4D signal processing for lung cancer treatment by radiotherapy

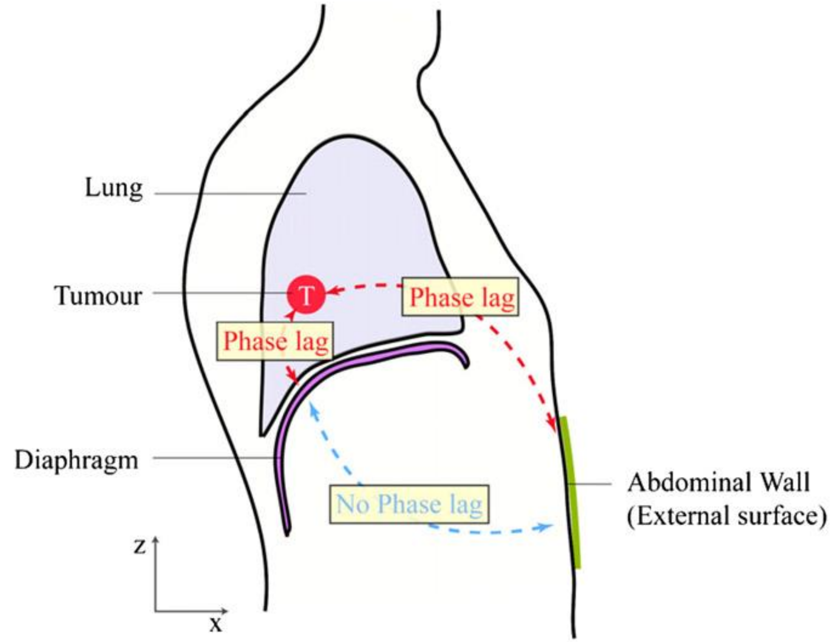
Nicolas Gallego-Ortiz

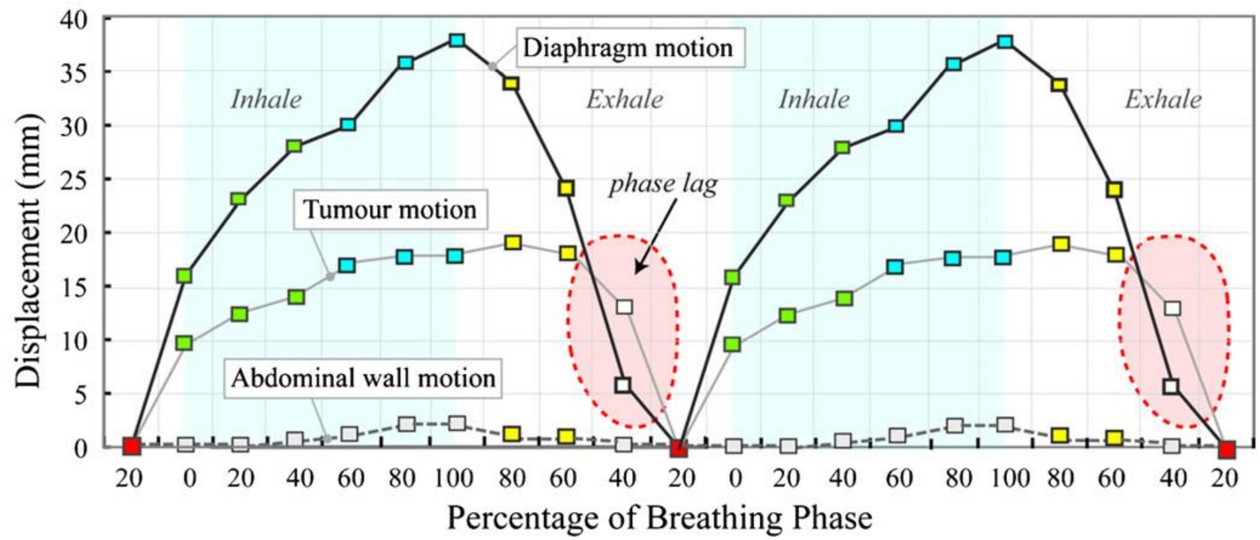
Respiratory motion

- Breath in, breath out
- What moves and how does it moves?

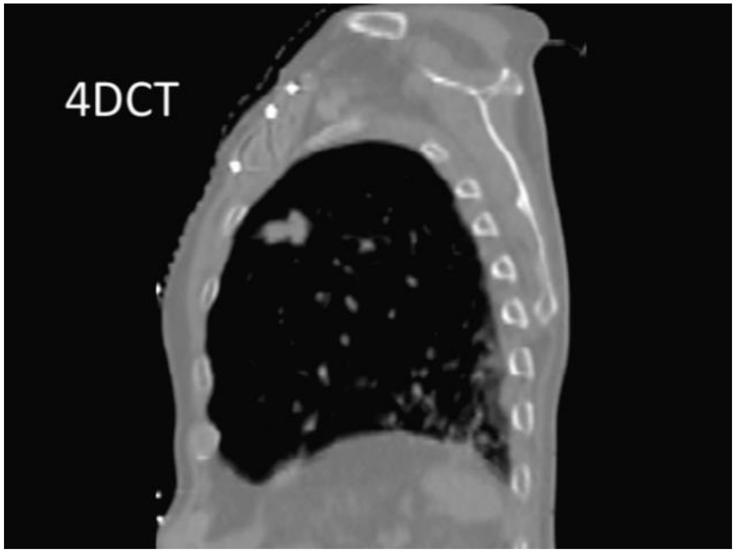
Respiration dynamic relations

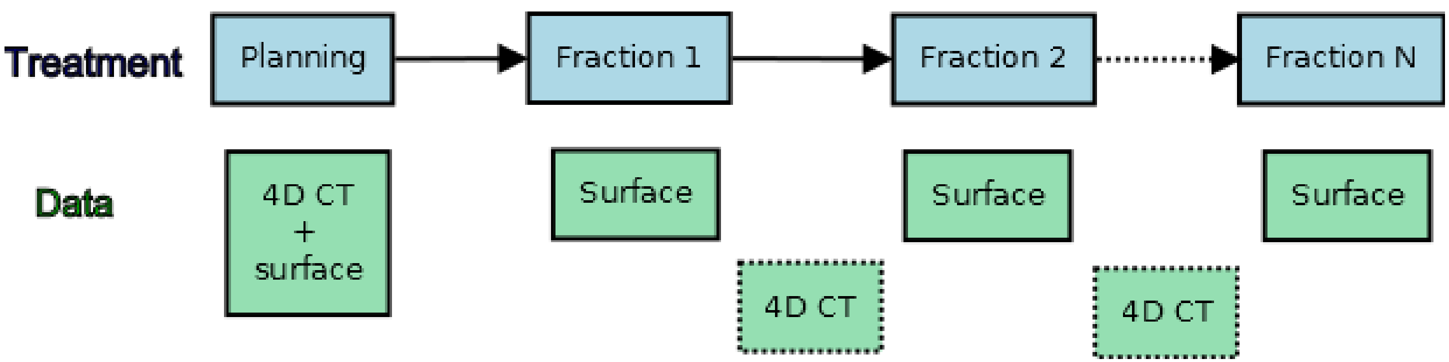
Kyriakou et al.
Phys. Med. Biol. **56** (2011) 2999–3013





Treatment: patient setup critical





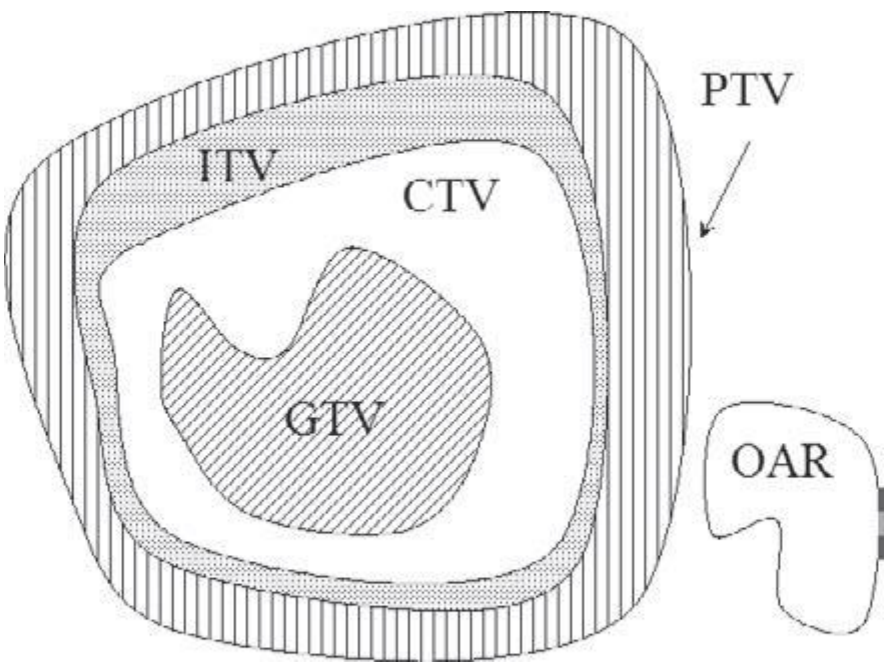
4D CT: four dimensional computed tomography

Agenda

- Why respiratory motion in RT?
- Imaging technologies
- Tumor and lungs motion modeling
  - Finite Element Method
  - Deformable Image Registration

Why study respiratory motion?

- Correct for image artefacts
- To reduce tumor position **uncertainty margins**



GTV Gross Tumor Volume
CTV Clinical Target Volume
ITV Internal Target Volume
PTV Planning Target Volume
OAR Organ At Risk

E.B. Podgorsak
RADIATION ONCOLOGY PHYSICS.
Vienna : International Atomic Energy Agency, 2005. Ch 7 p 220

Variations

- **Intra-fraction variations**
  - Short time changes in a regular respiratory pattern
  - Coaching to keep respiration regular
- **Interfraction variations**
  - Day to day changes. Organ fillings, weight loss / gain etc. Changes in respiratory pattern from one day to the other
- Constraints to have real-time tumor tracking
  - Need to model

Agenda

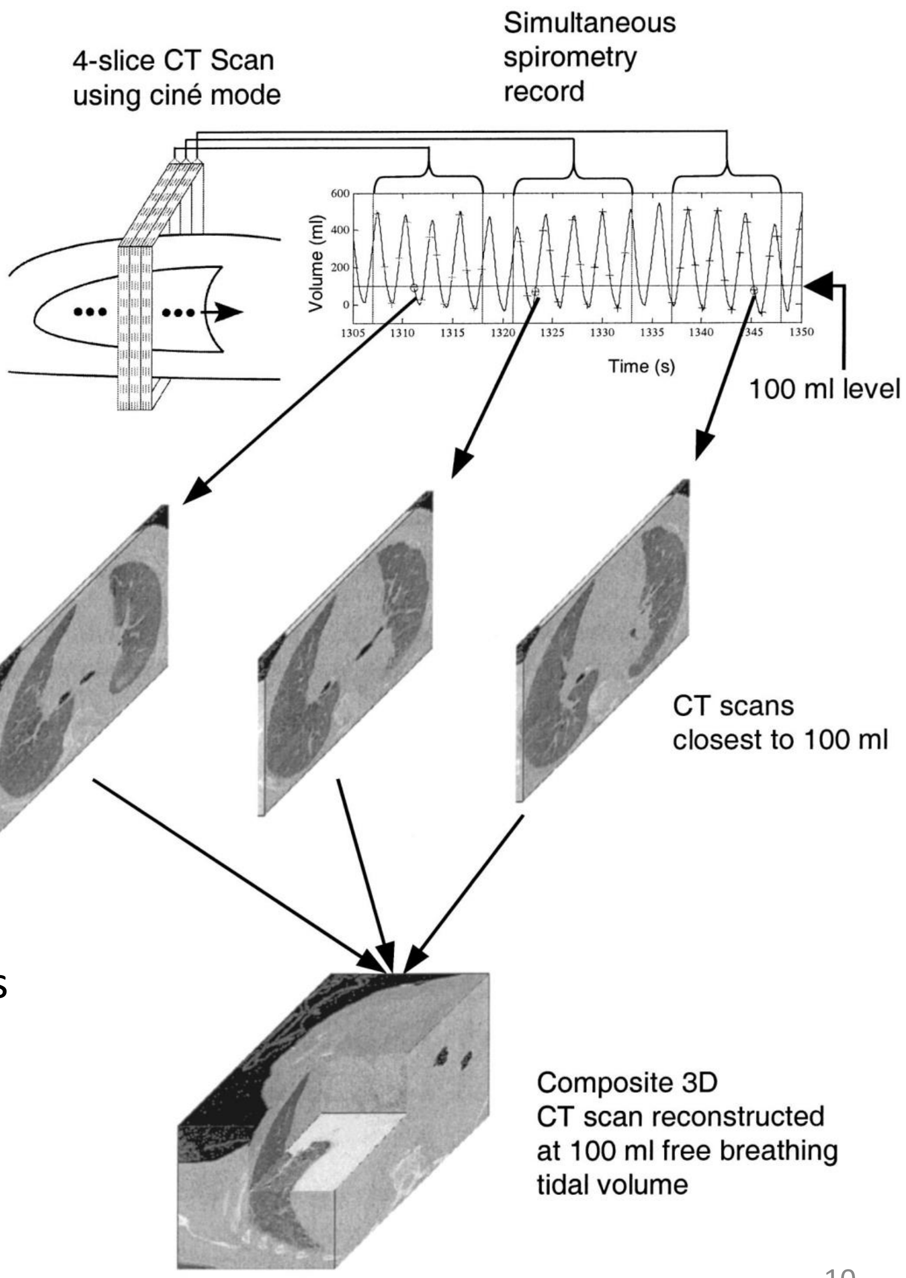
- Why respiratory motion in RT?
- **Imaging technologies**
- Tumor and lungs motion modeling
  - Finite Element Method
  - Deformable Image Registration

Imaging technologies

- Computed tomography
- **4D Computed Tomography**
- 4D Magnetic Resonance
- … multimodality solutions with flouroscopy, Cone-beam CT.
- **Optical surface scanning technologies**

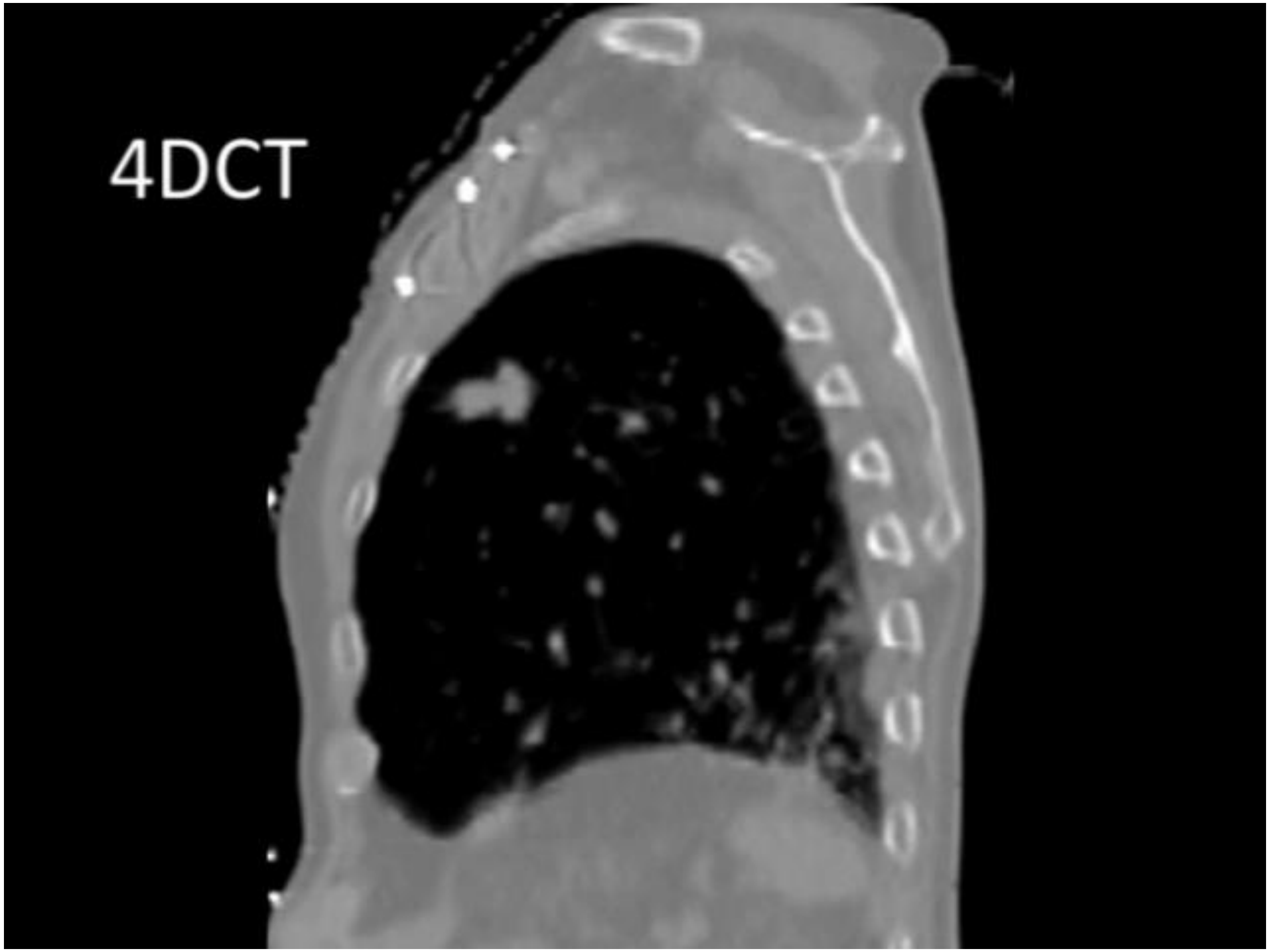
Concept of 4D CT

- (3D + t) Computed Tomography



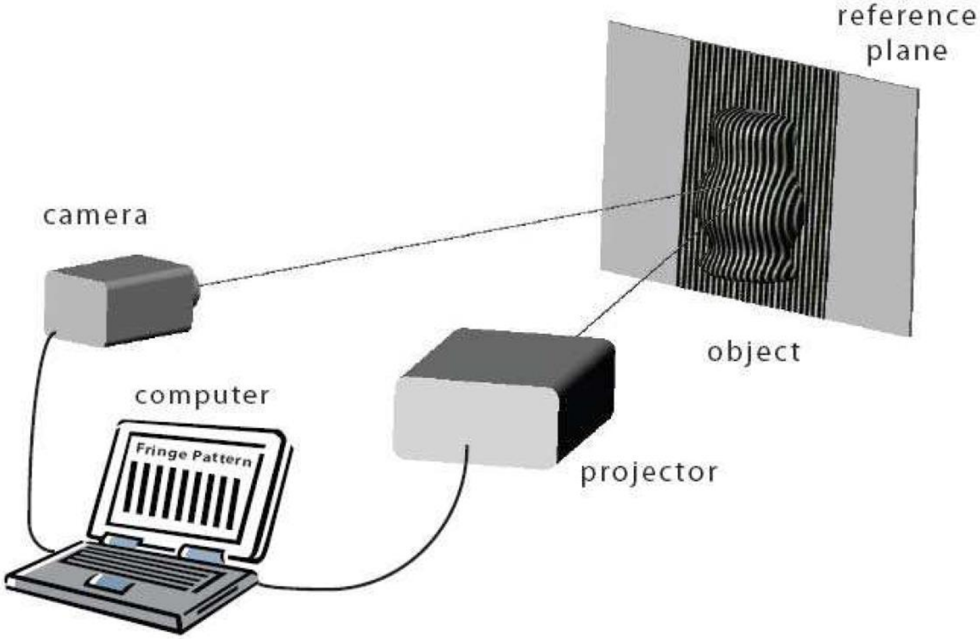
Low et al.: Breathing motion measurements
Medical Physics, Vol. 30, No. 6, June 2003

A sagittal slice of a lung tumor in motion

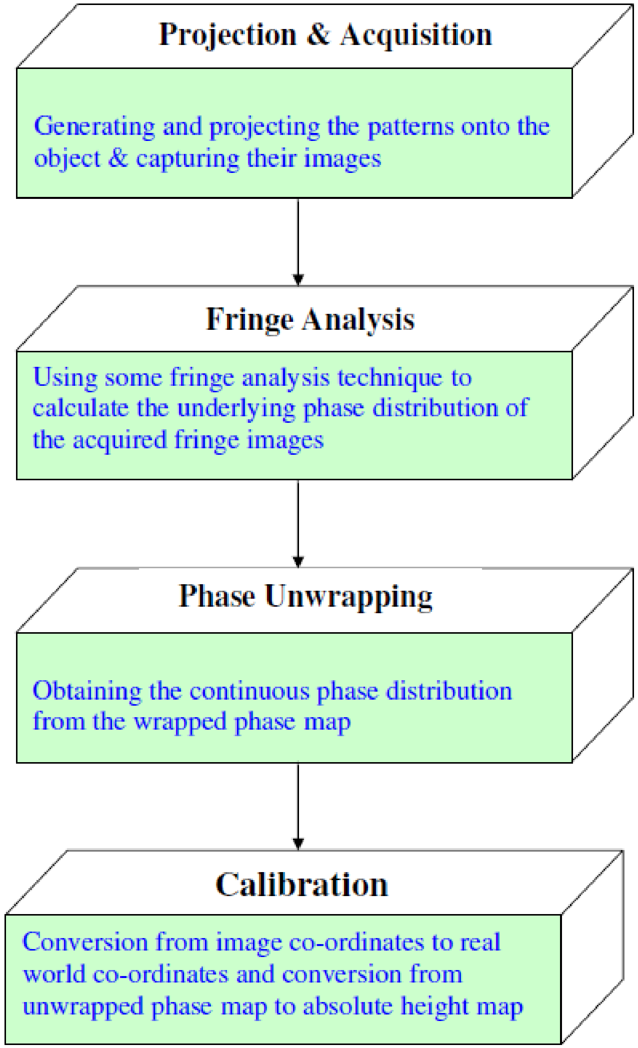


4DCT

Optical surface technologies



Gorthi, S. S. and Rastogi,
P. Optics and Lasers in Enginering, 48(2):133-140, 2010.



Agenda

- Why respiratory motion in RT?
- Imaging technologies
- **Tumor and lungs motion modeling**
  - Finite Element Method
  - Deformable Image Registration

Lung and tumor motion modeling

- Biophysical models
- Deformable registration (data-driven)
  - Internal deformations related to surface
  - Surface deformation -> motion field

Agenda

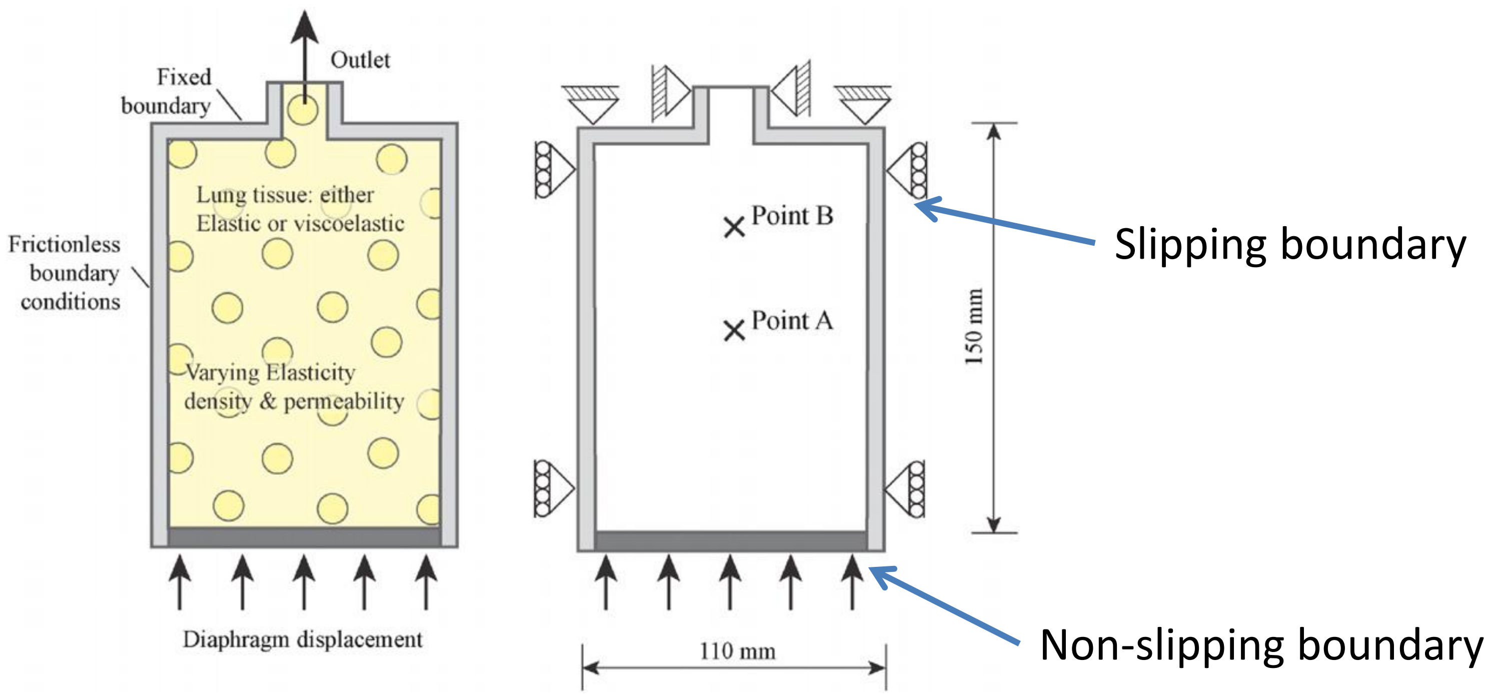
- Why respiratory motion in RT?
- Imaging technologies
- Tumor and lungs motion modeling
  - **Finite Element Method**
  - Deformable Image Registration

What is Finite Element Method?

- Numerical method
- Solve boundary problems
- Partial differential equations
- On a discrete finite element set (discretized solution domain)

Dynamic model:
simplified geometry

Kyriakou et al.
Phys. Med. Biol. **56** (2011) 2999–3013



- Finite element model: Rectangle driven by a piston. Sinusoidal displacement profile

Dynamic model:

lung material:
hookean linear and viscoelastic

Kyriakou et al.
Phys. Med. Biol. **56** (2011) 2999–3013

Table 1. Median values for the key parameters of the model.

Parameter	Value	Reference
Permeability	1.3×10^{-9} m^2	West (2005)
Elasticity	2000 Pa	Fung *et al* (1985)
Density	200 kg	West (2005)

Variations
Explore effects

Resistence flow of air

$$R = \frac{P_{\text{alveolar}} - P_{\text{atm}}}{Q}$$

pressures

flow

Dynamic viscosity

Permeability of medium

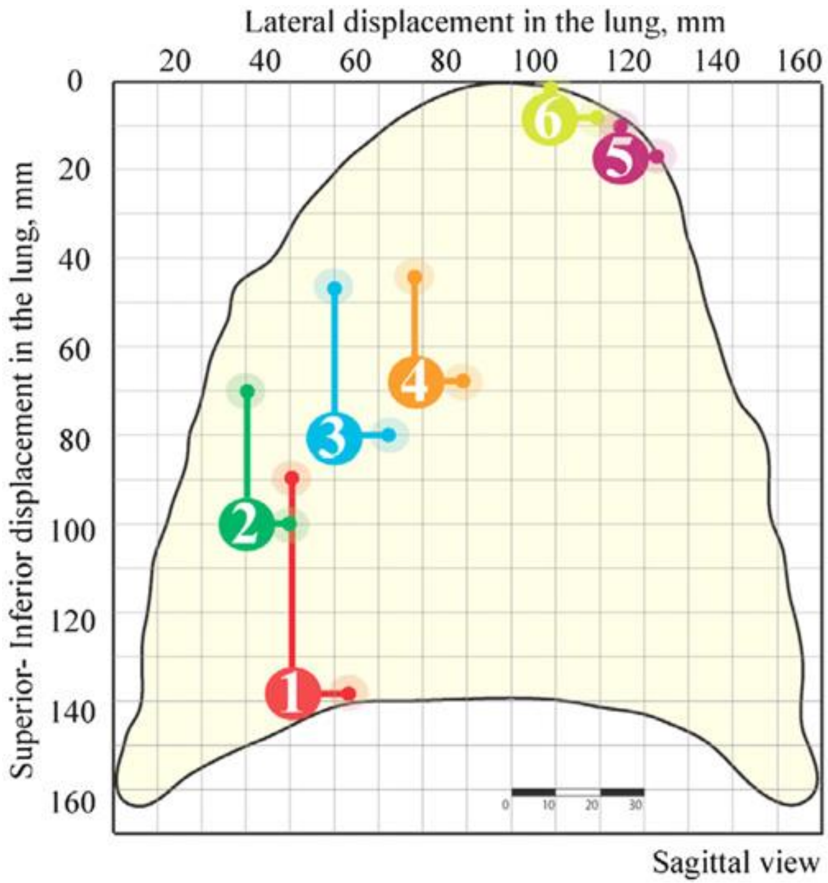
$$\kappa = \frac{Q\mu L}{A(P_{\text{alveolar}} - P_{\text{atm}})} = \frac{Q\mu L}{ARQ} = \frac{\mu L}{AR}$$

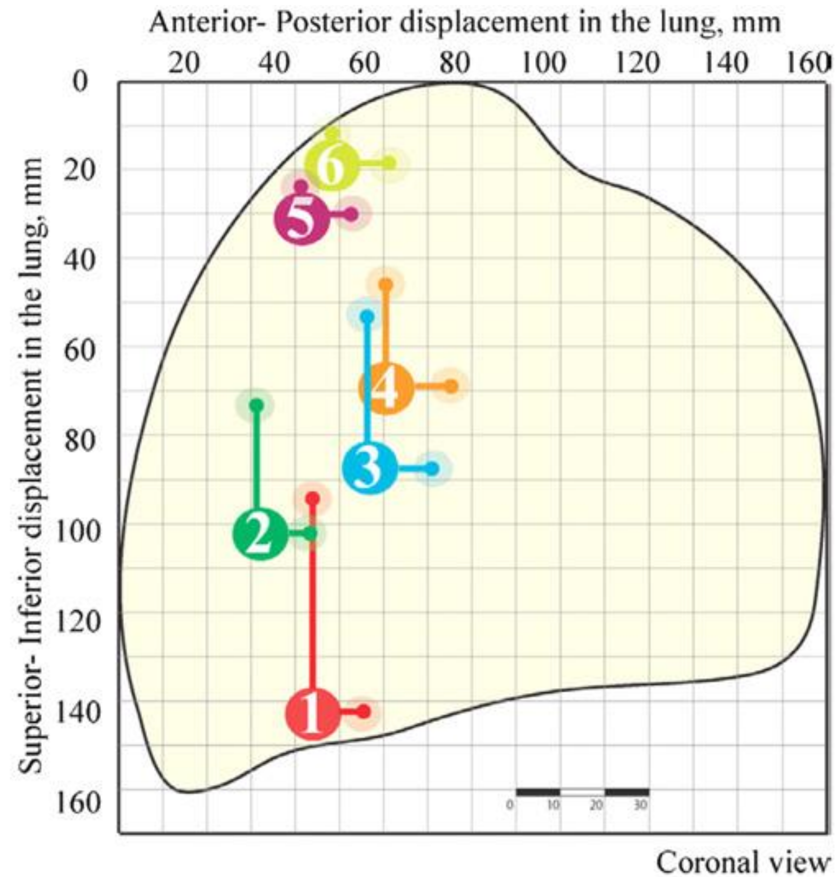
Area, length

ADINA (commercial software for Automatic Dynamic Incremental Nonlinear Analysis).

Dynamic model:
Assessment: 4DCT data

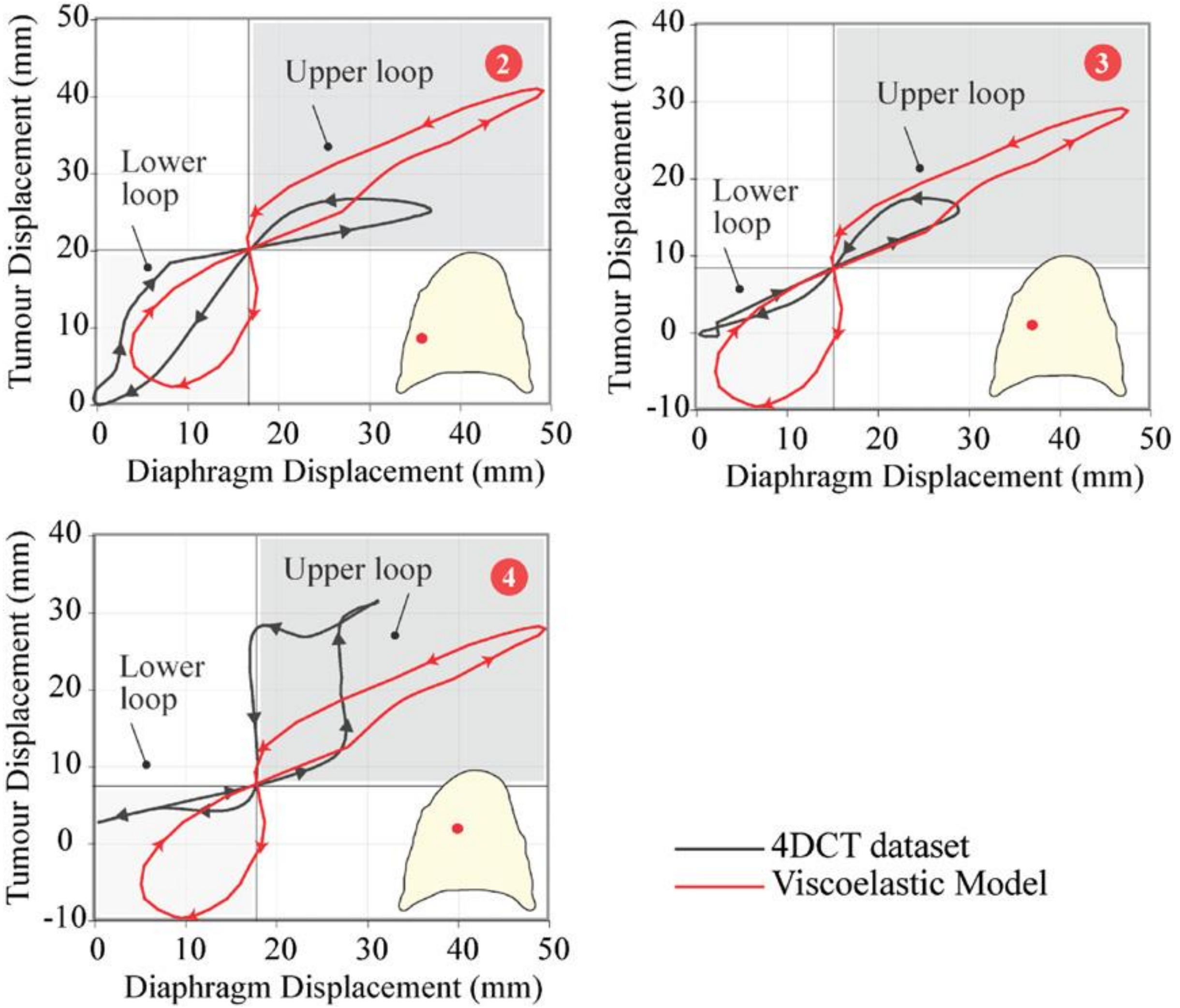
Kyriakou et al.
Phys. Med. Biol. **56** (2011) 2999–3013





Dynamic model:
Parameters tunning

Kyriakou et al.
Phys. Med. Biol. **56** (2011) 2999–3013

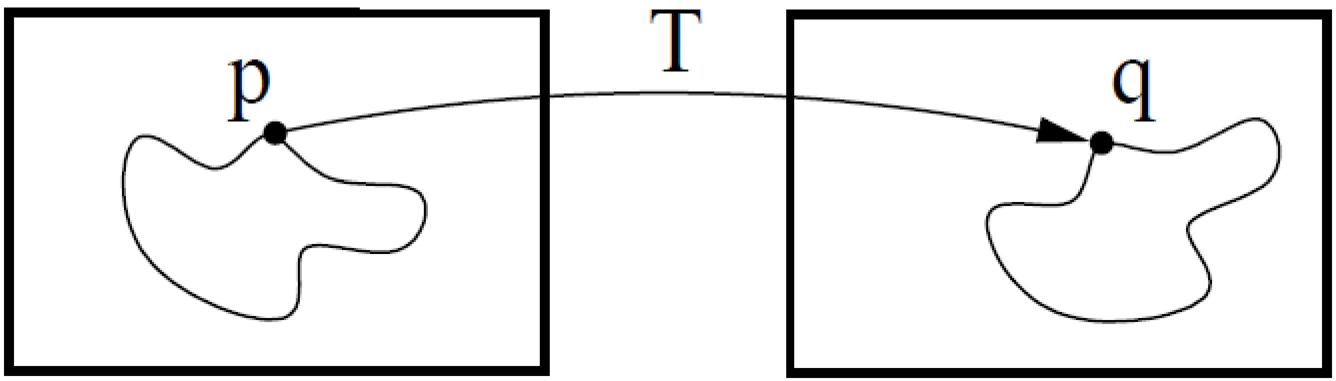


Agenda

- Why respiratory motion in RT?
- Imaging technologies
- Tumor and lungs motion modeling
  - Finite Element Method
  - **Deformable Image Registration**

What is image registration?

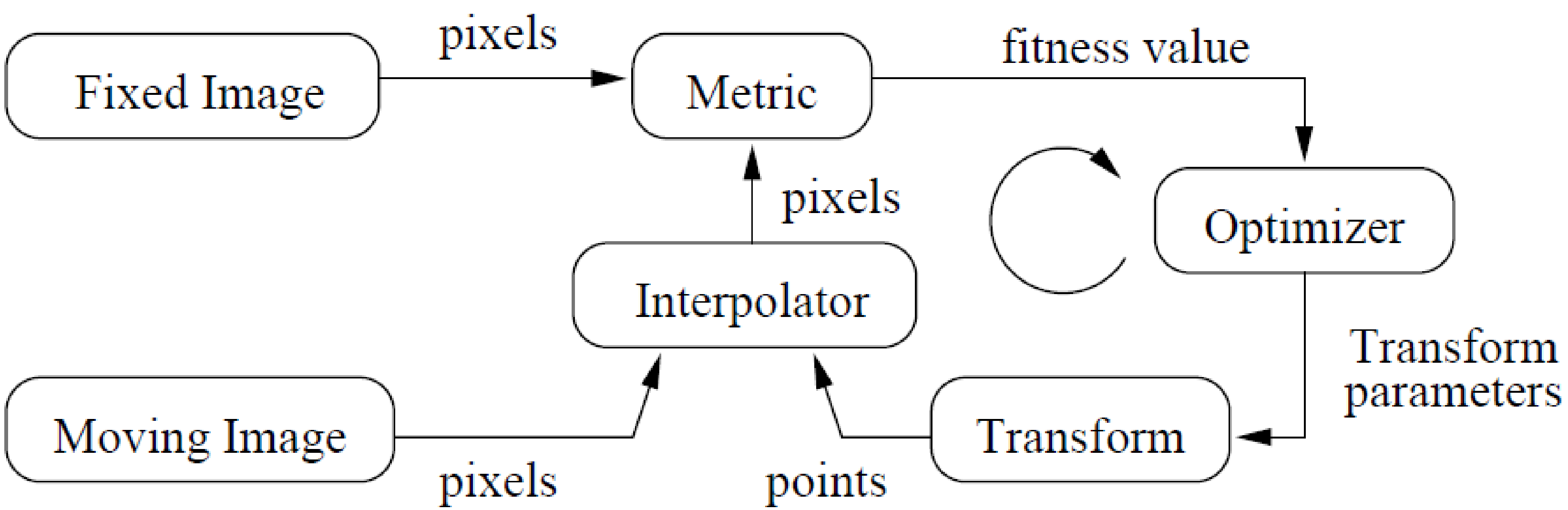
http://www.itk.org/ItkSoftwareGuide.pdf



How does it work?

http://www.itk.org/ItkSoftwareGuide.pdf

Image Registration

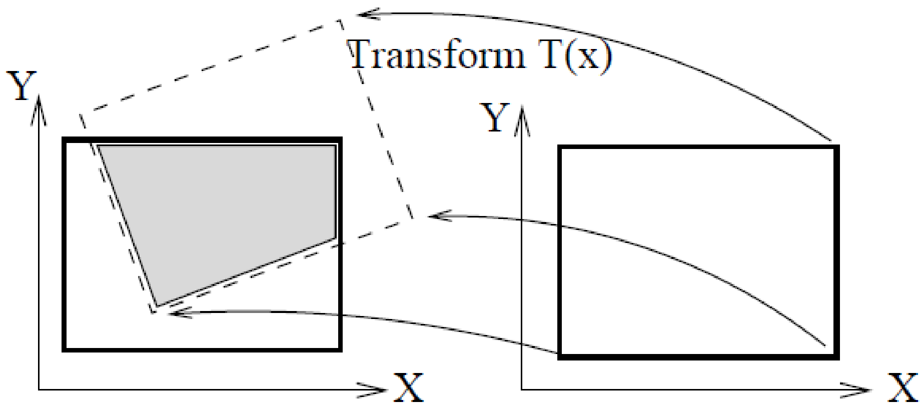


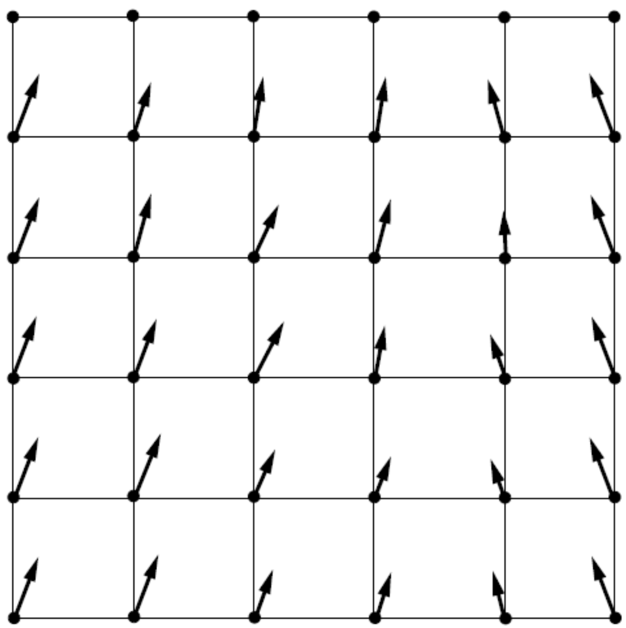
What is de difference between?

http://www.itk.org/ItkSoftwareGuide.pdf

Rigid Registration

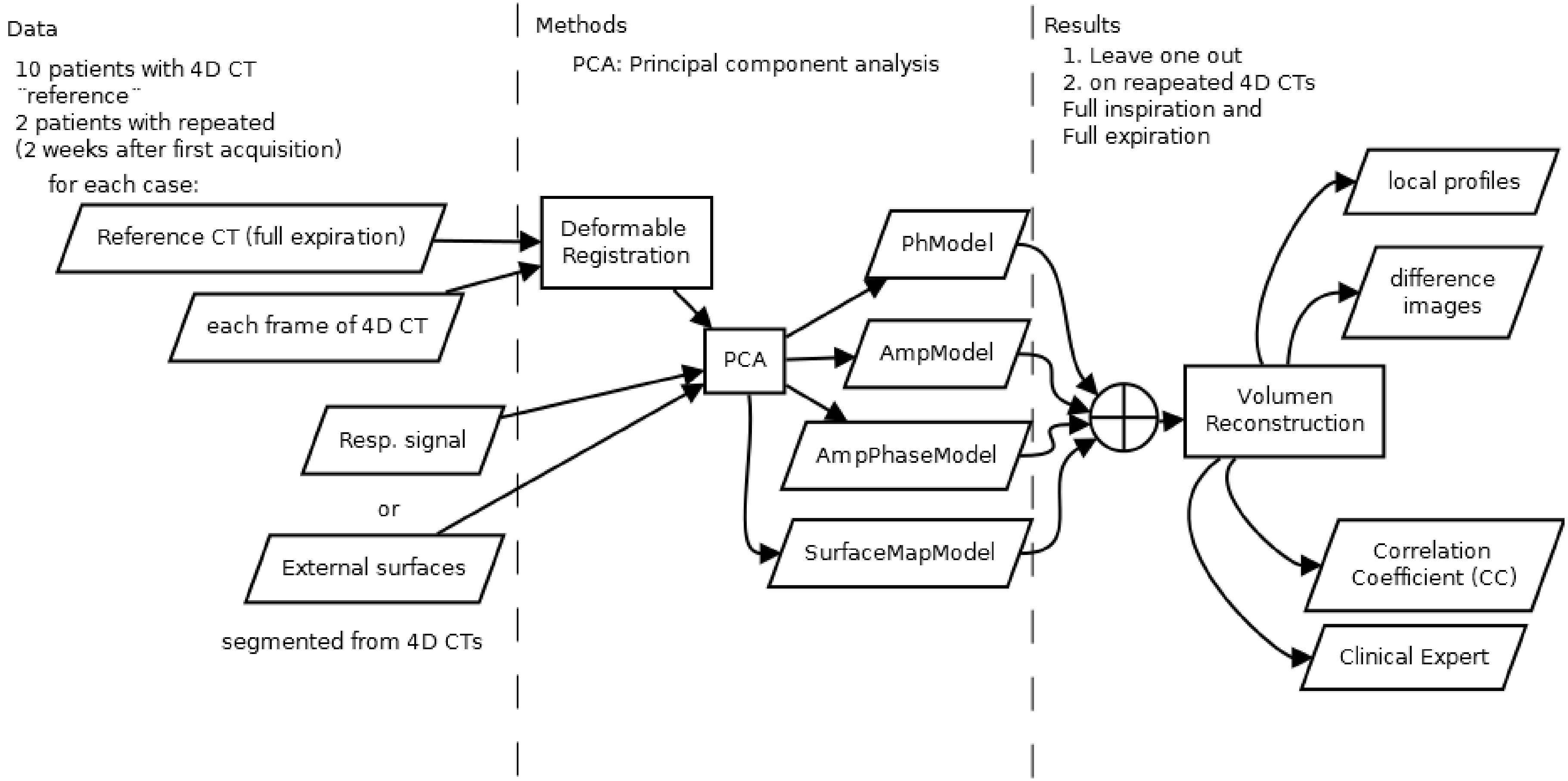
Deformable Registration?





Surface Volume Model
Deformable registration

Fayad et al.
Med. Phys. 39 (6), June 2012



Principal Component Analysis
Approximated relation surface volume

$$d_j = [u_{1,1,j}, u_{1,2,j}, u_{1,3,j}, \ldots, u_{M,3,j}, s_{1,j}, s_{2,j}, \ldots, s_{N,j}]^T, \quad (4)$$

$u_{m,i,j}$ i th displacement of Voxel m at time j

$$D = [\tilde{d}1, \ldots, \tilde{d}j, \ldots, \tilde{d}J], \quad (5)$$

$s_{n,j}$ Displacement nth Surrogate at time j

N = 1 amplitude

N = 1 phase

N = 2 ampl and phase

N = 10 (surface ROIs)

$$\bar{d} = \frac{1}{J}\sum_{j=1}^{J} d_j. \quad (6)$$

$$DD^T(DX) = D(D^T DX) = \lambda DX. \quad (7)$$

Take the K first eigen vectors

$$d(t) \approx \bar{d} + \sum_{k=1}^{K} w_k(t) e_k. \quad (8)$$

$$\tilde{d} \approx EW, \quad (9)$$

$$E = [e_1, \ldots, e_k]$$

$$W = [\ldots, w_k, \ldots]$$

$$\tilde{u} \approx E_u W$$

$$\tilde{s} \approx E_s W,$$

$$\tilde{d} = [\tilde{u}, \tilde{s}]^T$$

$$\tilde{u}(t) = E_u E_s^{-1} \tilde{s}(t) = B\tilde{s}(t), \quad (11)$$

Fayad et al.
Med. Phys. 39 (6), June 2012

Principal Component Analysis

Approximated relation surface volume

$$d_j = [u_{1,1,j}, u_{1,2,j}, u_{1,3,j}, \ldots, u_{M,3,j}, s_{1,j}, s_{2,j}, \ldots, s_{N,j}]^T, \quad (4)$$

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Displacement nth

ime j

de

d phase

e ROIs)

$\bar{d}$

D

$$\tilde{u}(t) = E_u E_s^{-1} \tilde{s}(t) = B\tilde{s}(t),$$

Take the K first eigen vectors

$$d(t) \approx \bar{d} + \sum_{k=1}^{K} w_k(t) e_k. \quad (8)$$

INTERNAL

EXTERNAL

$$\tilde{d} \approx EW, \quad (9)$$

$$E = [e_1, \ldots, e_k]$$

$$\tilde{u} \approx E_u W$$

$$\tilde{s} \approx E_s W,$$

$$W = [\ldots, w_k, \ldots]$$

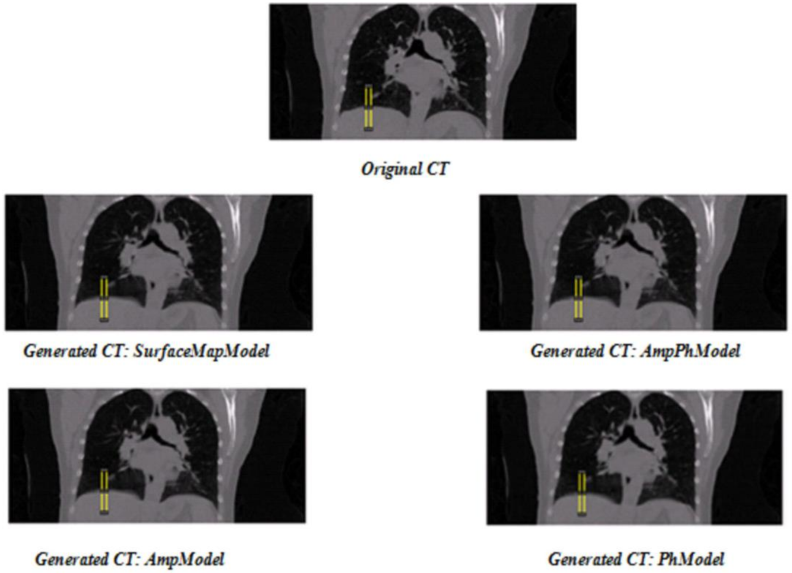
$$\tilde{d} = [\tilde{u}, \tilde{s}]^T$$

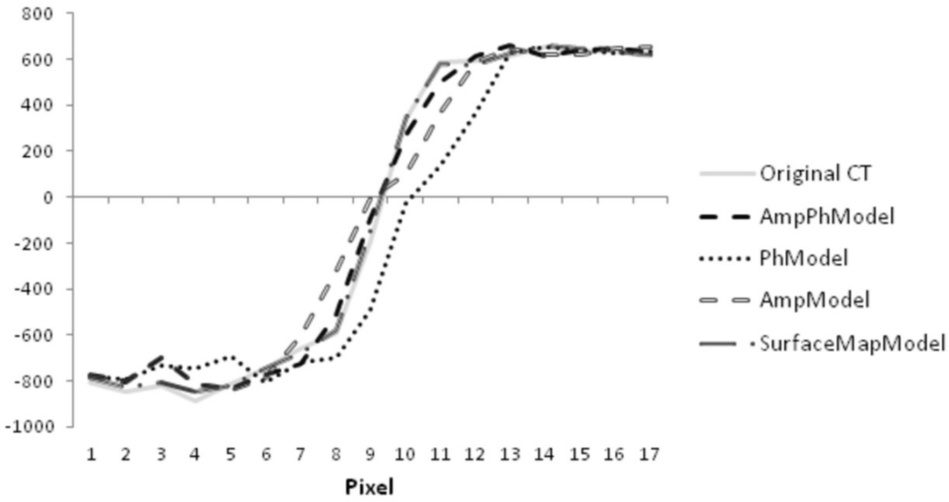
Fayad et al.
Med. Phys. 39 (6), June 2012

$$\tilde{u}(t) = E_u E_s^{-1} \tilde{s}(t) = B\tilde{s}(t), \quad (11)$$

Reconstructed volumes

Fayad et al.
Med. Phys. 39 (6), June 2012

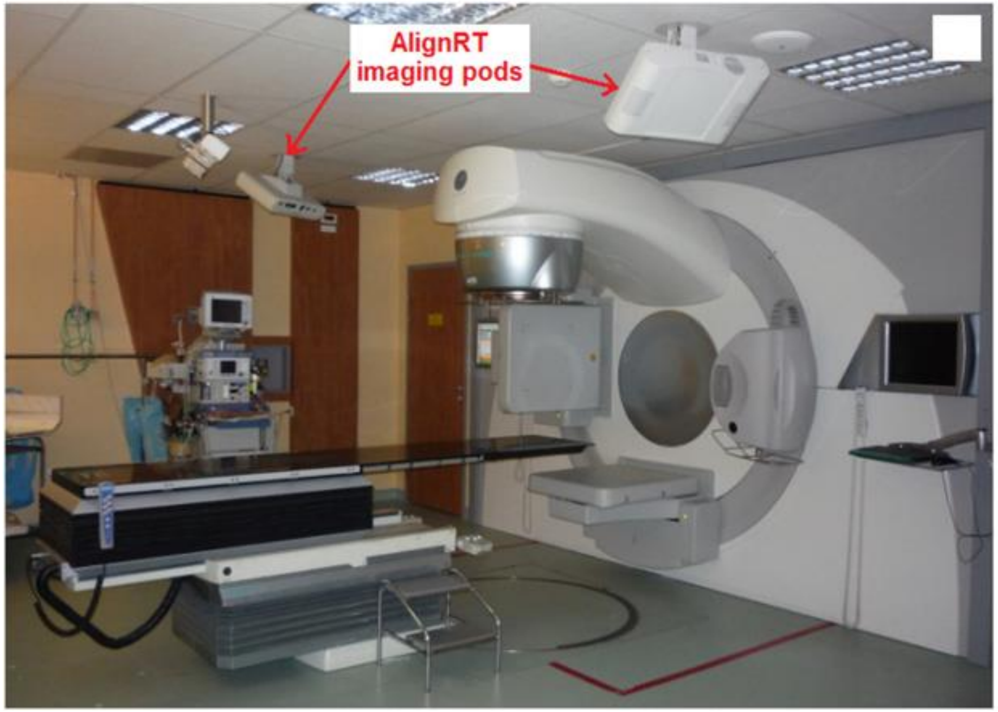


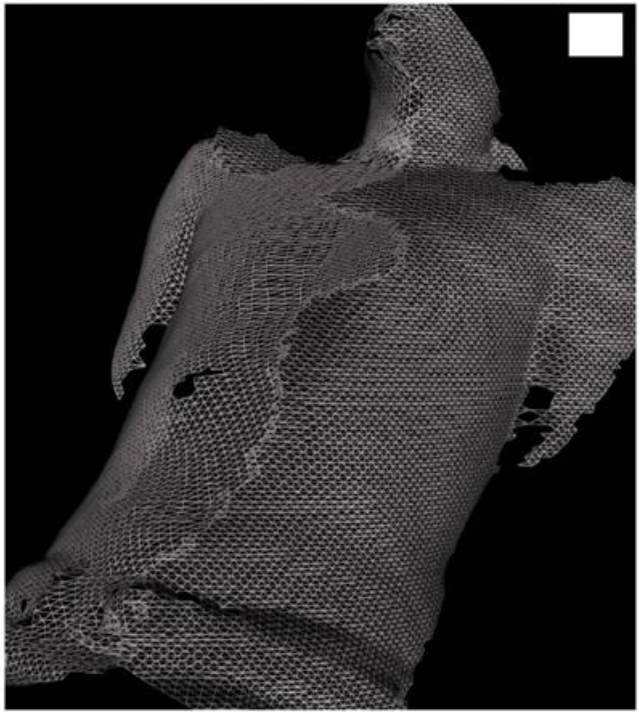


Surface + registration

Measuring respiratory patterns

J Schaerer et al.
Phys. Med. Biol. **57** (2012) 357–373





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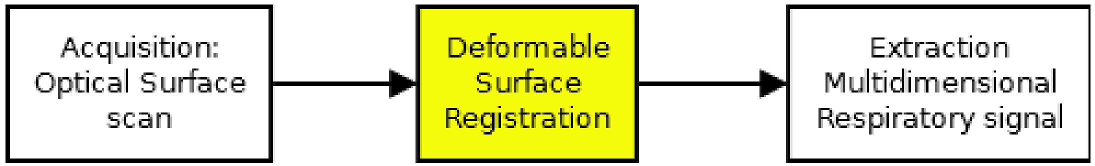

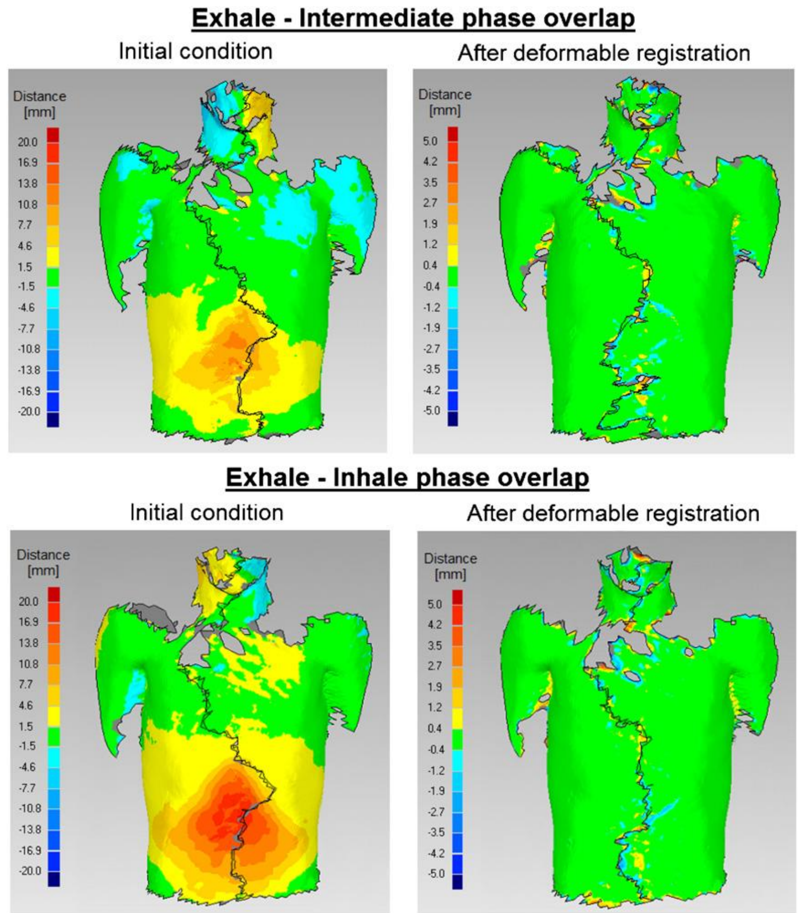

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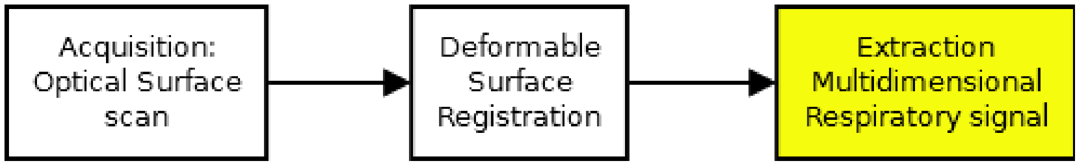

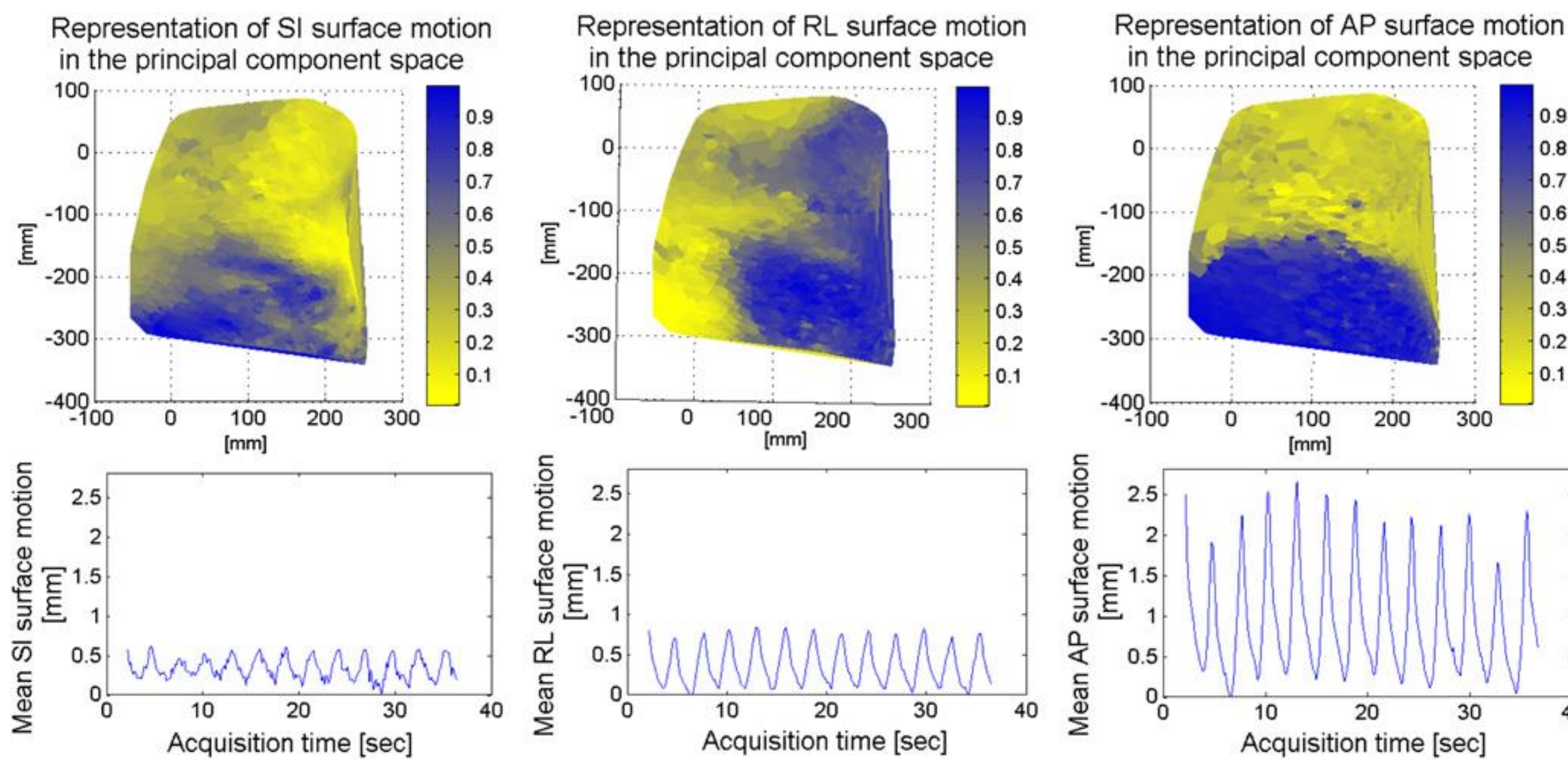

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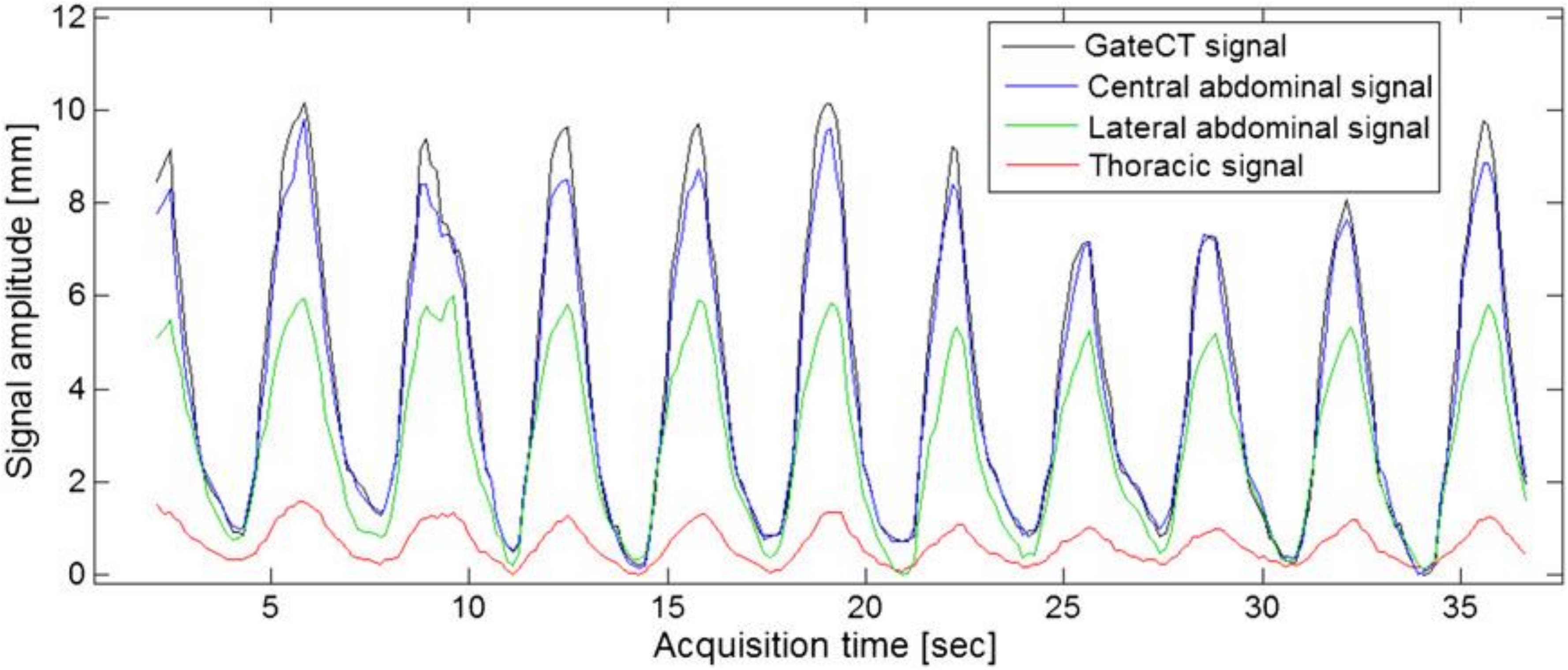

J Schaerer et al.
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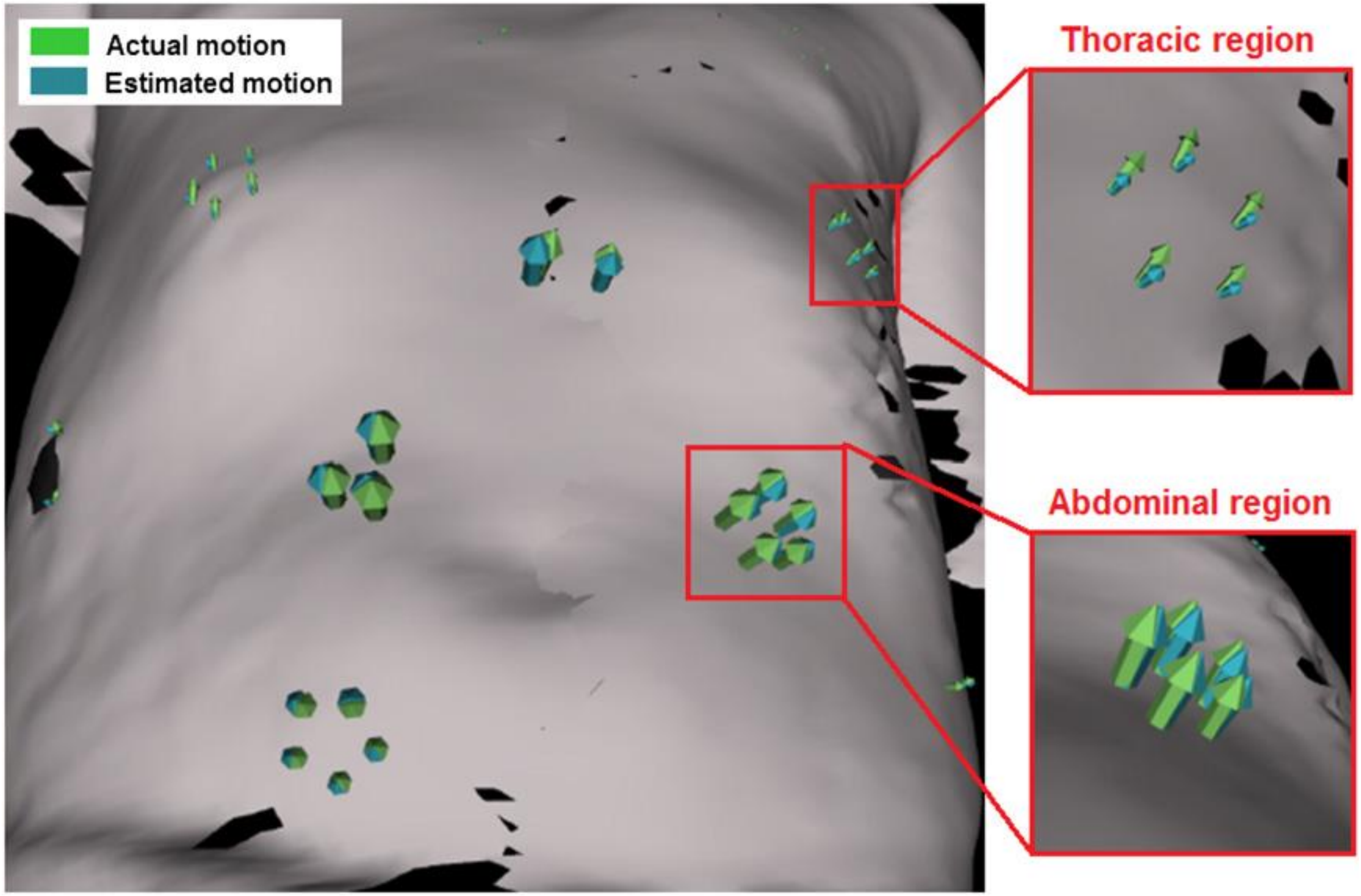
Patient surface motion



Summary

- Modeling + Simulation
  - Very simplified model approaches real tumor trajectories
- Deformable registration (motion field)
  - Typical breathing cycle motion (4D CT data)
  - Given a surfaces -> reconstruct volumen
  - Sensing + registering surfaces -> extract external motion field

Discussion

- Still no evidence that monitoring skin thoraco-abdominal area can improve tumor position estimation
  - Initial condition for tumor trajectories
  - Breaking correlation -> changes in respiratory pattern
  - Same tumor size and position DONT => same trajectory
- Will a model based on planning data hold for delivery fractions? (Time invariance)

Thank you!
What is your opinion?

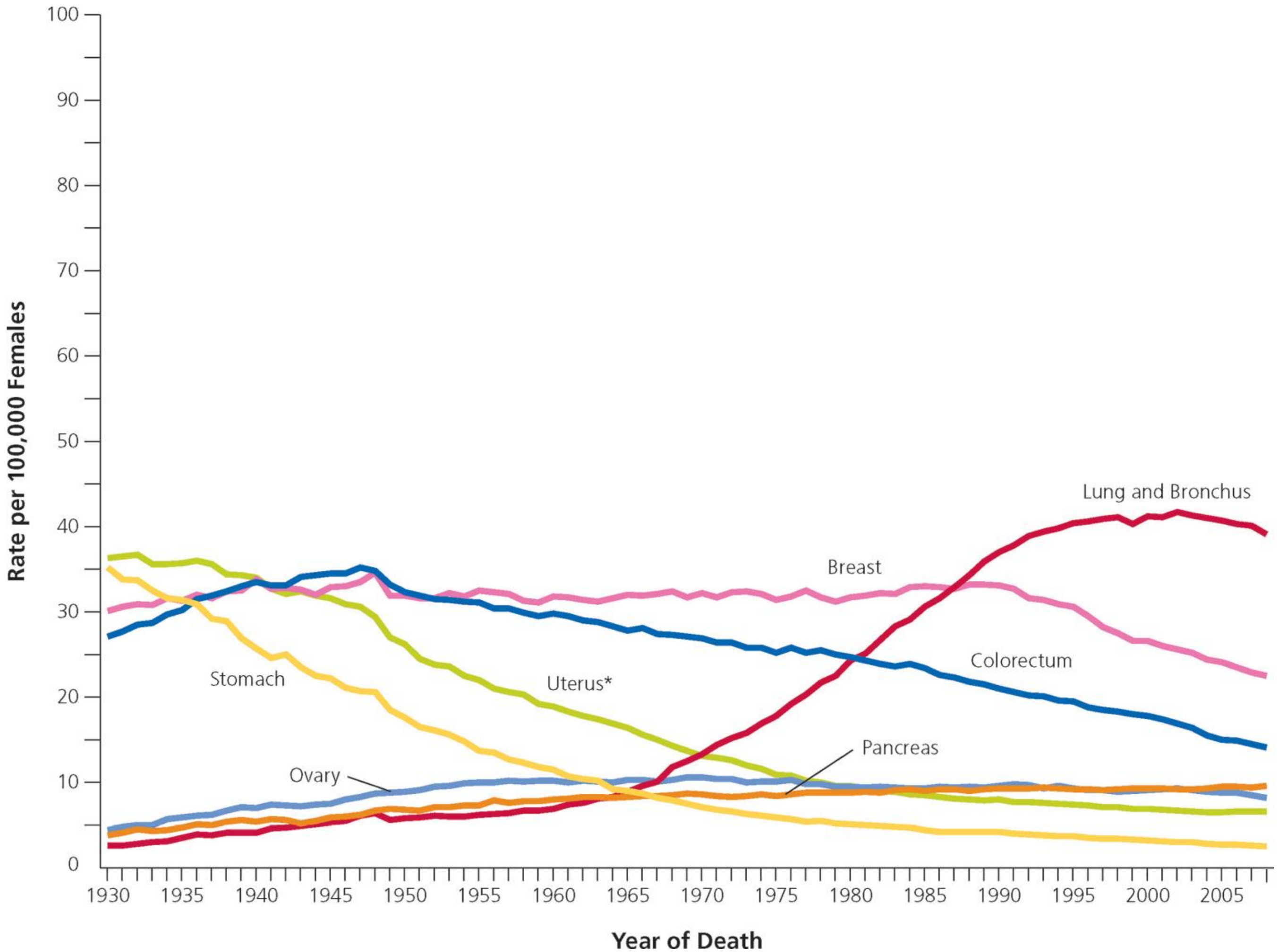
Lung cancer

- Mortality rates
- Categories
- Treatment options
- Radiotherapy
  - Margins

♀ death rates

US data 1930-2007

CA: A Cancer Journal for Clinicians
Volume 62, Issue 1, pages 10-29, 4 JAN 2012



♂ death rates

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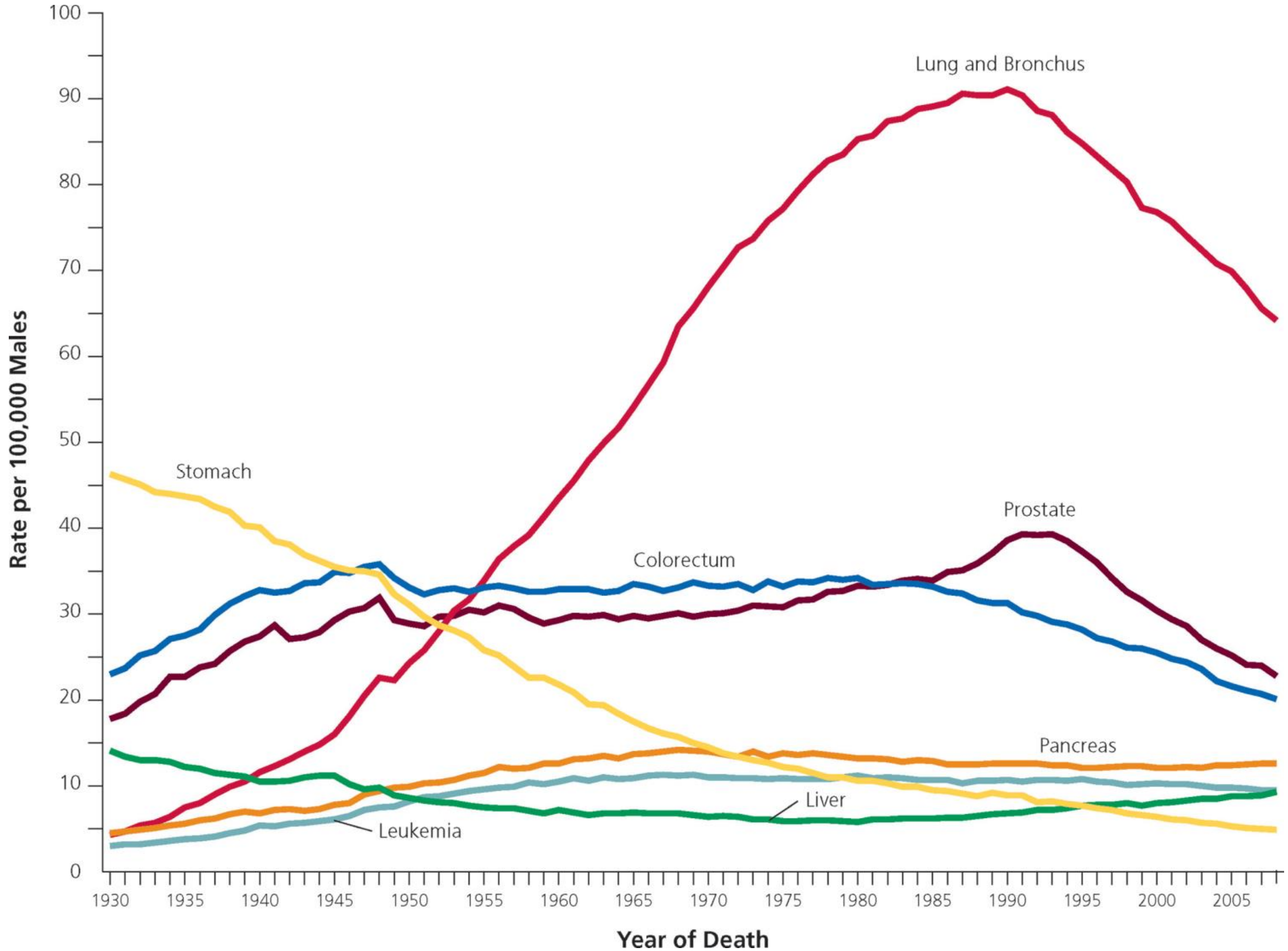


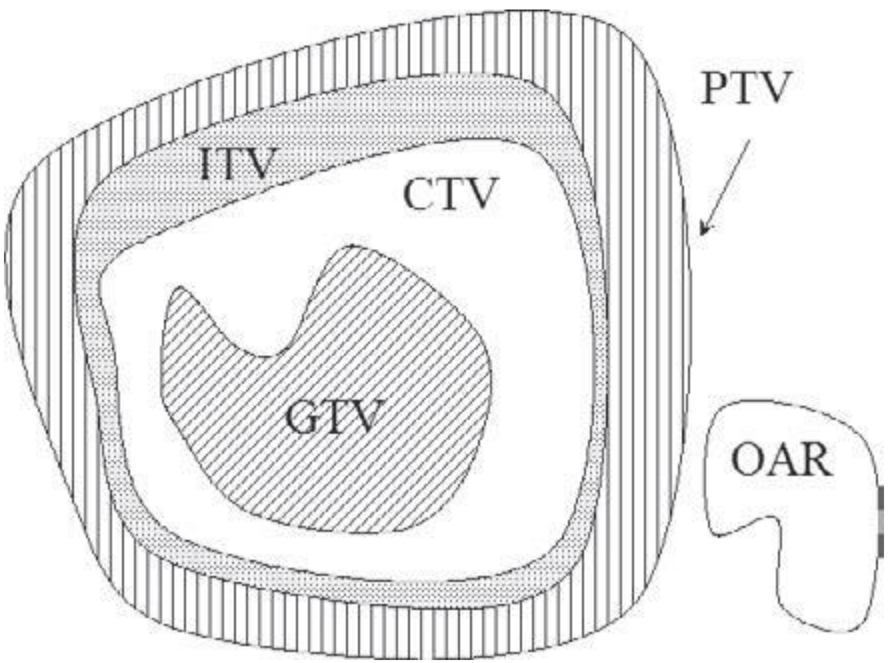
Two categories

- Small cell lung cancer (SCLC)
  - 15 – 20 % of lung cancers
  - Agressive
- Non-small cell lung cancer (NSCLC)

Patient setup

- Registration
- Surface Matching

Margins



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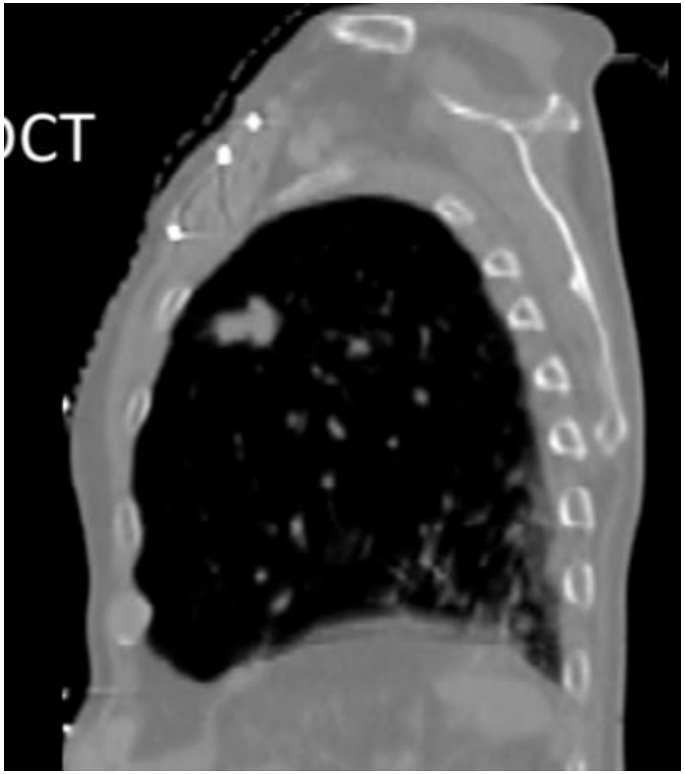
4D CT



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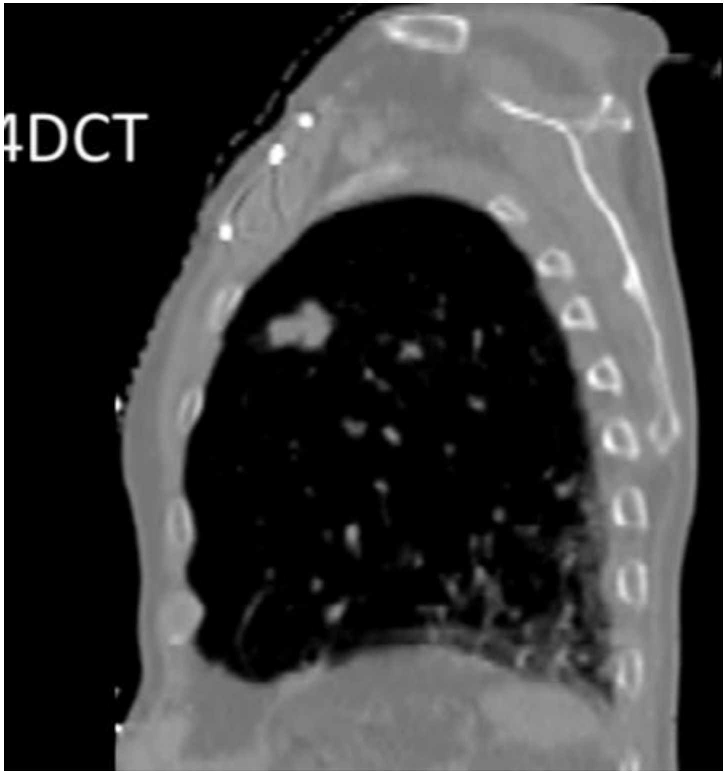

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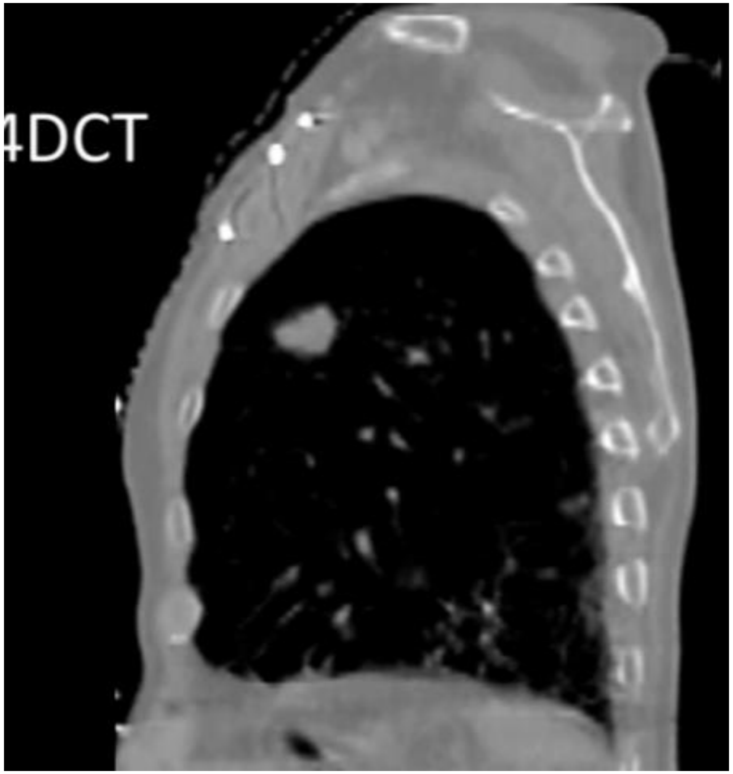

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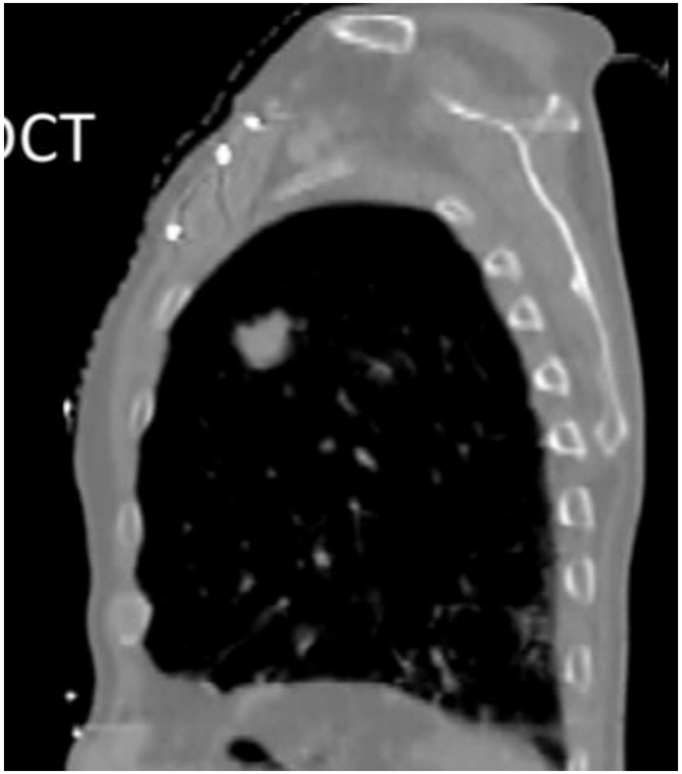

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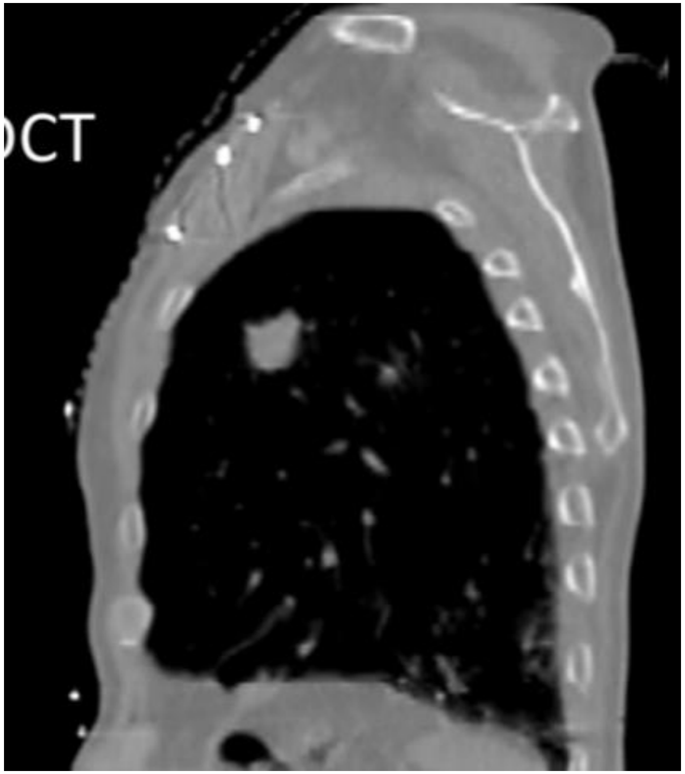

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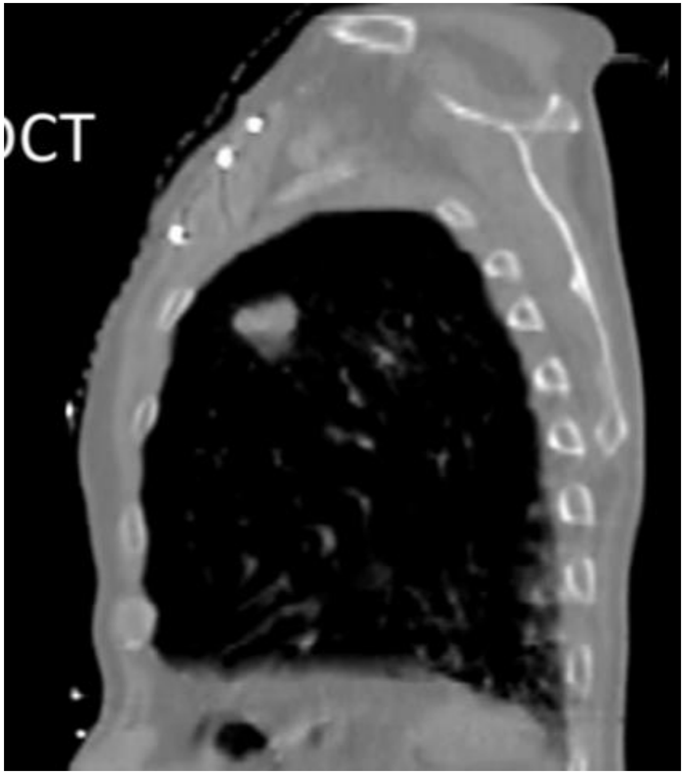

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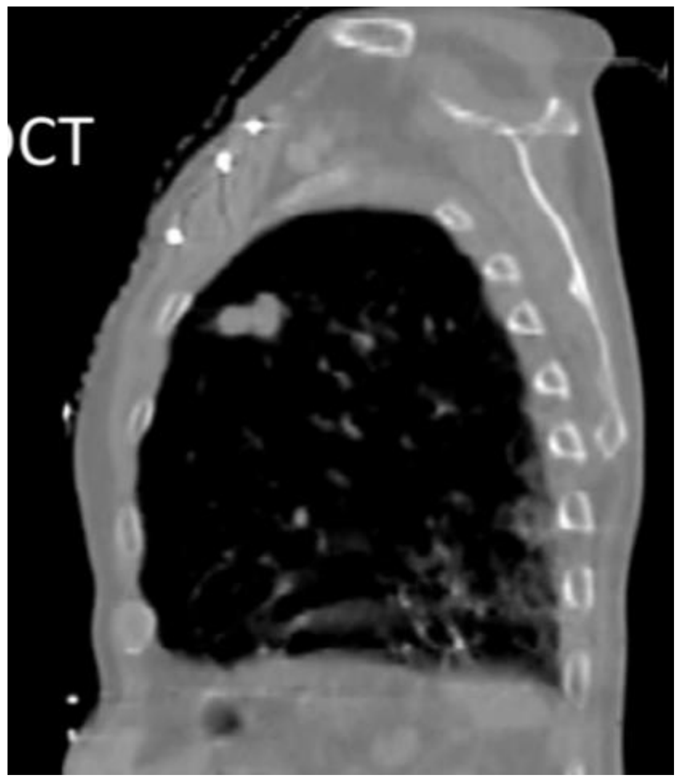
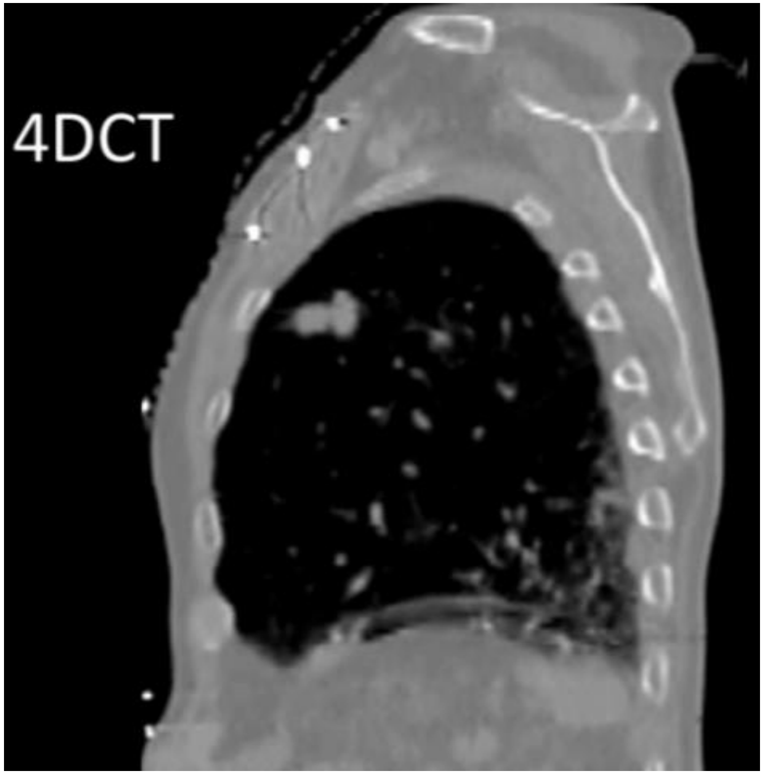


4D CT



4D CT

4D CT

[restart](#)

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