Radiation therapy

- A major cancer treatment (2/3 of patients)
- Use radiation to kill cancer cells.
  - High energy x-ray
  - Alternative with proton, carbon (in development)
- Challenge:

  deliver maximum dose to target, while sparing healthy surrounding tissue

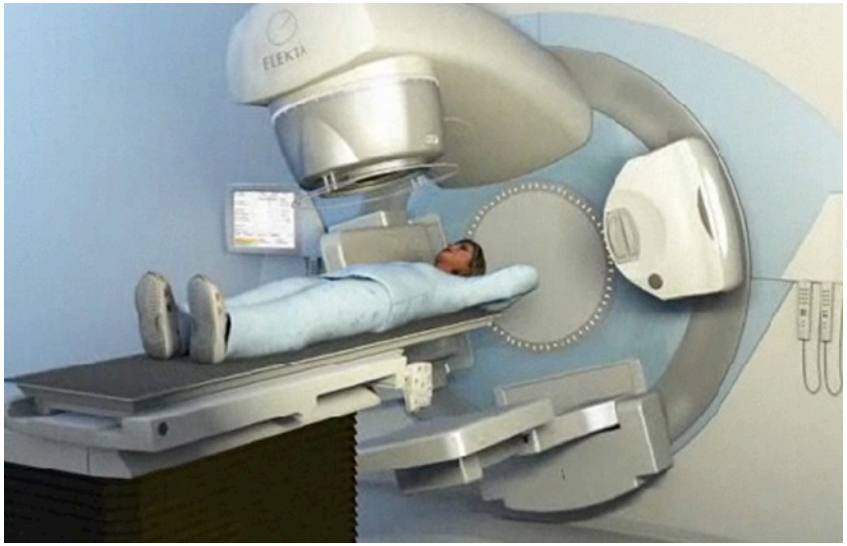
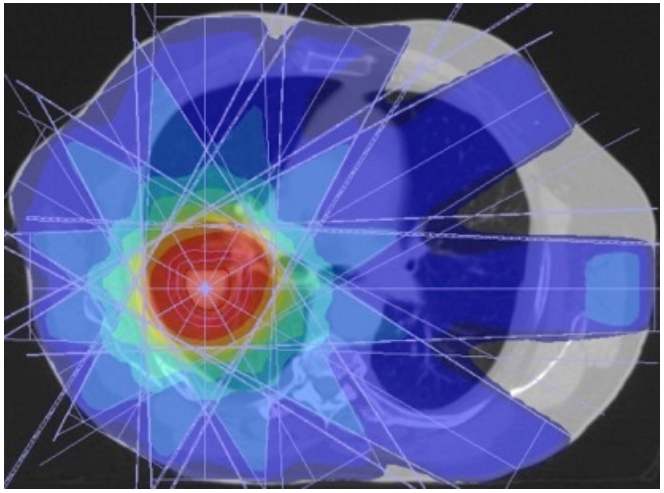


Image guided radiation therapy

Make heavy use of imaging

Treatment planning:

- Performed on CT
- Use fused MRI, PET
- Advanced development with 4D CT



In room image guidance

- CBCT Cone Beam CT
- US image guidance
- Video, surface based
- Future: embedded MRI

Outline

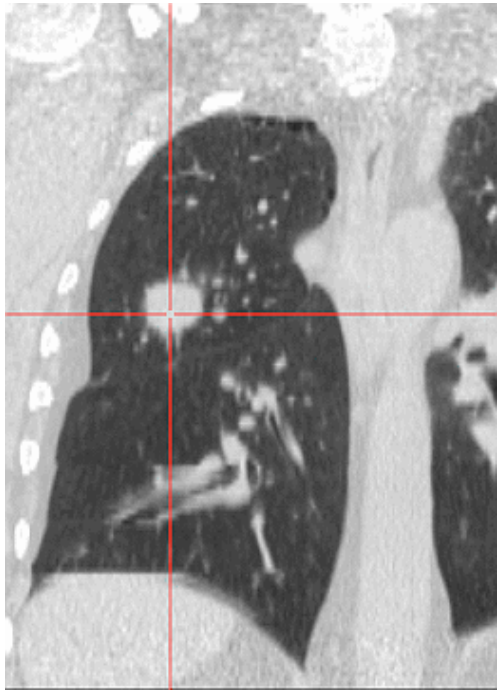
- Example1: lung cancer guidance with Cone-Beam CT
- Example2: lung cancer guidance with surface imaging
- Example2: prostate cancer guidance with US

Example 1

CONE-BEAM CT GUIDANCE

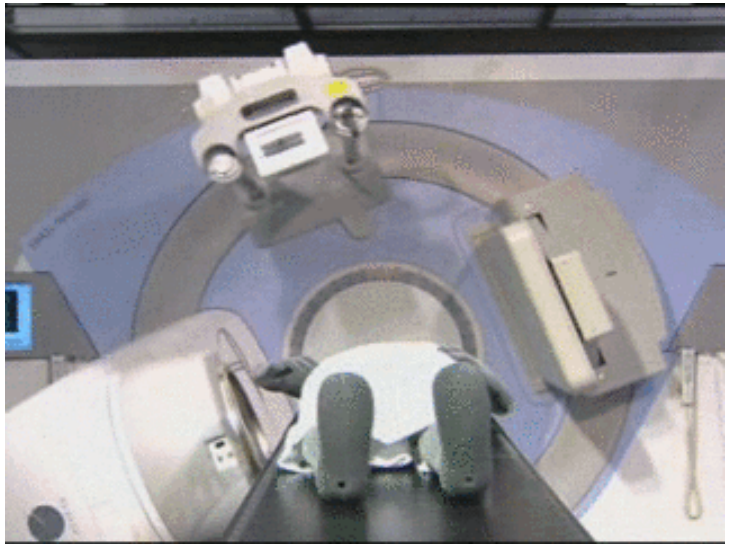
Lung cancer treatment strategy

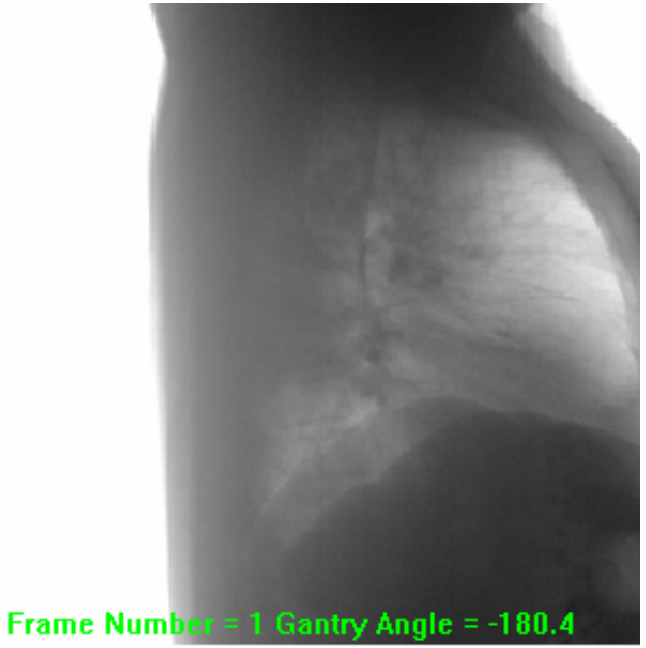
- For locally advanced NSCLC (stage III)
  - Poor 5y survival (<20% France)
  - Surgery impossible
  - RT 60-66 Gy, 30-33f (not hypofraction)
- Additional uncertainty: respiratory motion
- Consequences:
  - Safety margins are increased
  - Potential increased toxicity
  - Treatment less effective or patient excluded



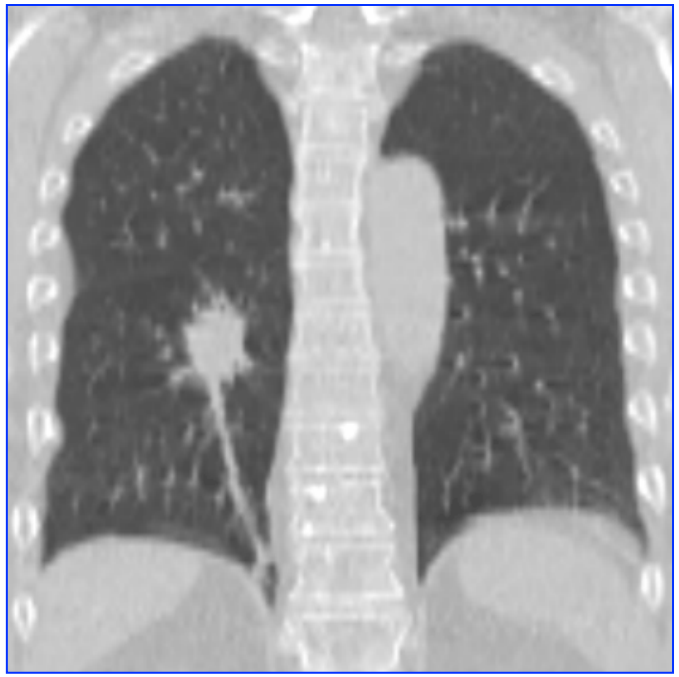
In room guidance

- Reconstruction from a set of 2D projection images
- Respiratory motion during acquisition (acquisition time > 1 min)

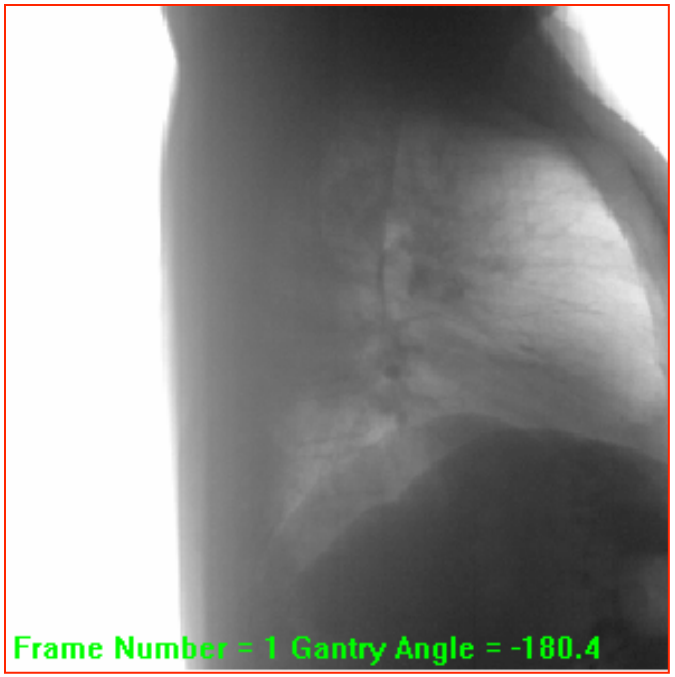




Registration

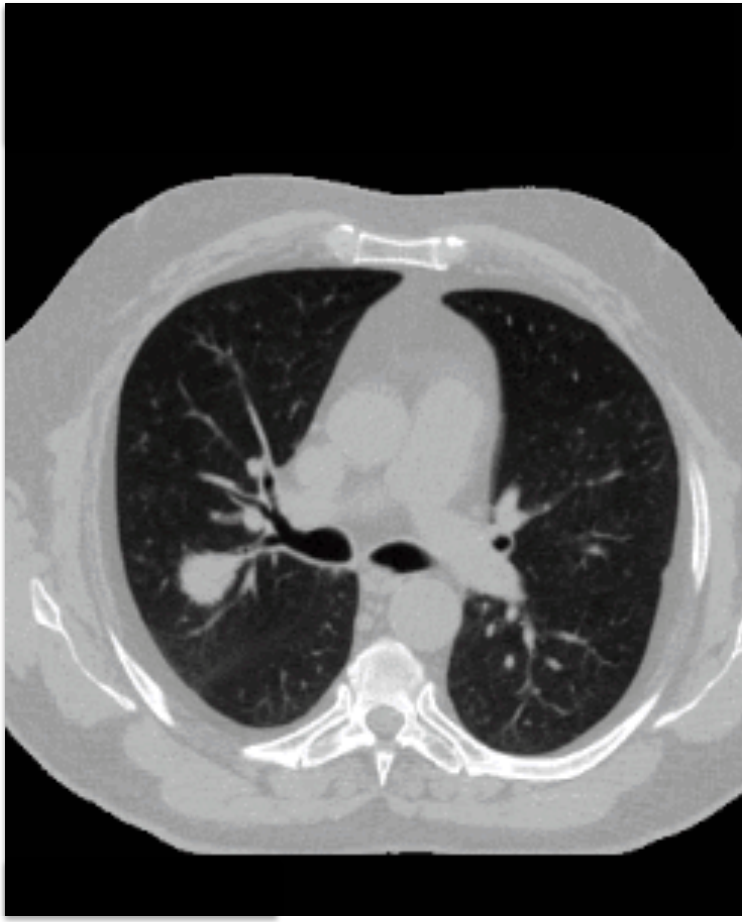


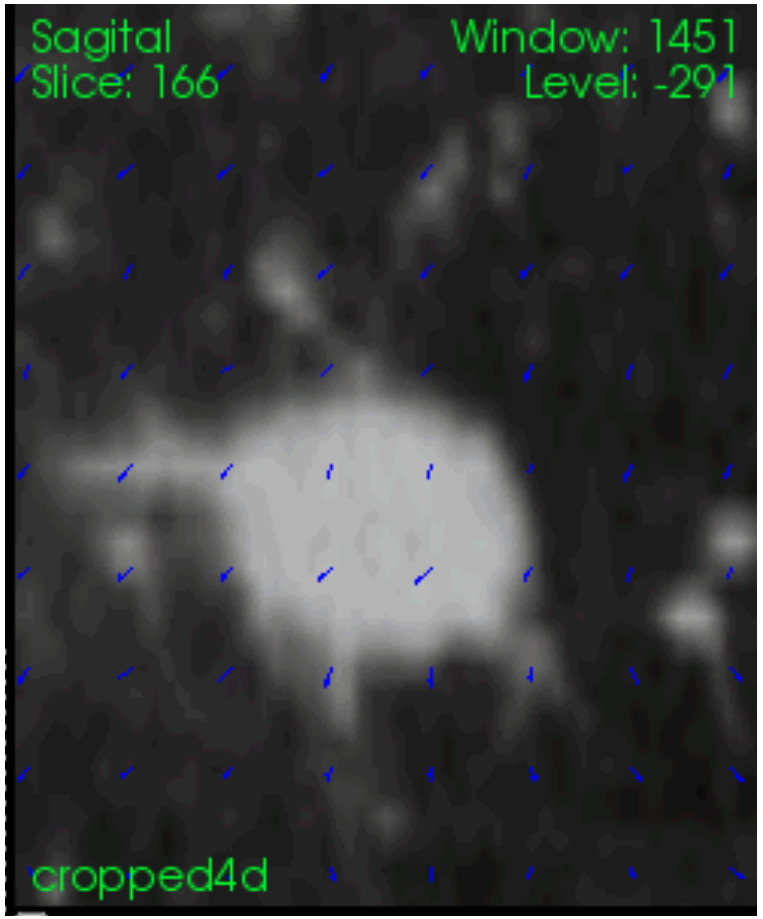
Planning CT (reference)



Daily CBCT

4D DVF – Deformable Image Registration



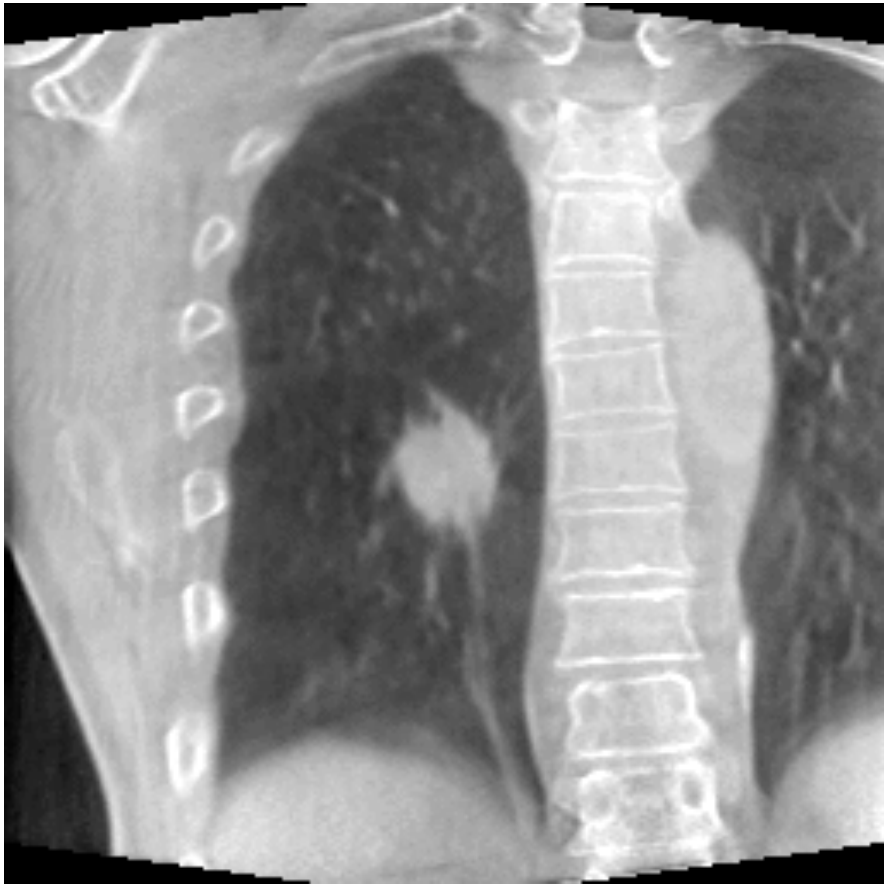


Methods

- Method1: motion compensated 4D reconstruction
- Method2: 2D/3D deformable registration

Non-corrected vs. Compensated

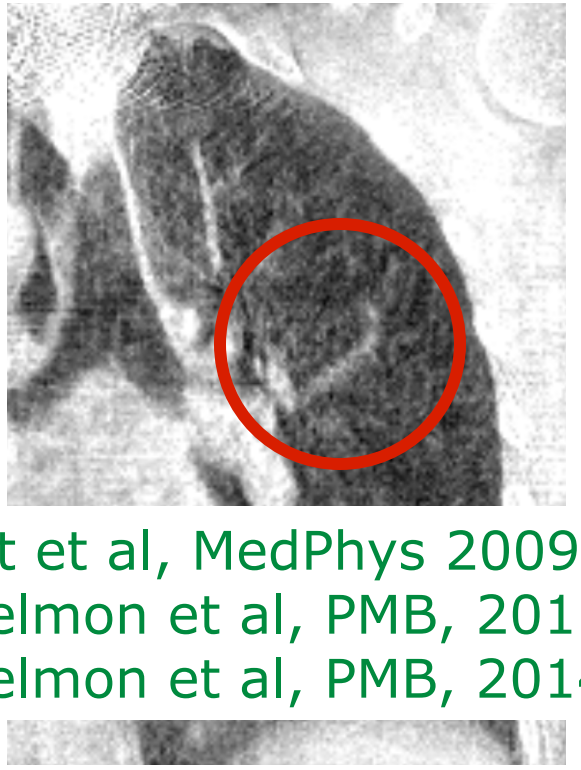
Slow acquisition (4 min)



Methods

- Method1: motion compensated 4D reconstruction
- Method2: 2D/3D deformable registration

No correction



Prior model

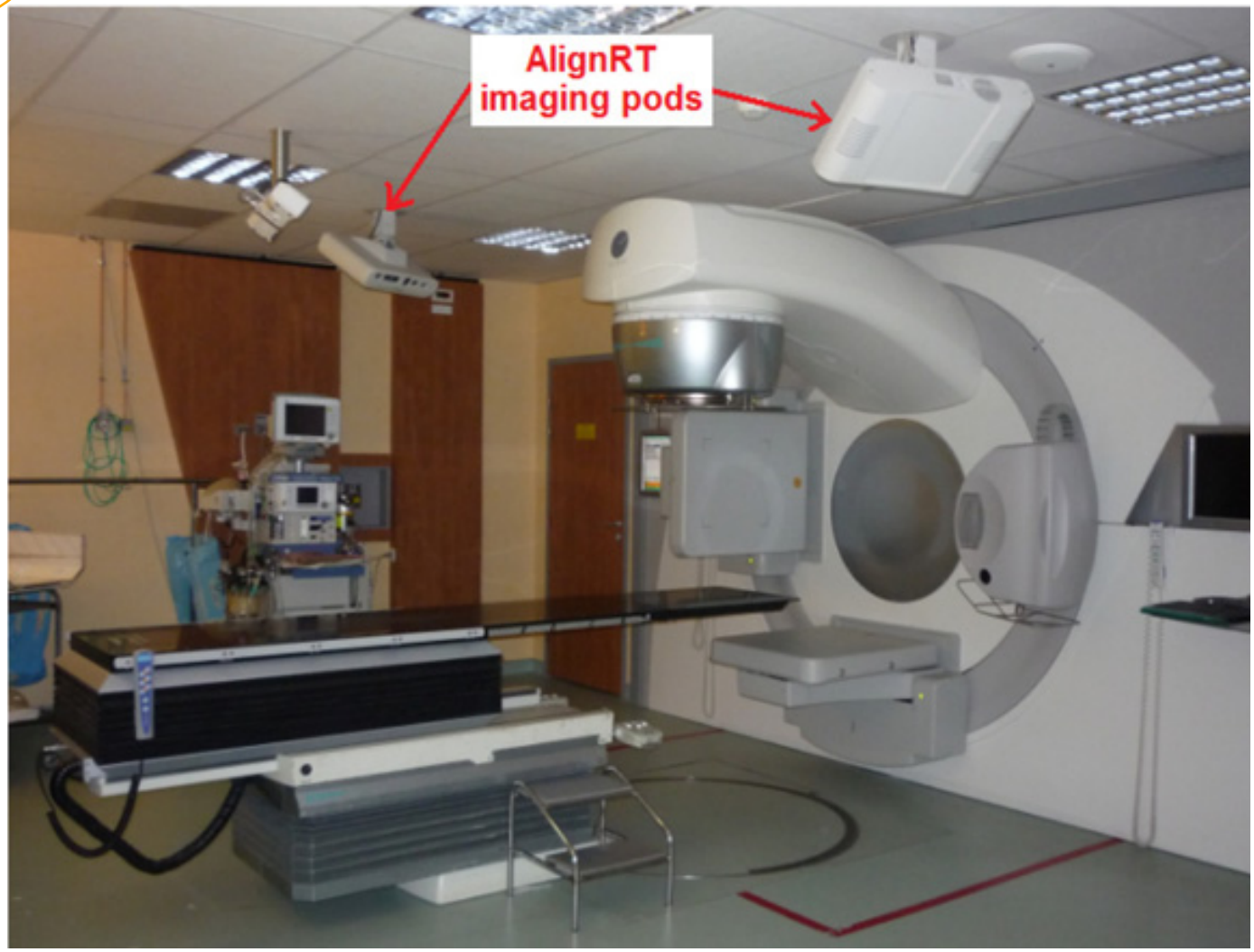
2D/3D registration

[Rit et al, MedPhys 2009]
[Delmon et al, PMB, 2013]
[Delmon et al, PMB, 2014]

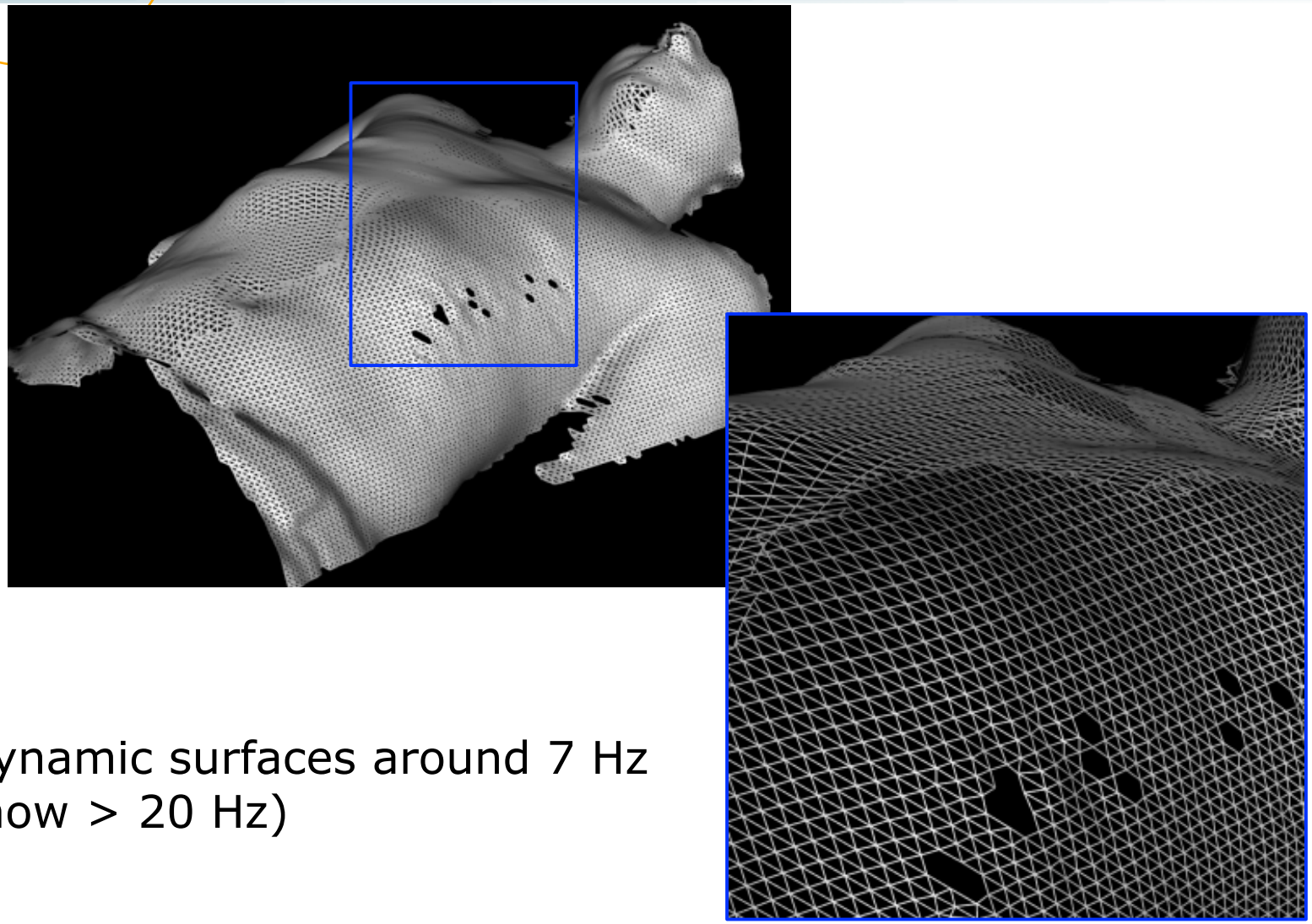
Example 2

SURFACE IMAGING GUIDANCE

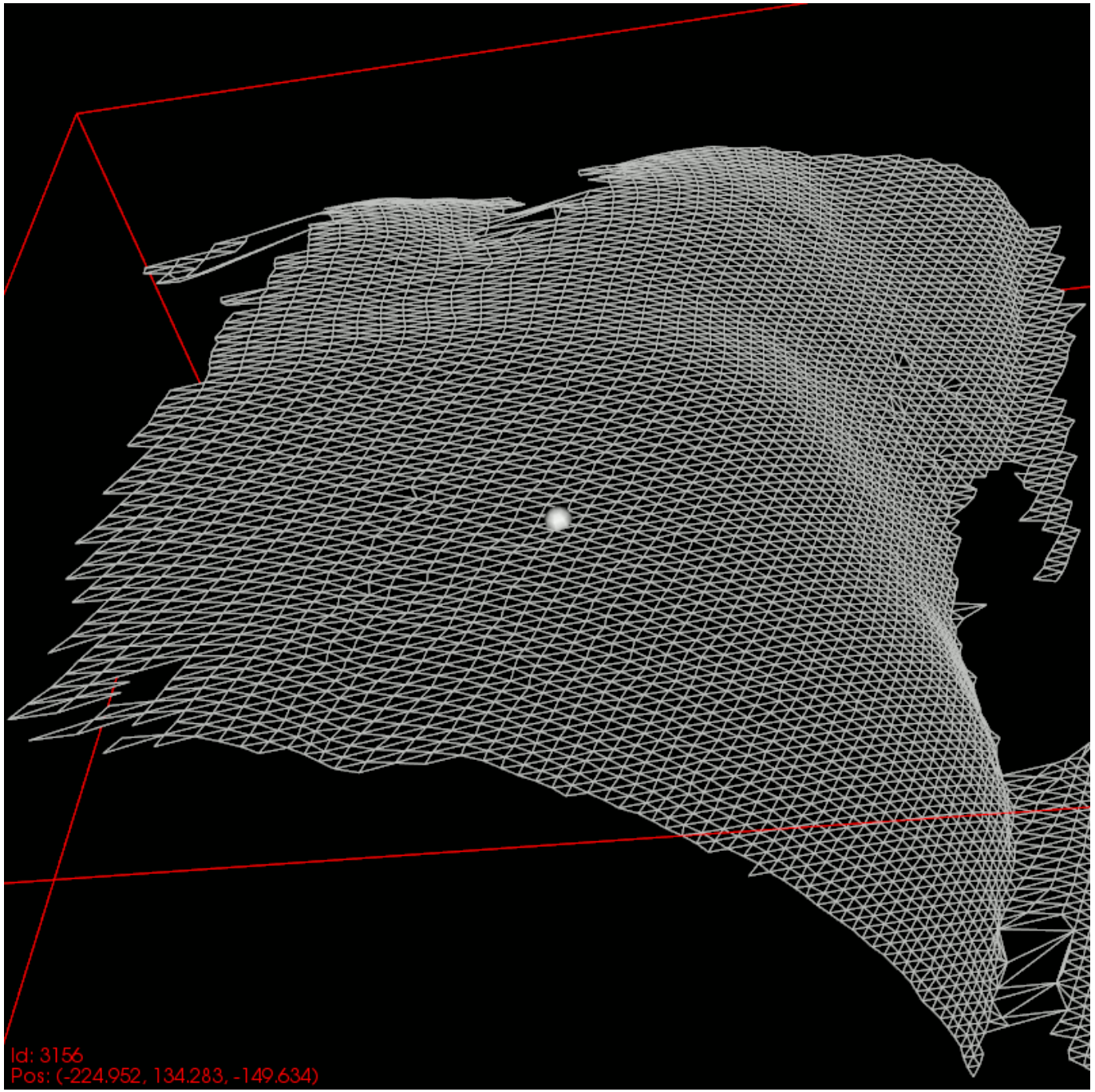
Surface imaging



Surface mesh



Dynamic surfaces around 7 Hz
(now > 20 Hz)


Id: 3156
Pos: (-224.952, 134.283, -149.634)

Deformable mesh registration

- Ed : distance between surfaces
- Es : stiffness term (rigidity)
- El : landmarks term (optional)
- T : Target surface

$$\boldsymbol{X} := \begin{bmatrix} \boldsymbol{X}_1 & \cdots & \boldsymbol{X}_n \end{bmatrix}^T$$

$$\boldsymbol{G} := \mathrm{diag}(1, 1, 1, \gamma)$$

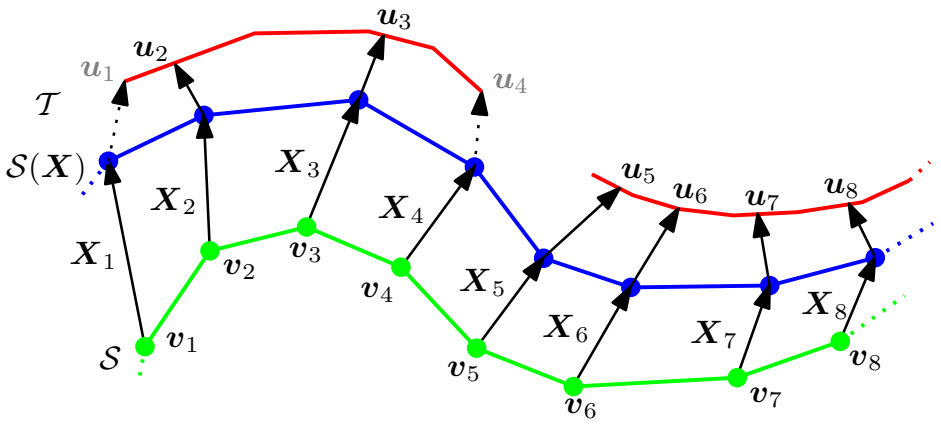
$$\mathcal{L} = \{(\boldsymbol{v}_{i_1}, \boldsymbol{l}_1), \ldots, (\boldsymbol{v}_{i_l}, \boldsymbol{l}_l)\}$$

$$E(\boldsymbol{X}) := E_d(\boldsymbol{X}) + \alpha E_s(\boldsymbol{X}) + \beta E_l(\boldsymbol{X})$$

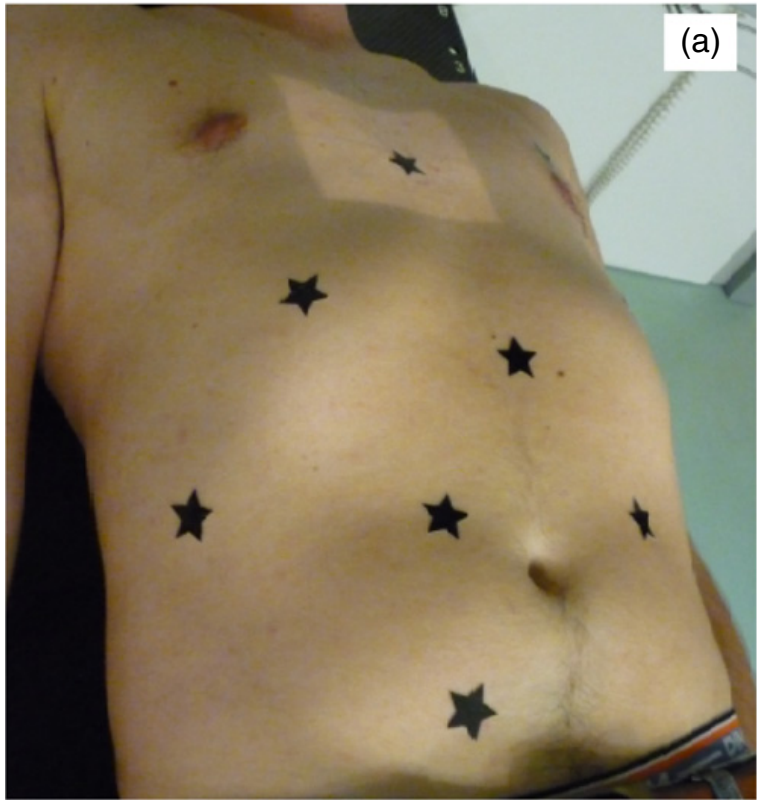
$$E_d(\boldsymbol{X}) := \sum_{\boldsymbol{v}_i \in \mathcal{V}} w_i \, \mathrm{dist}^2(\mathcal{T}, \boldsymbol{X}_i \boldsymbol{v}_i)$$

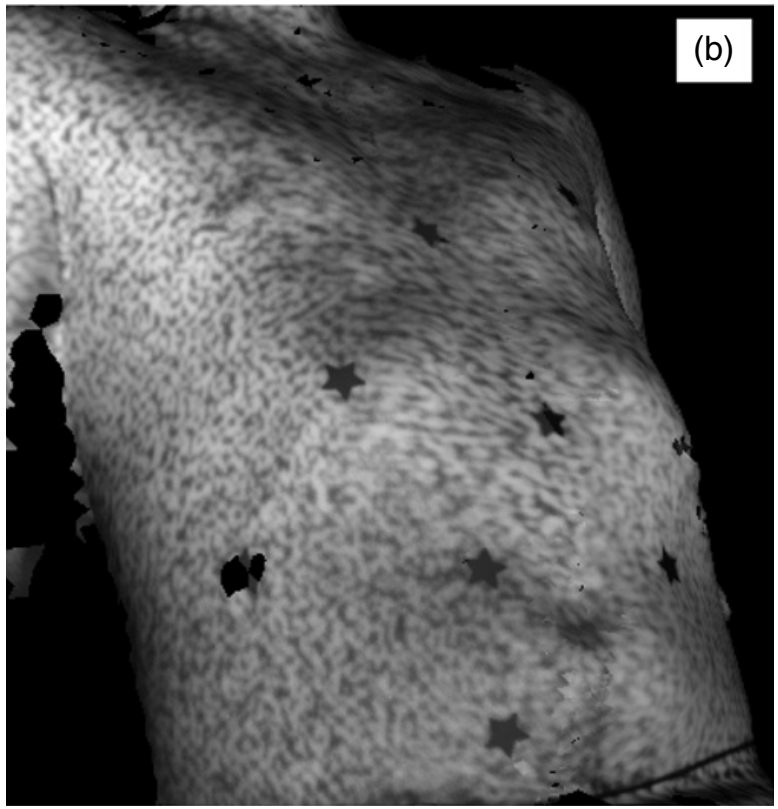
$$E_s(\boldsymbol{X}) := \sum_{\{i,j\} \in \mathcal{E}} \|(\boldsymbol{X}_i - \boldsymbol{X}_j)\boldsymbol{G}\|_F^2$$

$$E_l(\boldsymbol{X}) := \sum_{(\boldsymbol{v}_i, \boldsymbol{l}) \in \mathcal{L}} \|\boldsymbol{X}_i \boldsymbol{v}_i - \boldsymbol{l}\|^2$$



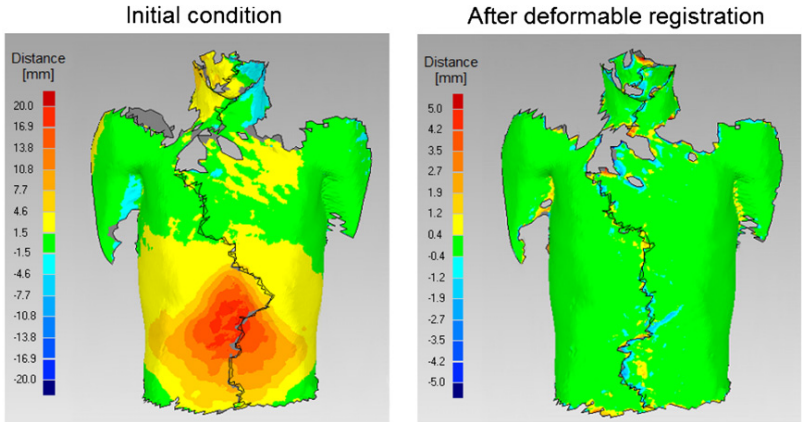
Validation





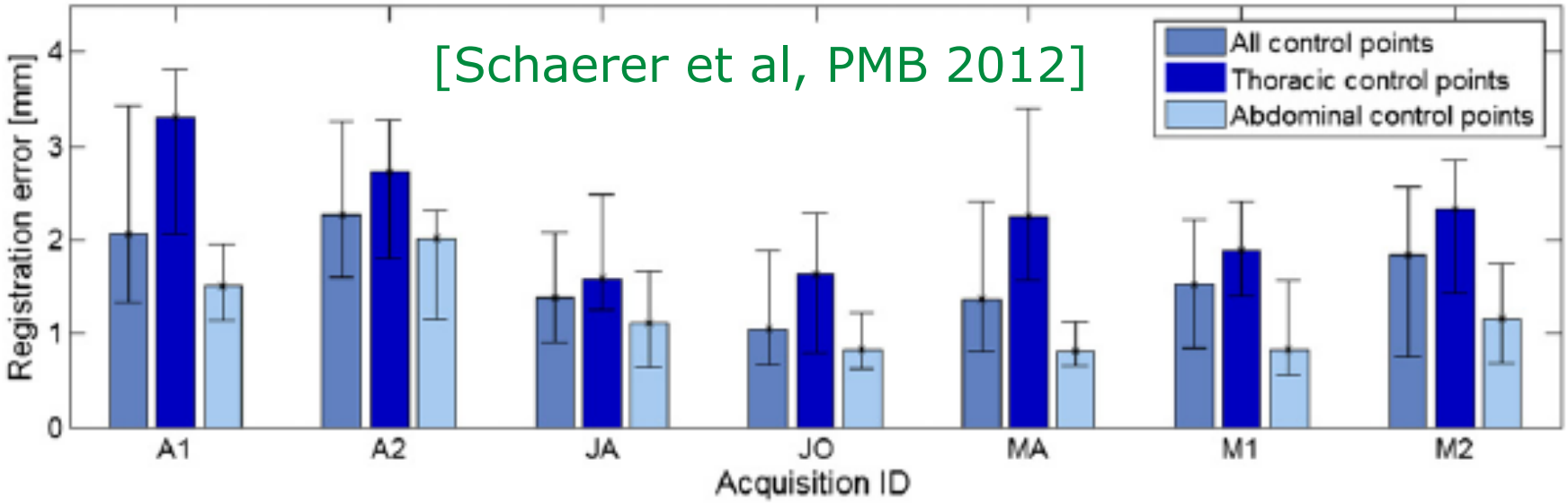
Some results

- TRE lower than 4 mm
- Thoracic errors > abdominal errors
- Too slow (now possible in real time)



Feasible …

… not really used in clinic

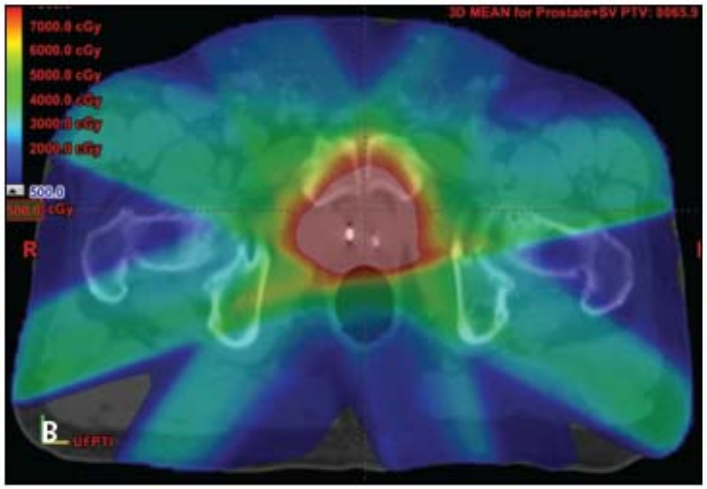


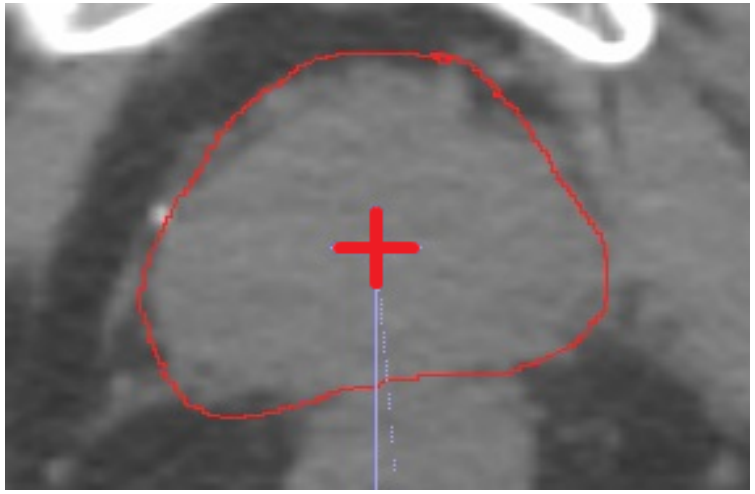
Example 3

US GUIDANCE FOR PROSTATE CANCER TREATMENT

Prostate cancer

- Hypofractionated treatment
  - Less fraction, higher dose
  - Could be beneficial [1,2]
  - Higher accuracy needed





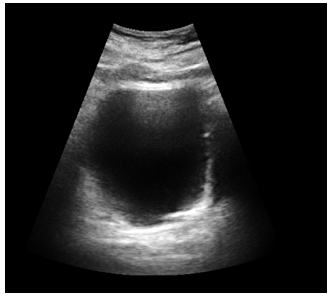
[1] King et al. *International Journal of Radiation Oncology Biology Physics*, (2012)
[2] Engels et al. *Radiotherapy and Oncology,* (2014)

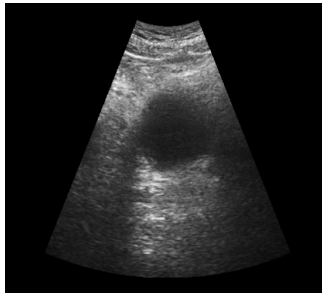
Ultrasound image guidance

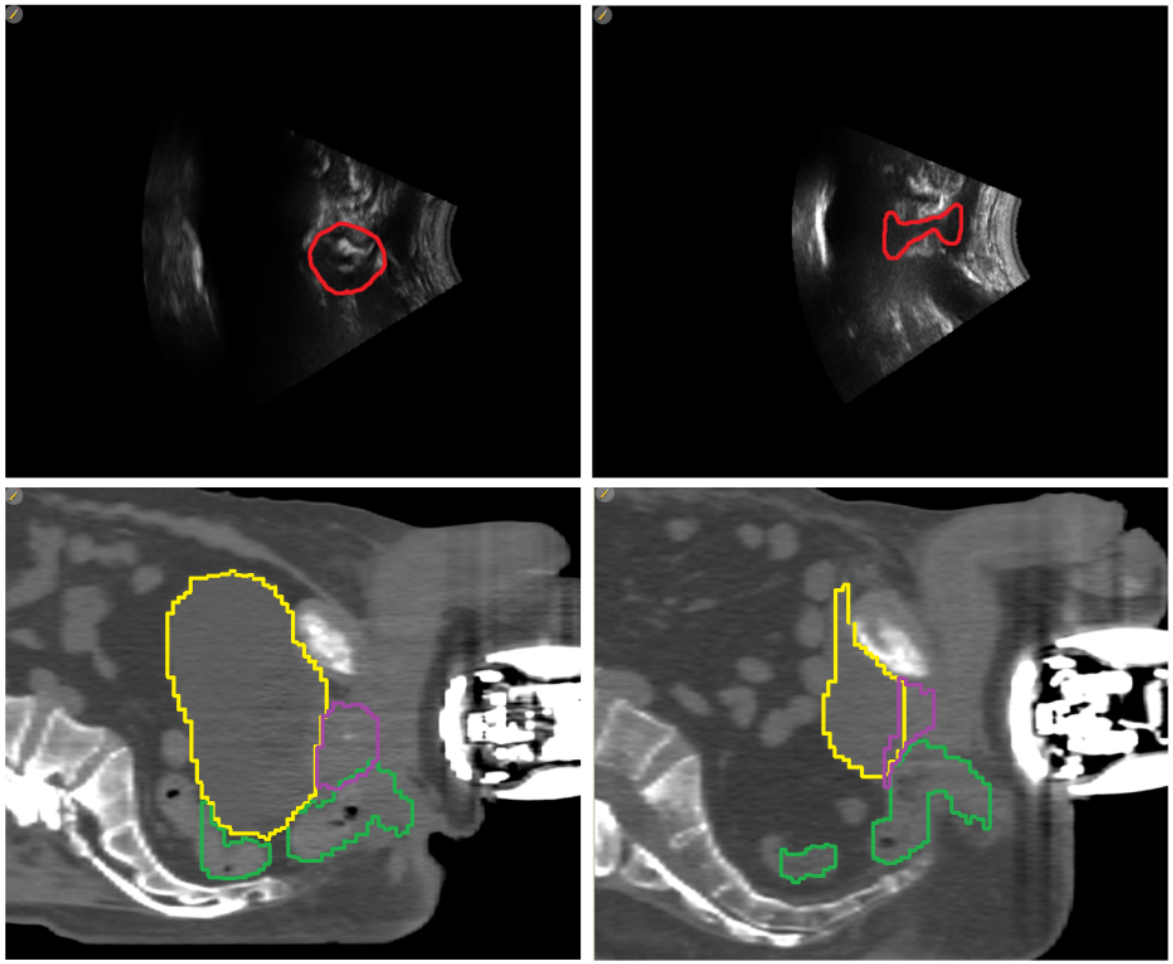
Registration US-US

Reference planning
CT and US

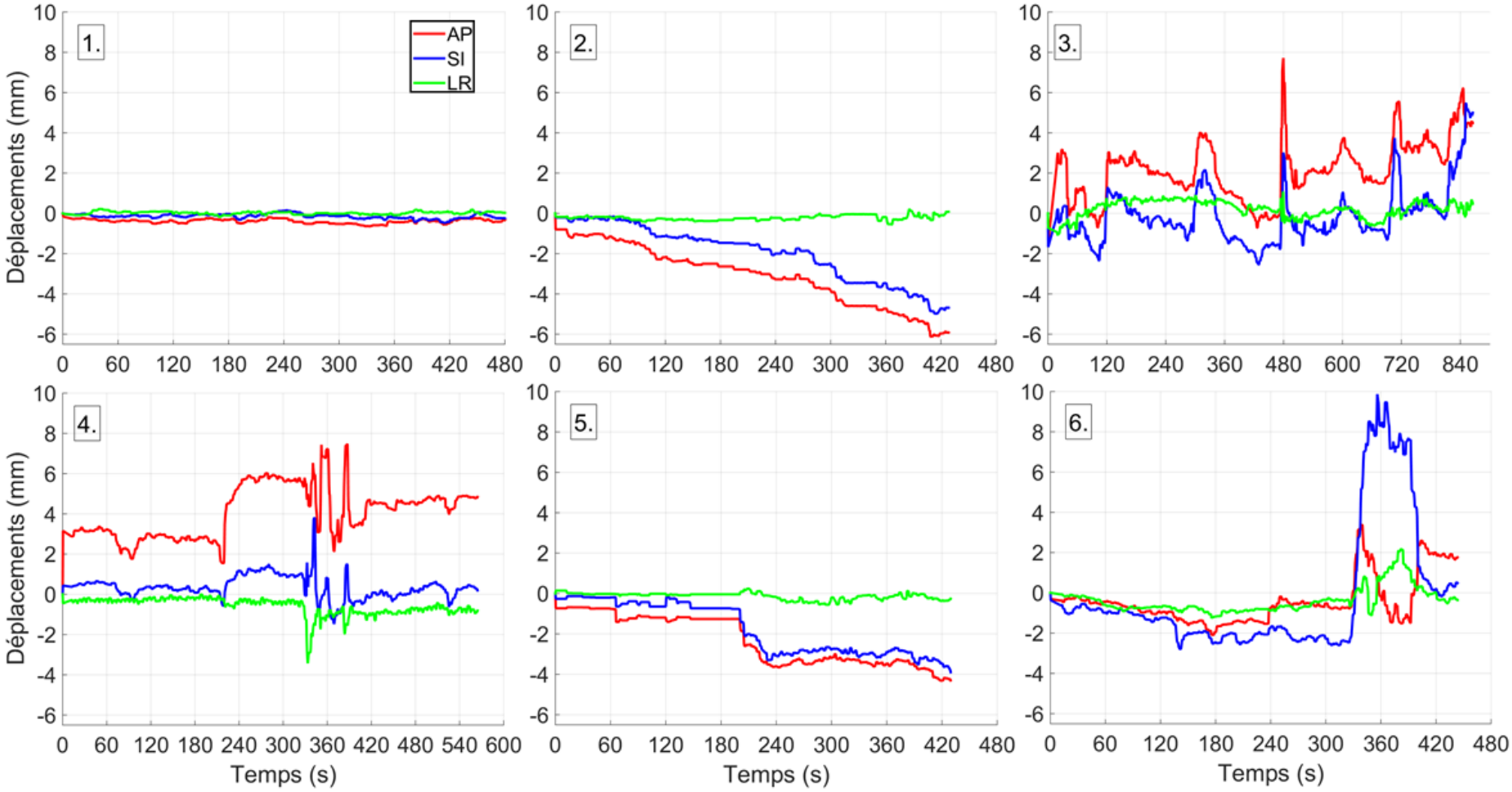
Registration bw
reference US
& current US



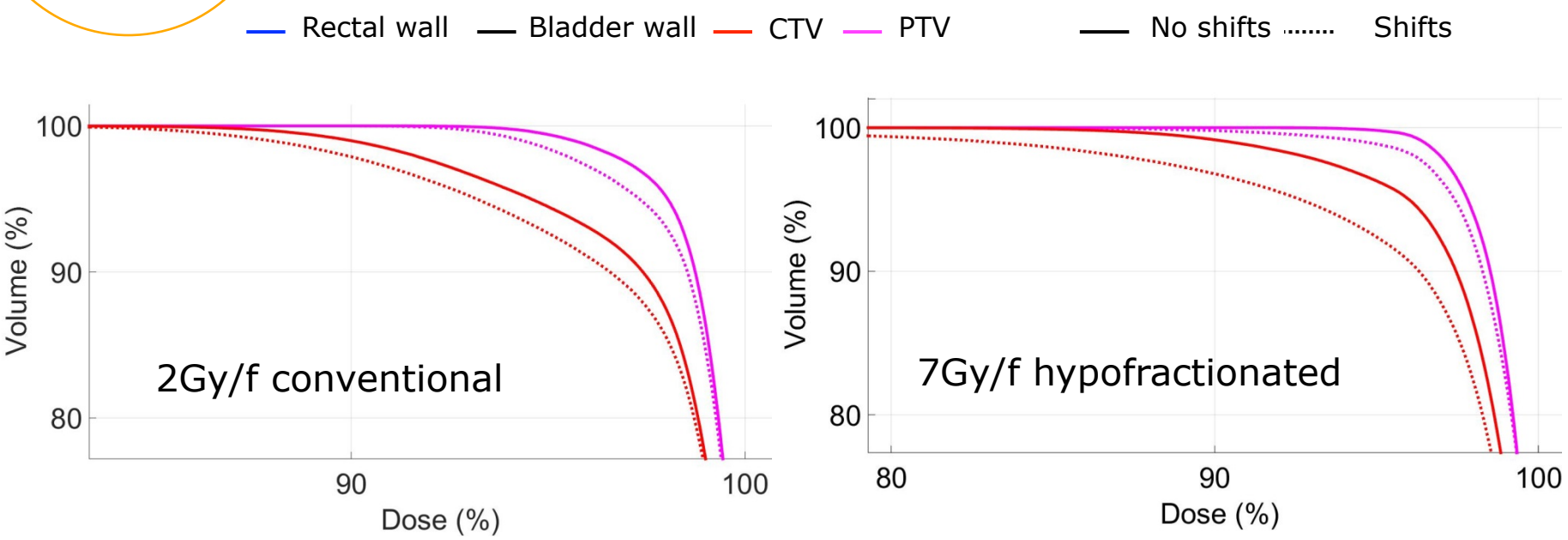




Continuous registration



Dosimetric results



- Bladder wall = Higher doses 1.3 ± 1% vs 1.7 ± 3.6%
- Rectal wall = Lower doses -1.2 ± 1.3% vs -1.7 ± 4%
- PTV (V95%) = loss of coverage -1.8 ± 1.9% vs **-3.9** ± 3.5%

- Loss of PTV coverage of **11%** (7Gy/f) for the patient with the largest motion

CONCLUSION

Conclusion

Context : radiation therapy

Not directly “interventional”, but in-room image guidance

Direct impact on treatment outcome

- Cone-Beam CT, surface monitoring, Ultrasound, On-board MRI ?
- Clinical trials
- A key class of algorithms: *Deformable Image Registration*

Interested ?

- vv.creatis.insa-lyon.fr
- www.openrtk.org
- www.creatis.insa-lyon.fr/rio/popi-model

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