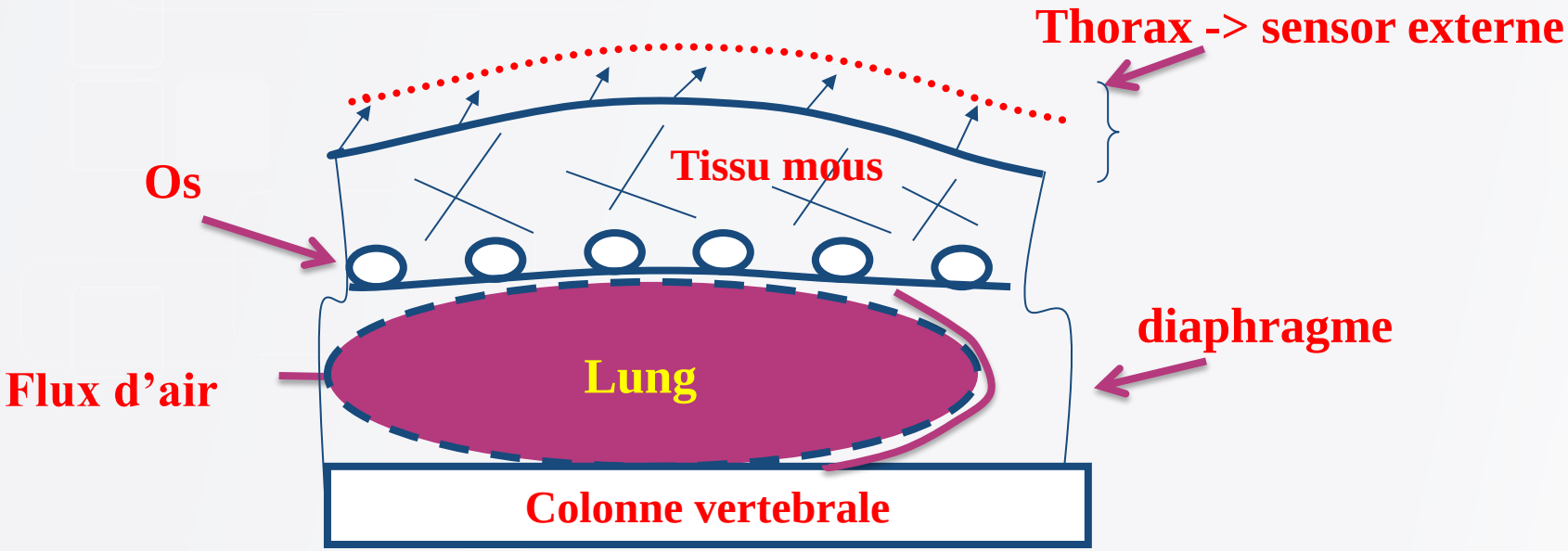
The breathing cycle is not regular, Varies in amplitude and in phase from one cycle to another

Diaphragm and Thorax

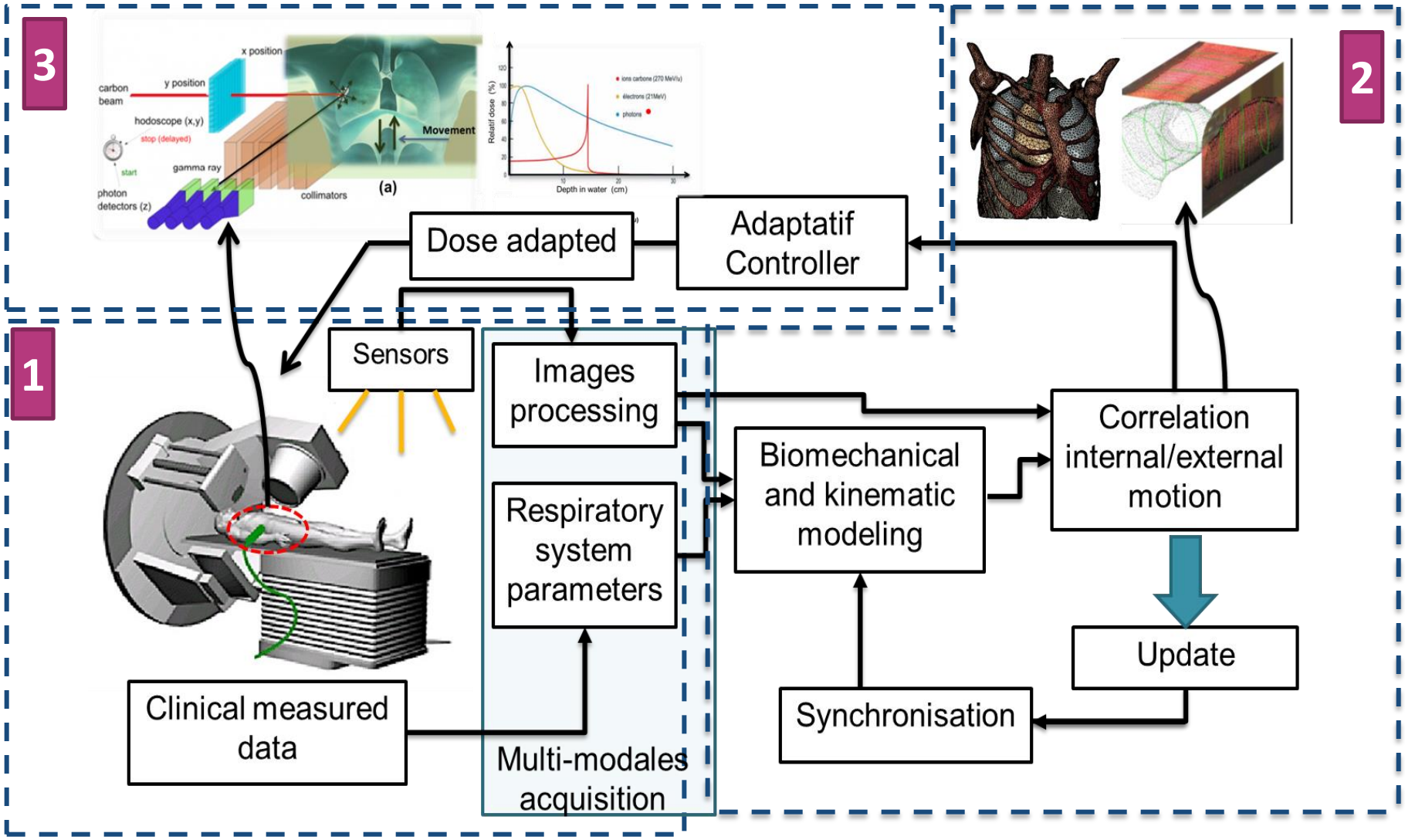
UNE APPROCHE BIOMECANIQUE

Approche basée sue la modélisation biomécanique des poumons permettant de :

1. Prendre en compte l'aspect non reproductible des mouvements
2. Utiliser les données géométrique et physiologique des patients
3. Controller les paramètres du modèle par des capteurs pendant le traitement
4. Simuler un CT-Scan 4D

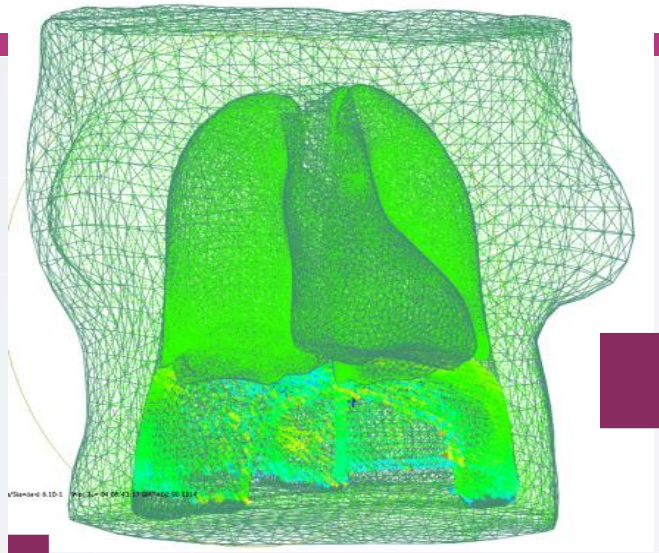


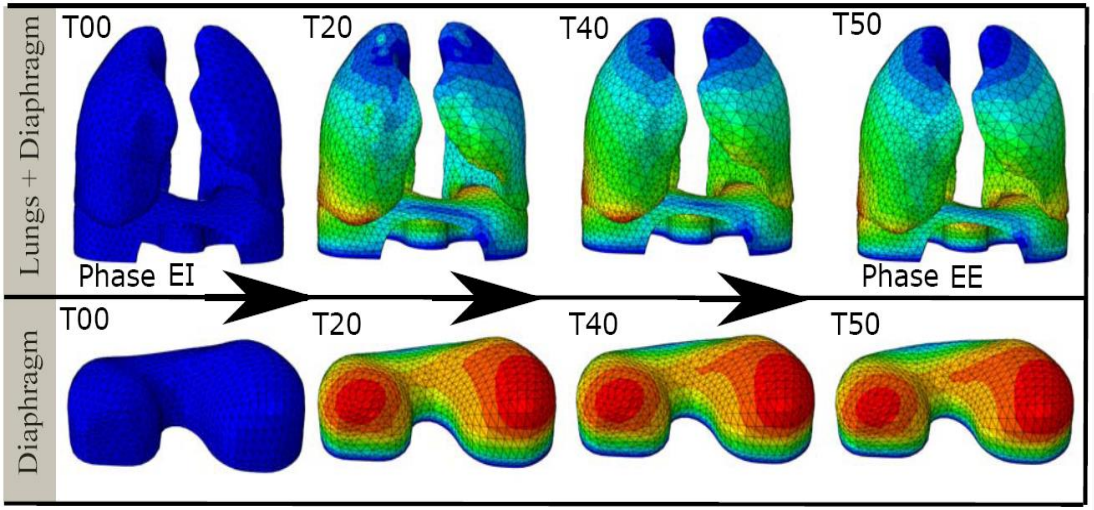
Methodology (general strategy)



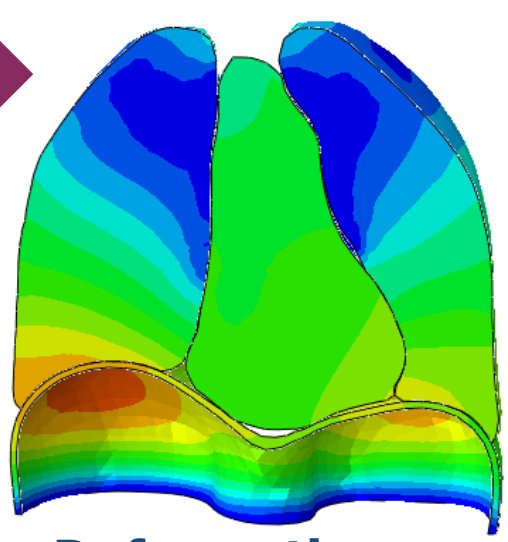
External surrogates and sensors track internal organs motion based biomechanical model during treatment.

Finite Element Patient Specific Simulation

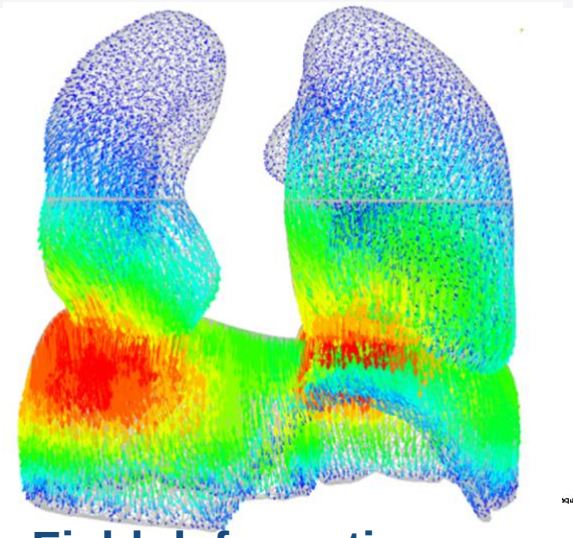




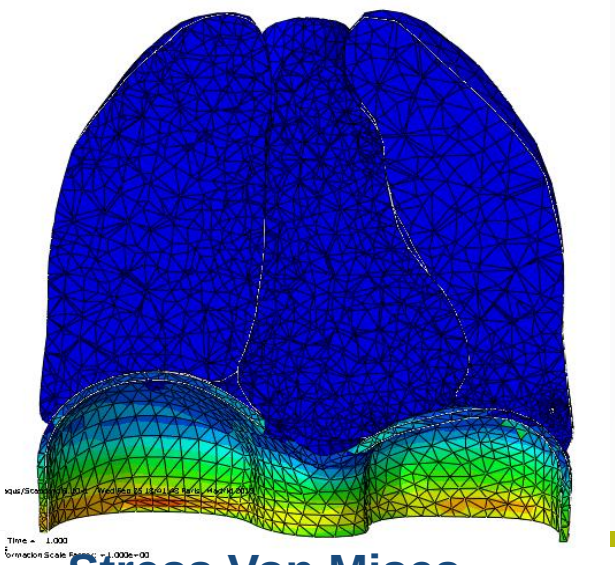
Finite element Patient specific of the respiratory system



Deformation amplitude



Field deformation and orientation



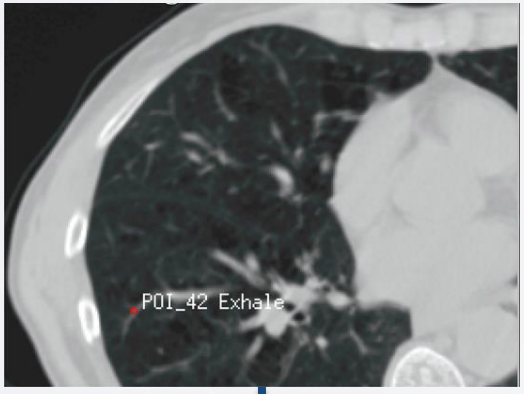
Stress Von Mises

Validation Experimentale

End Expiration

State Ti ….

End Inspiration



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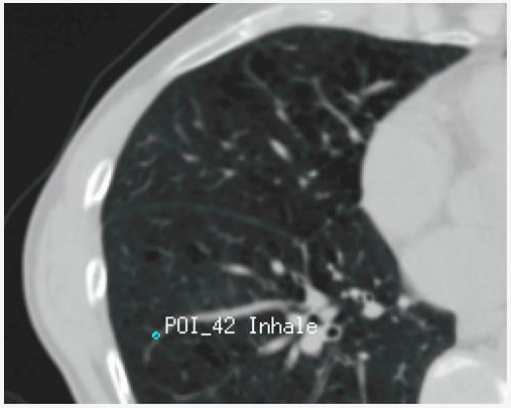

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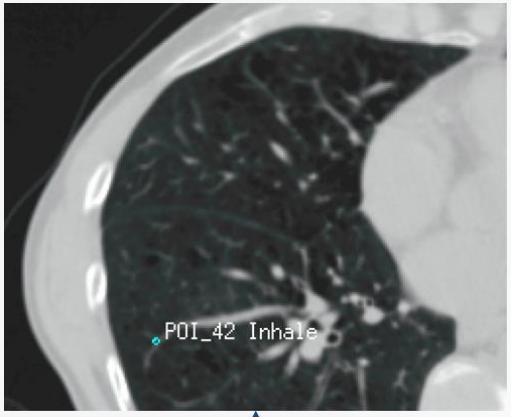
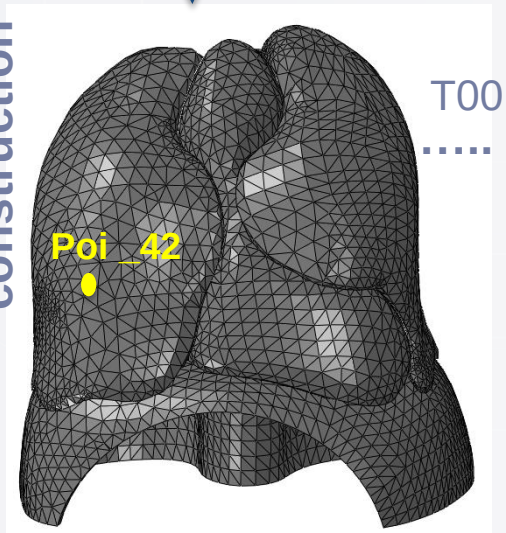


Validation

Euclienne distance

Model construction



T00

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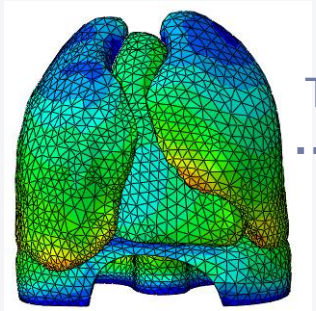

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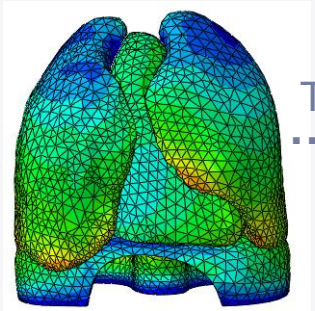

T50

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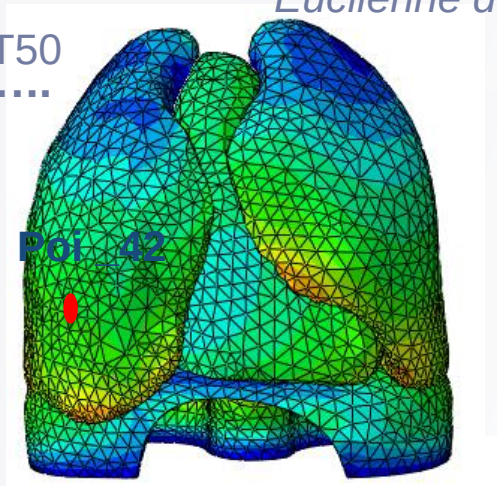
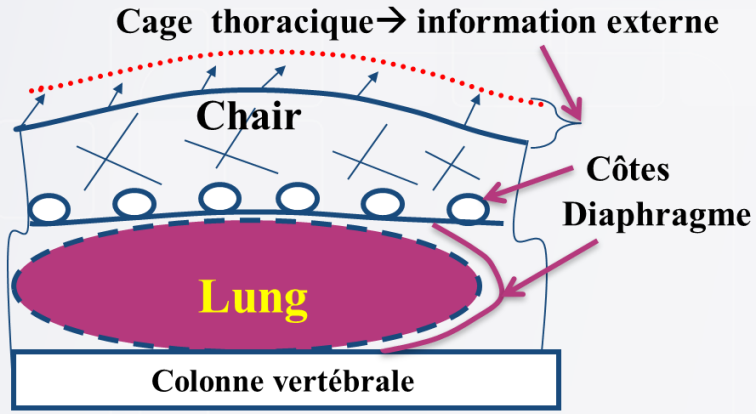


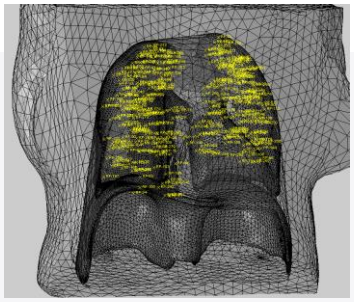
FEM Simulation

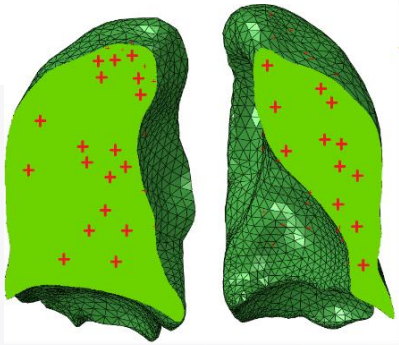
Patient specific at EE

FEM simulation

Modélisation Biomécanique du système respiratoire

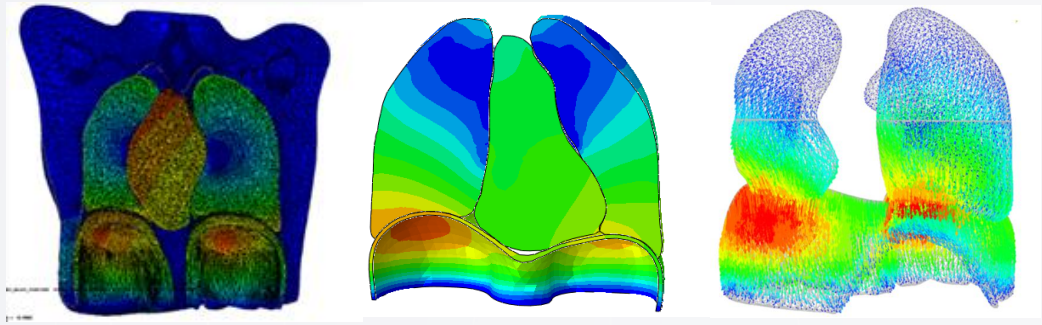


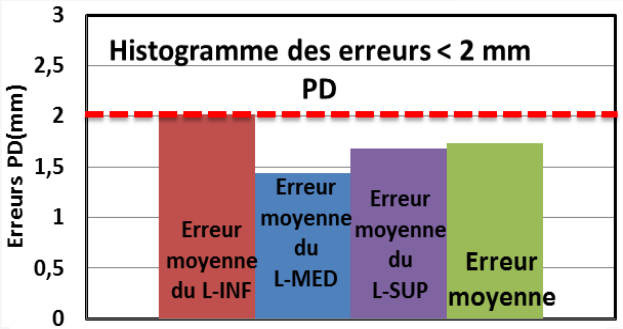


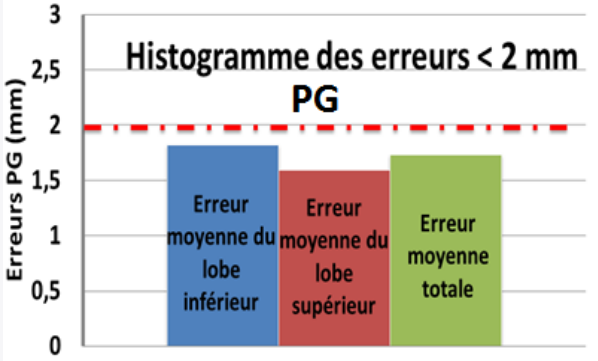


Validation clinique **75 marqueurs**

Conditions limites du système respiratoire

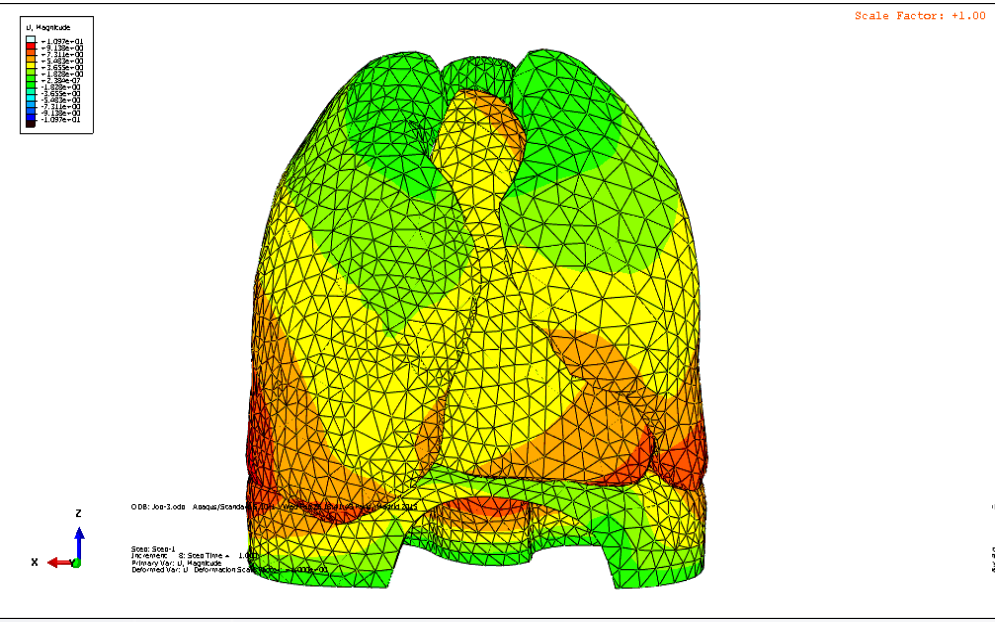


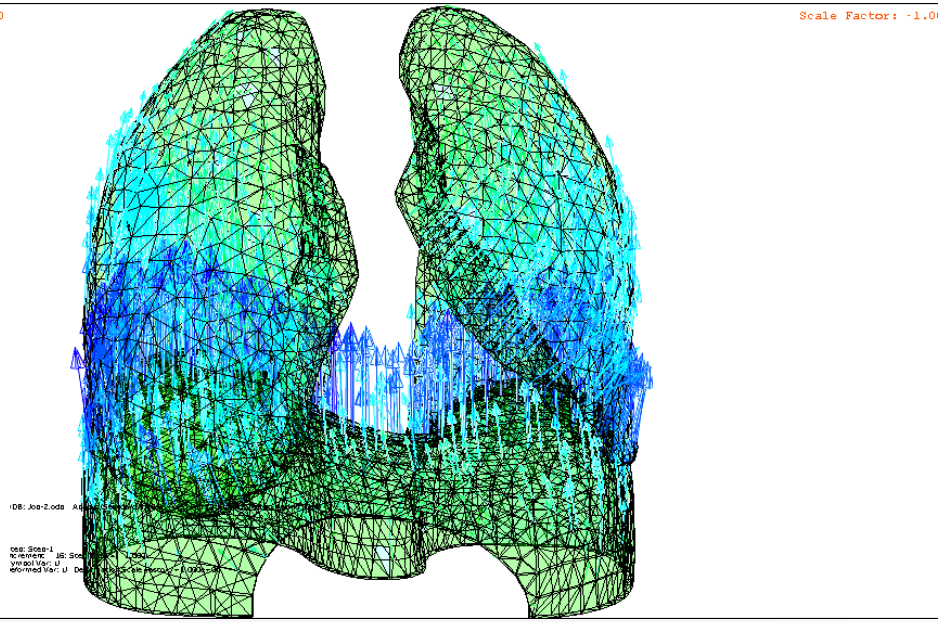


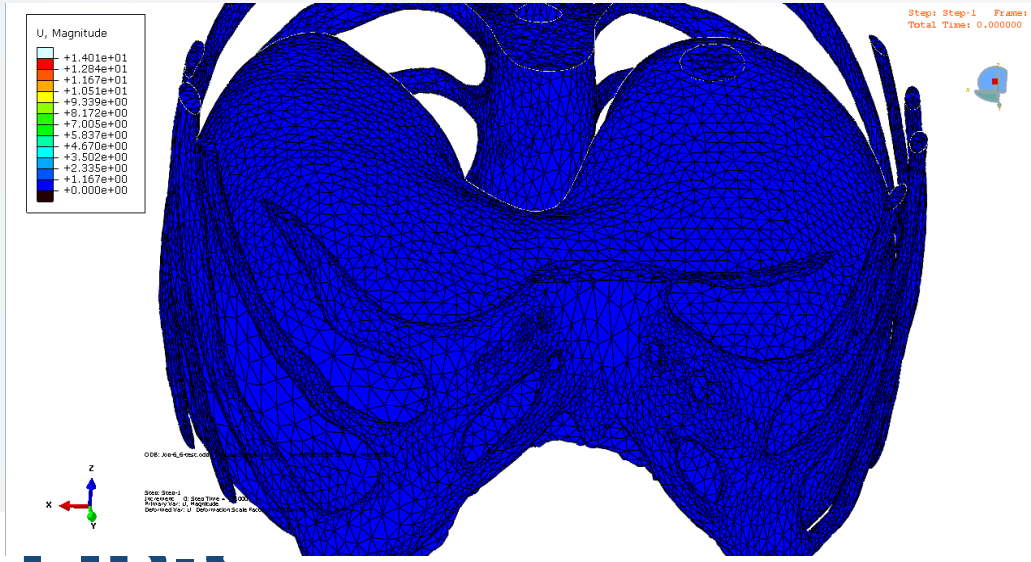


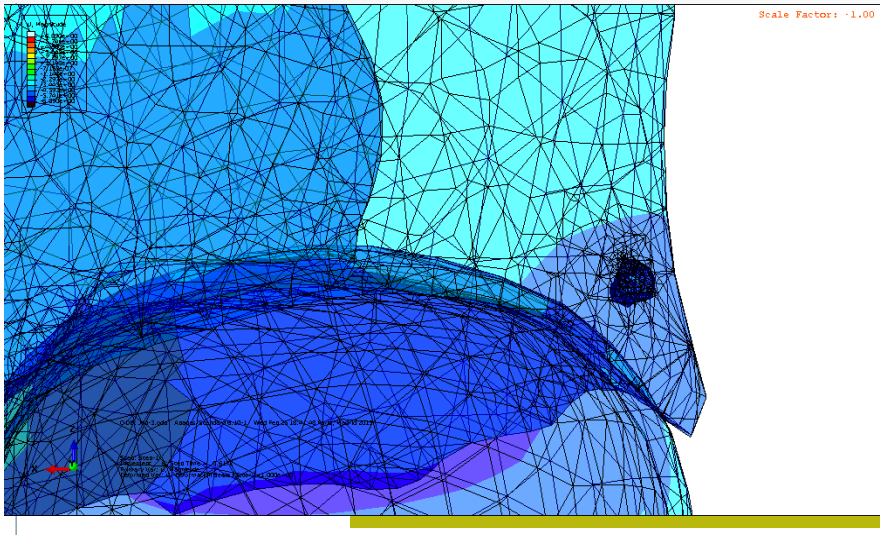
Lobes	Supérieur			Milieu			Inférieur		
Directions	G/D	S/I	A/P	G/D	S/I	A/P	G/D	S/I	A/P
Poumon droit (mm)	0.77	1.11	1.72	0.23	0.55	1.04	1.35	0.60	1.15
Poumon gauche (mm)	0.84	0.95	1.38	-			0.69	0.65	1.03

4D Biomechanical simulation

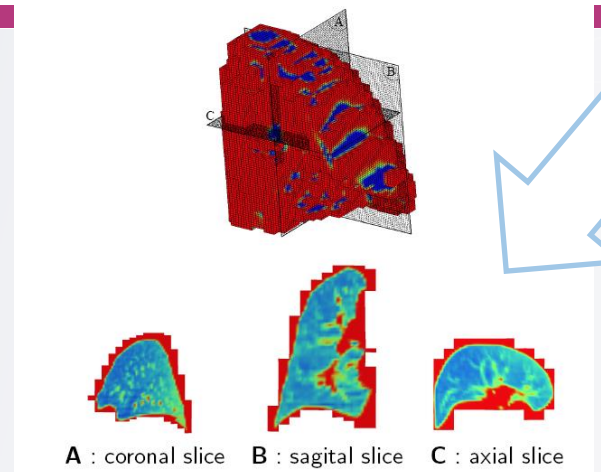


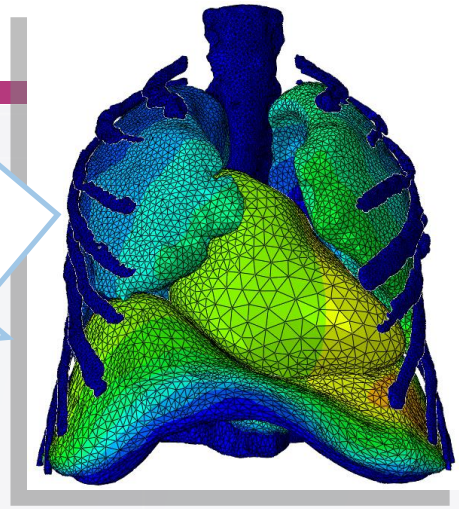


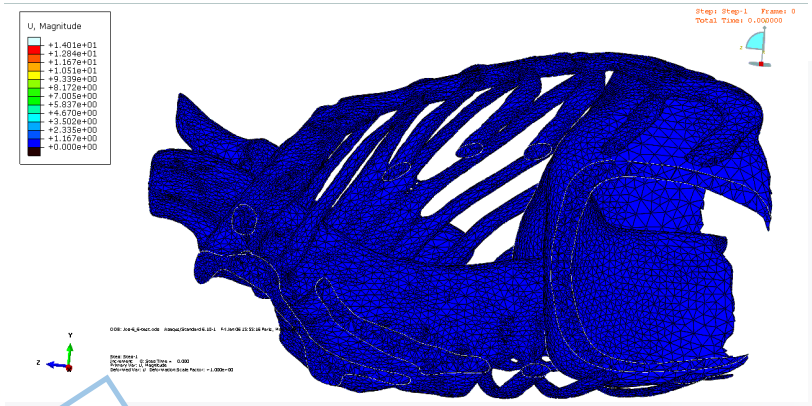




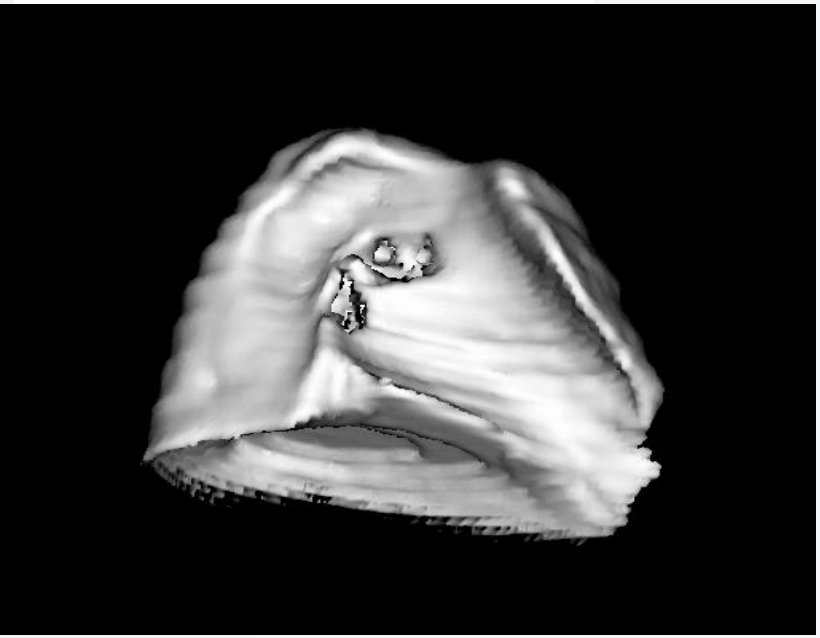
Virtual 4D CT scan reconstruction & dose simulation



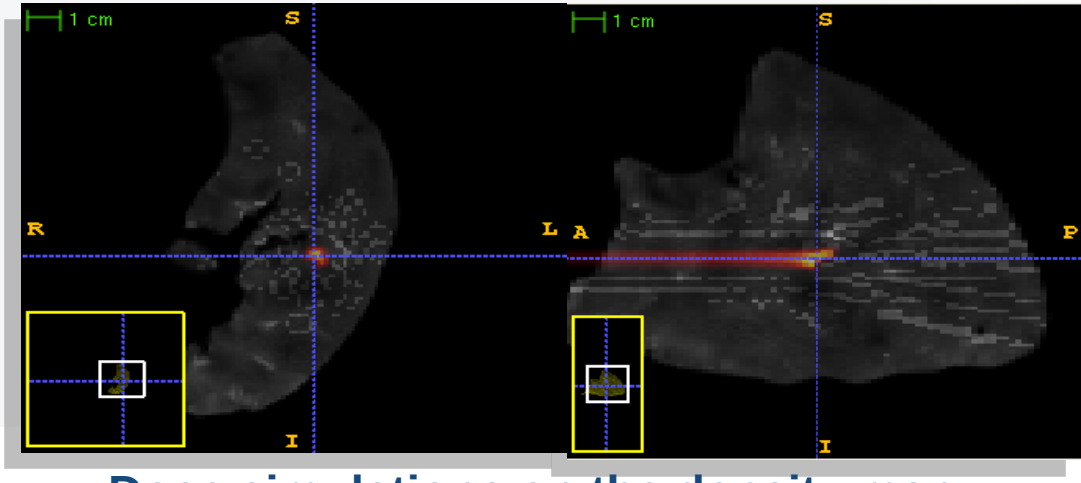




Transformation of biomechanical model into a 4D density map



Conversion of displacement simulation into CT scan



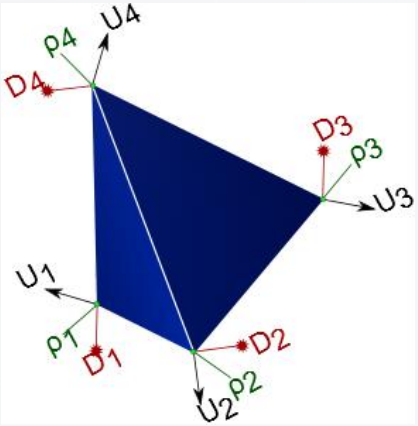
Dose simulations on the density map

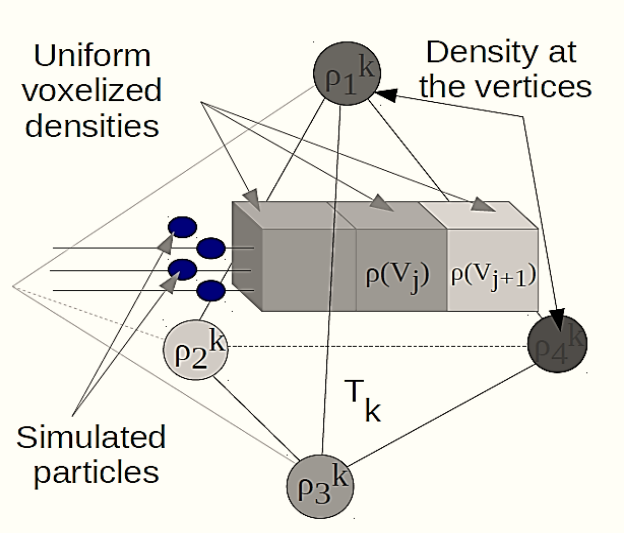
Maillage continu multi-physique

Structure tétraédrique multi-physique et continue

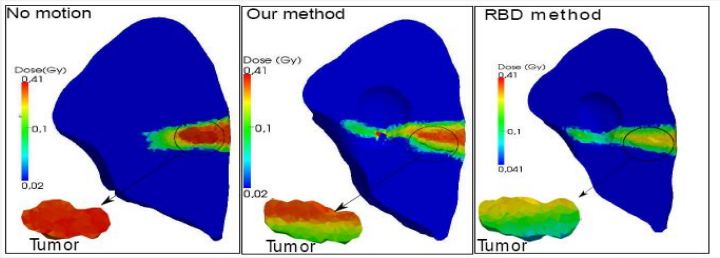
- Densité
- Masse
- Déplacements
- Dose

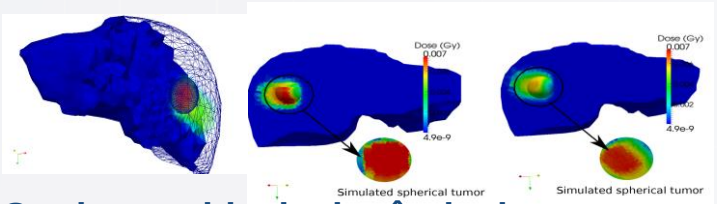
….



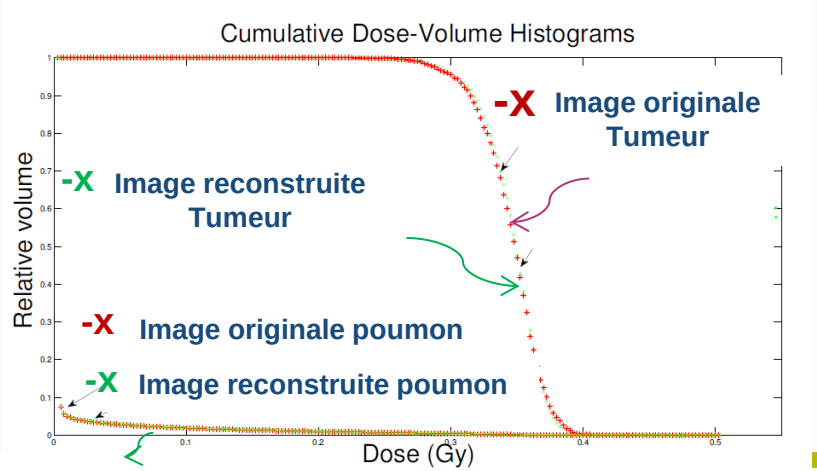


Voxelization





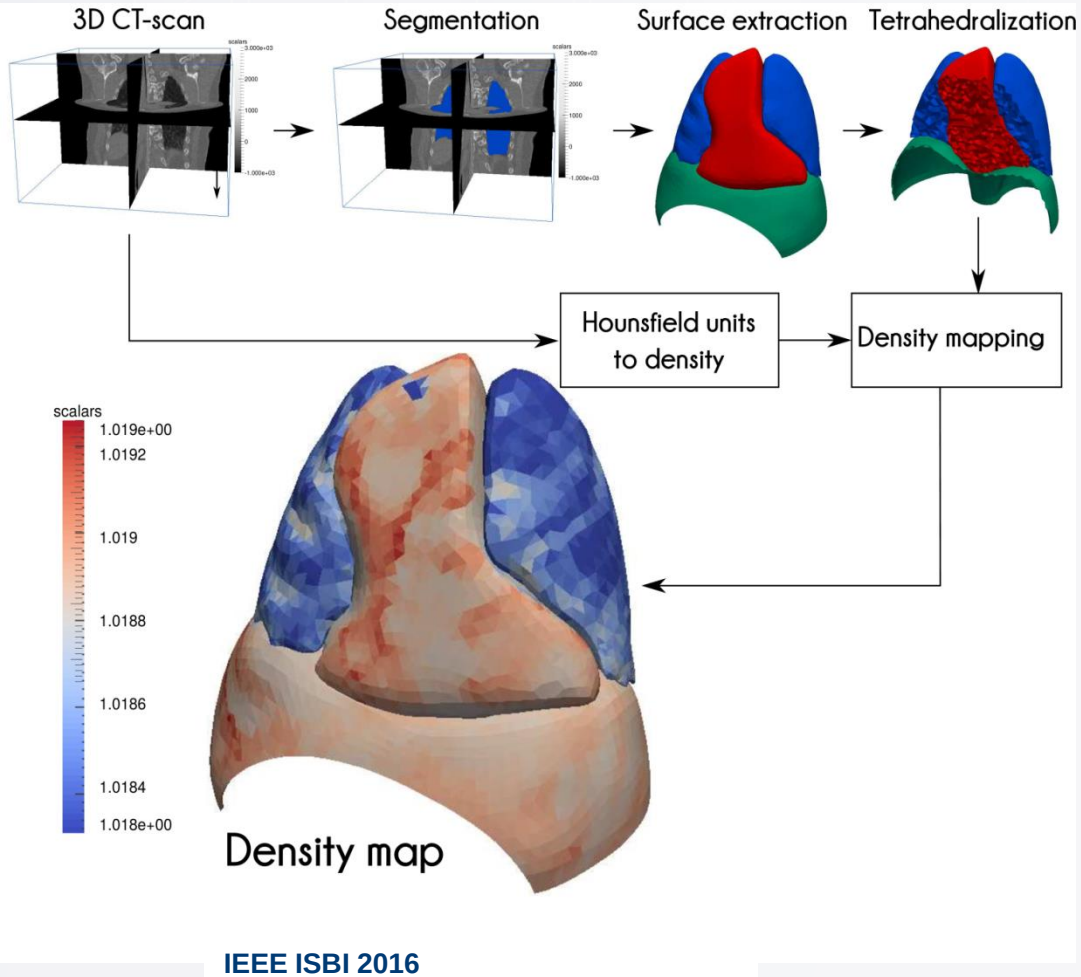
Carthographie de depôt de dose



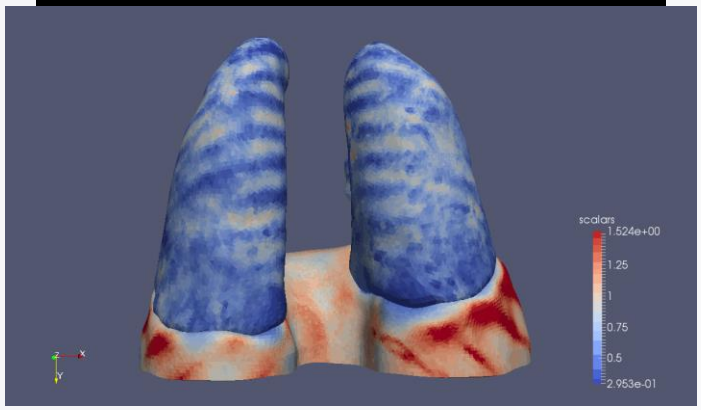
IEEE ISBI 2014 ,JCARS 2014

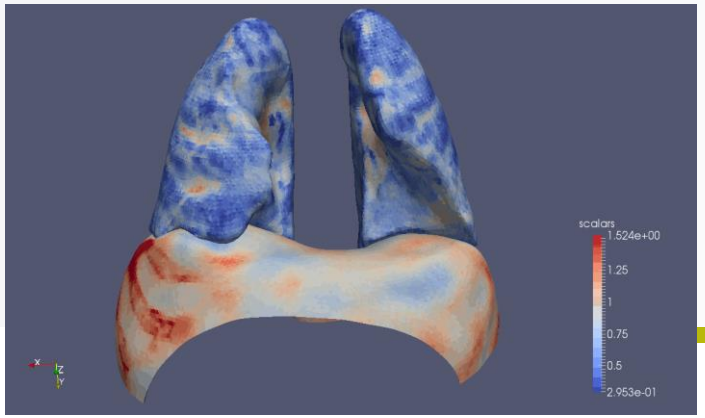
LIRIS

Distribution de densité 4D



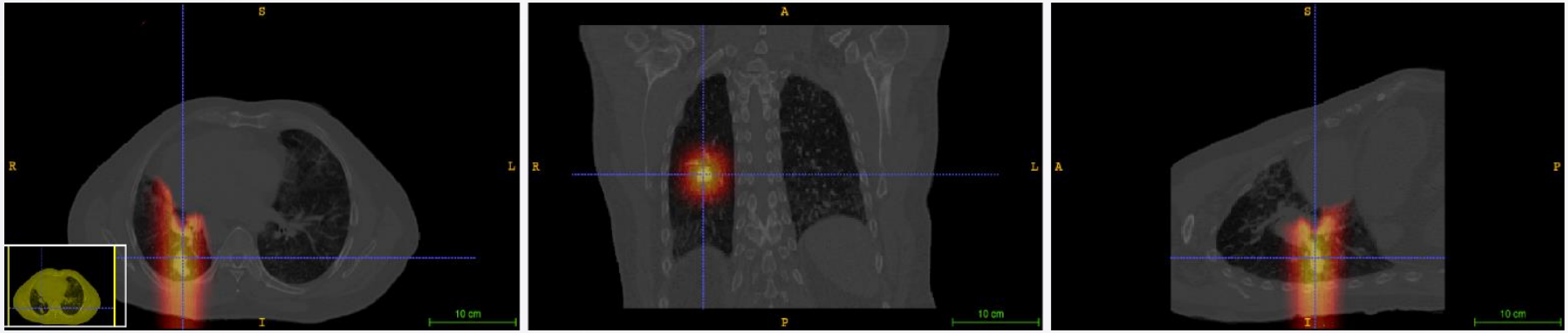
IEEE ISBI 2016



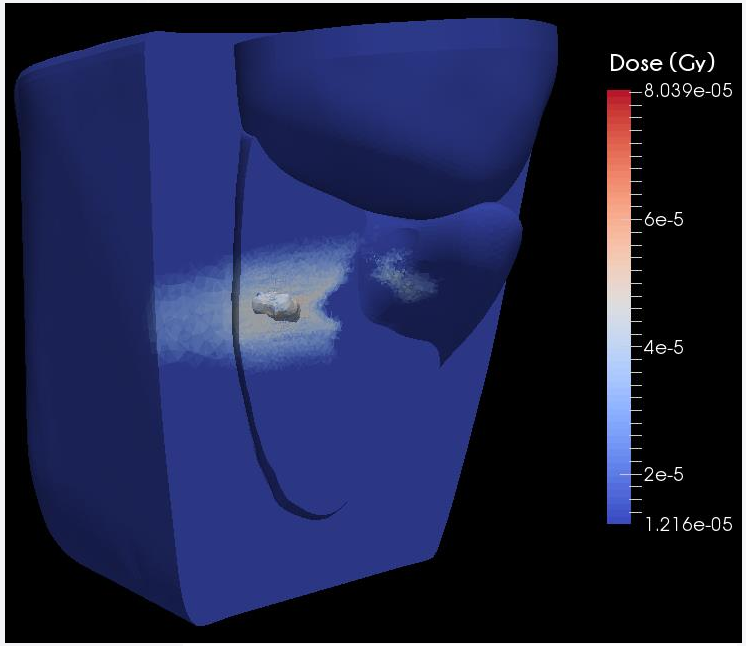


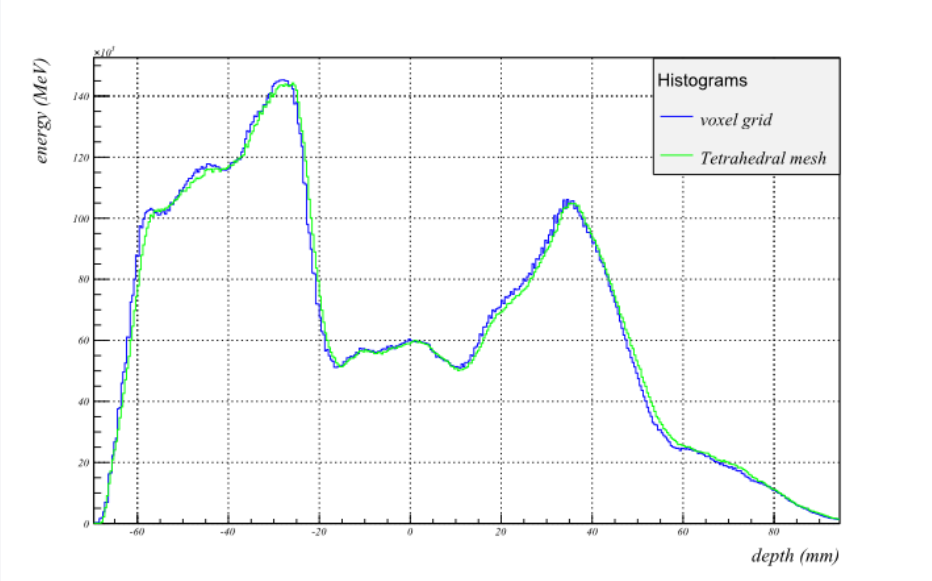
Résultats: distribution de dose et d'énergie en statique

Modèle voxélique



Modèle tétraédrique

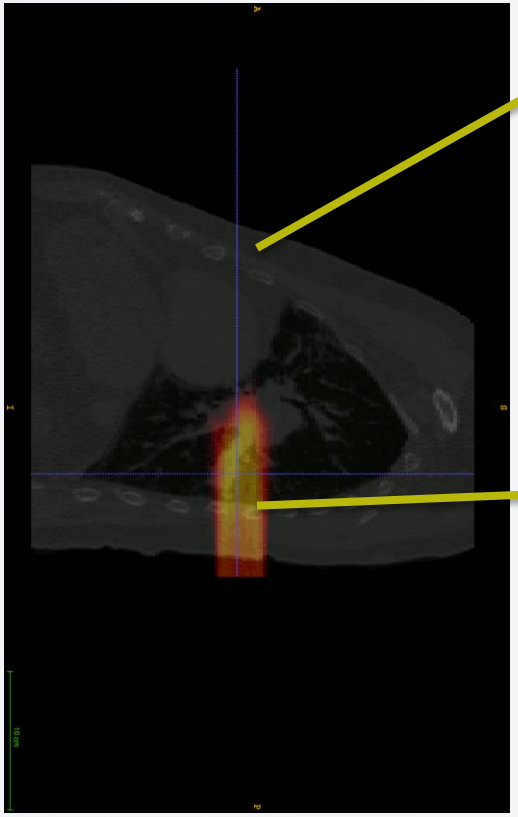


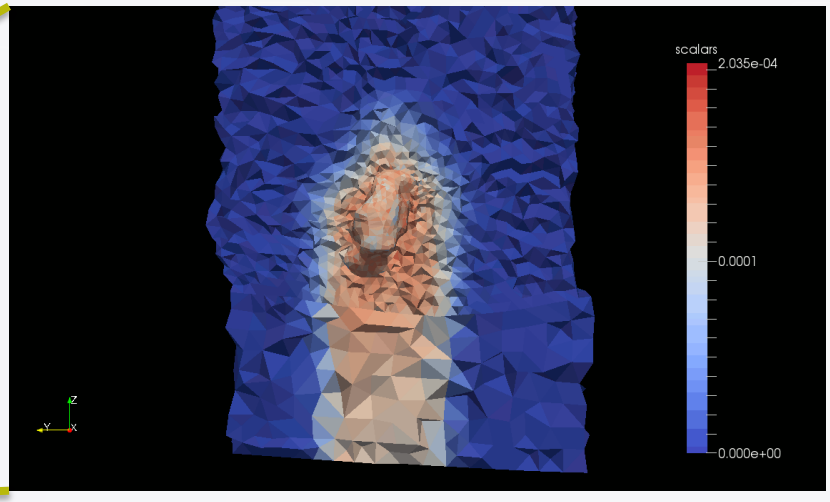


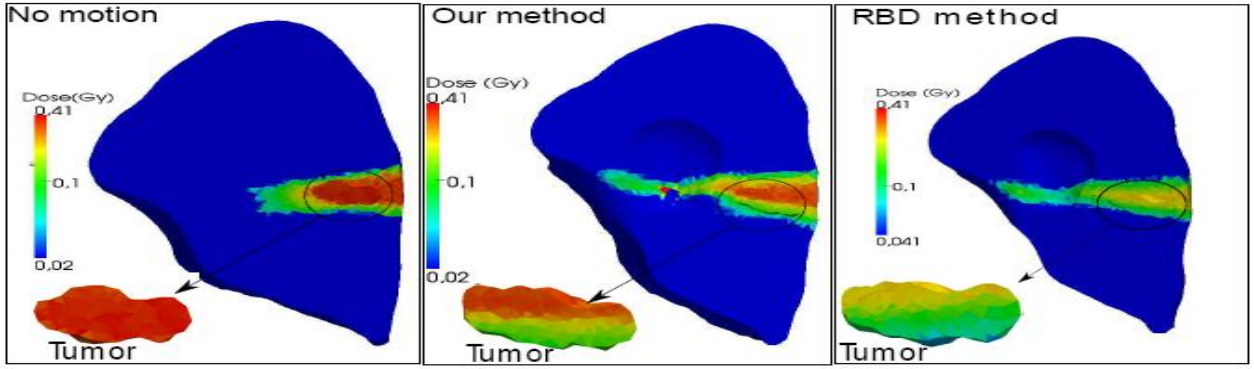
Profil de densité en profondeur

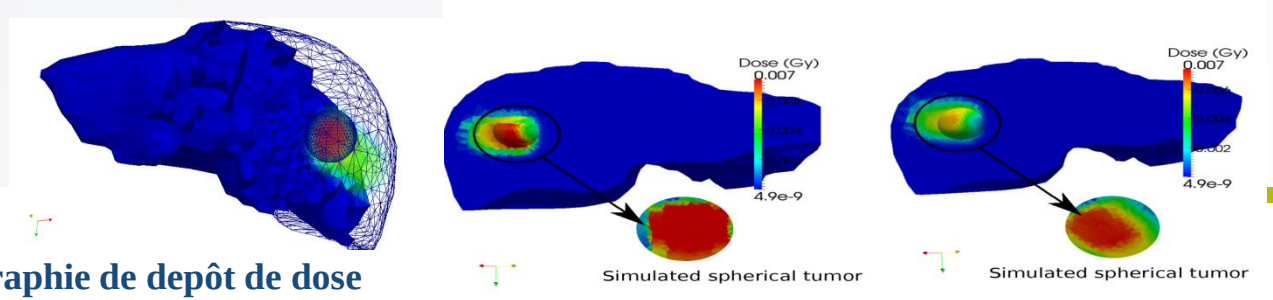
Distribution de dose 4D

Résultats





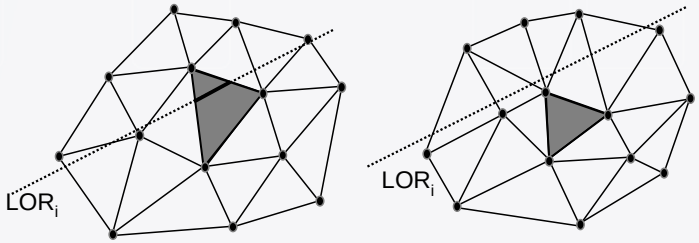




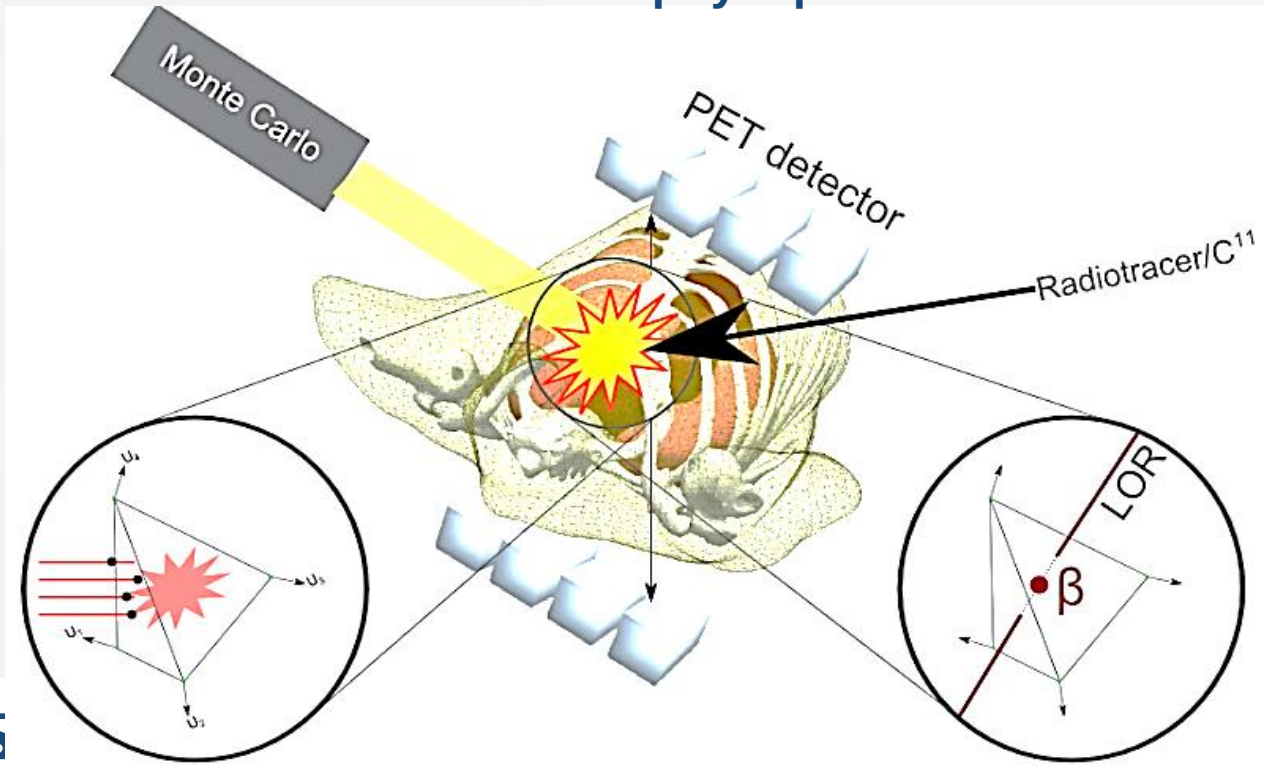
Carthographie de depôt de dose

Reconstruction des images PET-4D

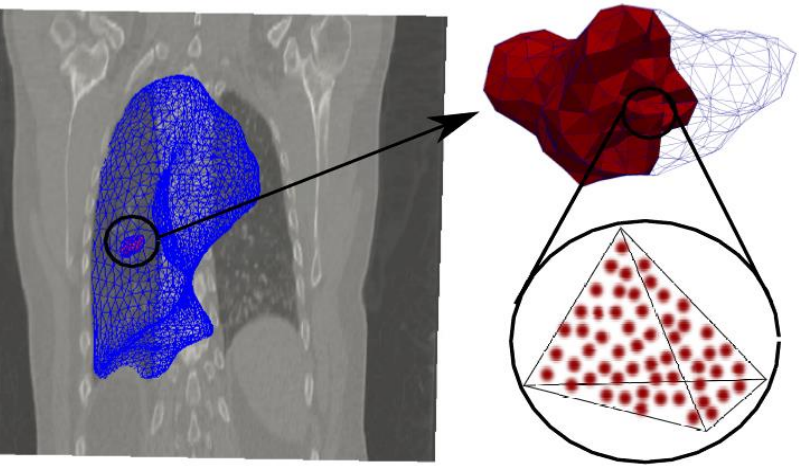
- Suivi implicite des tissues
- Prise en compte de la variation de volume



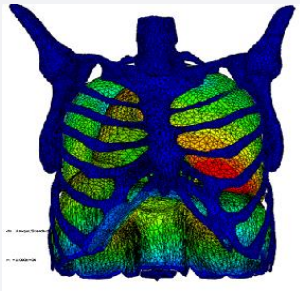
Modèle multi-physique

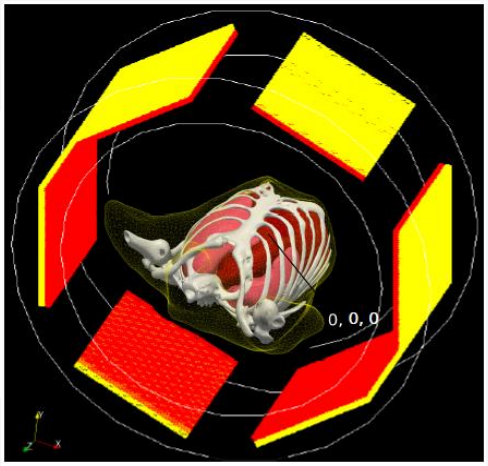


4D PET Scan reconstruction: Patient specific

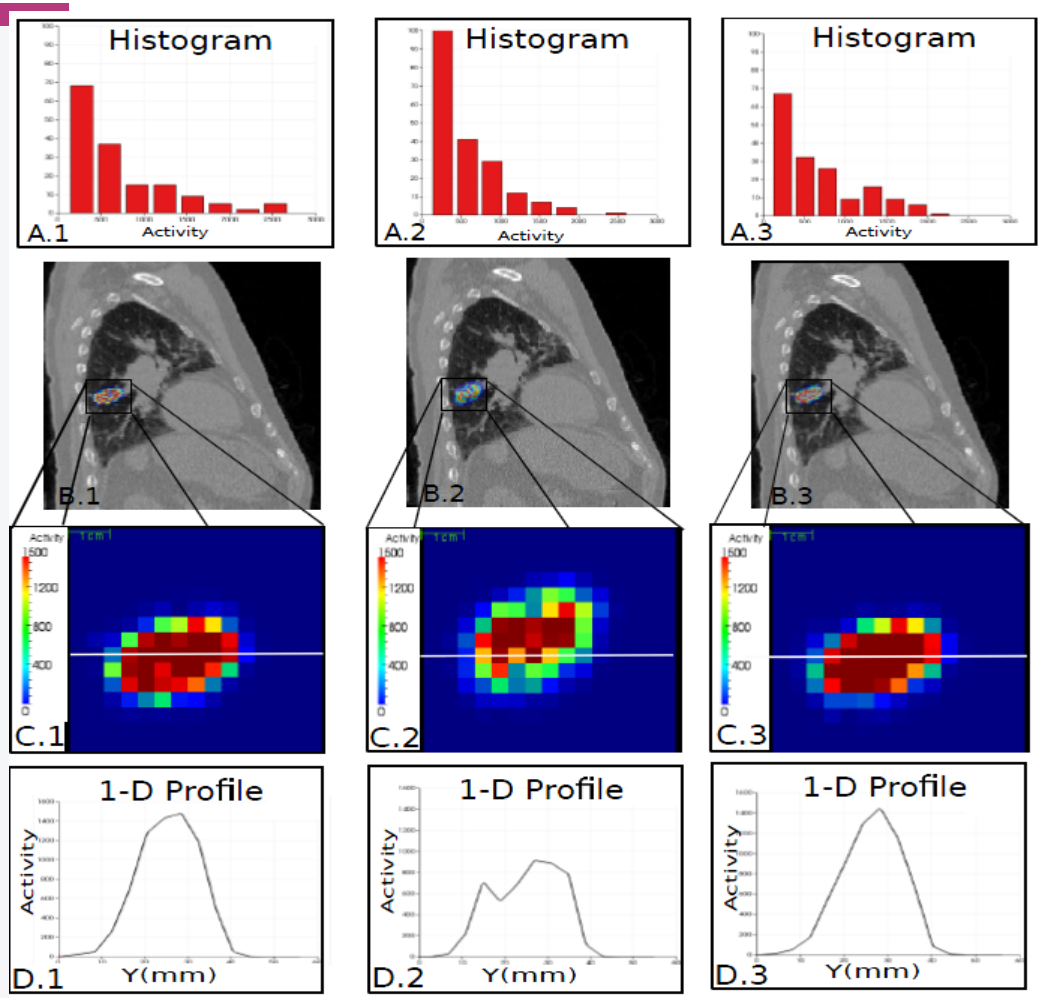


Maillage tétraédrique





Monte Carlo Simulation



Recontruction4D

PMD 2015, IEEE ISBI 2016

Conclusion et perspectives

Fantôme physique anthropomorphe genre LUCAS (PSI) équipé d'une pompe pseudo aléatoire pour reproduire la respiration.

Conclusion et perspectives

- Confrontation expérimentale du dépôt de dose dans le fantôme physique, avec les résultats obtenus par nos algorithmes de simulation

- Expérimenter plusieurs types respiration et leur impact sur la distribution de dose
- Valider nos algorithmes de reconstruction d'imagerie TEP pour les organes mobiles

- Contribuer à l'intégration du mouvement dans la reconstruction d'imagerie Gamma-Prompt

- Mettre en place une boucle fermée du suivi du mouvement par des repères externes croisé avec les différentes modalités d'imagerie de contrôle

Merci pour votre attention

Thanks for all team

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Michael Beuve, Philippe Giraud and Behzad Shariat