Image processing for cardiac and vascular applications

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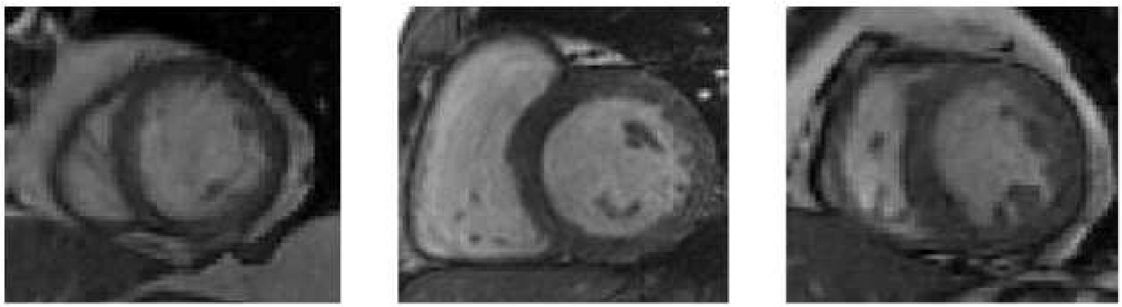
Image processing for cardiac imaging

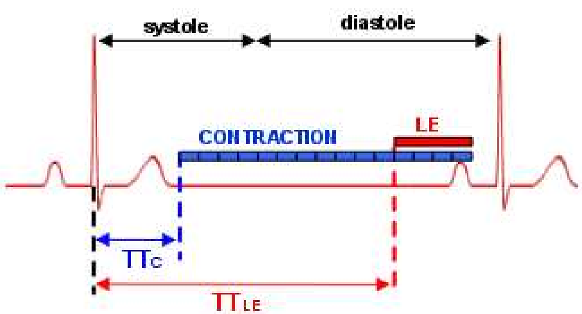
1. For diagnosis in cardiology: segmentation, derived measures, perfusion, movement.
2. For oncology applications (heart = organ at risk).

Requirements and validation depend on the application.

Segmentation for diagnosis

- Examples from R. El Berbari's PhD (collaboration with LIF and HEGP).
- Contraction and late enhancement images.
- Evaluation of left ventricle cinetics.
- Quantification of transmurality of myocardium infarctus.



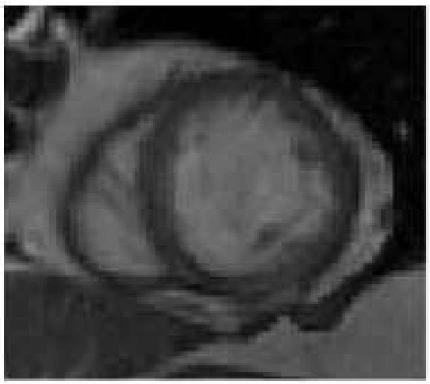


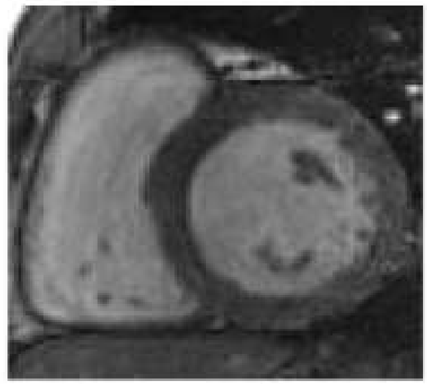
Late enhancement

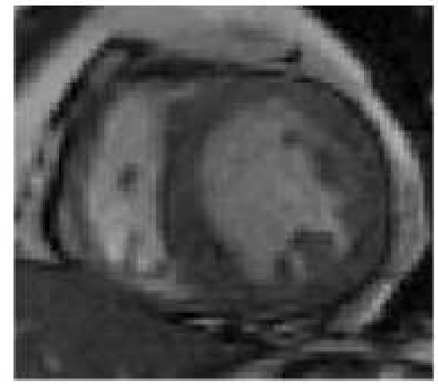
One slice during the cardiac cycle

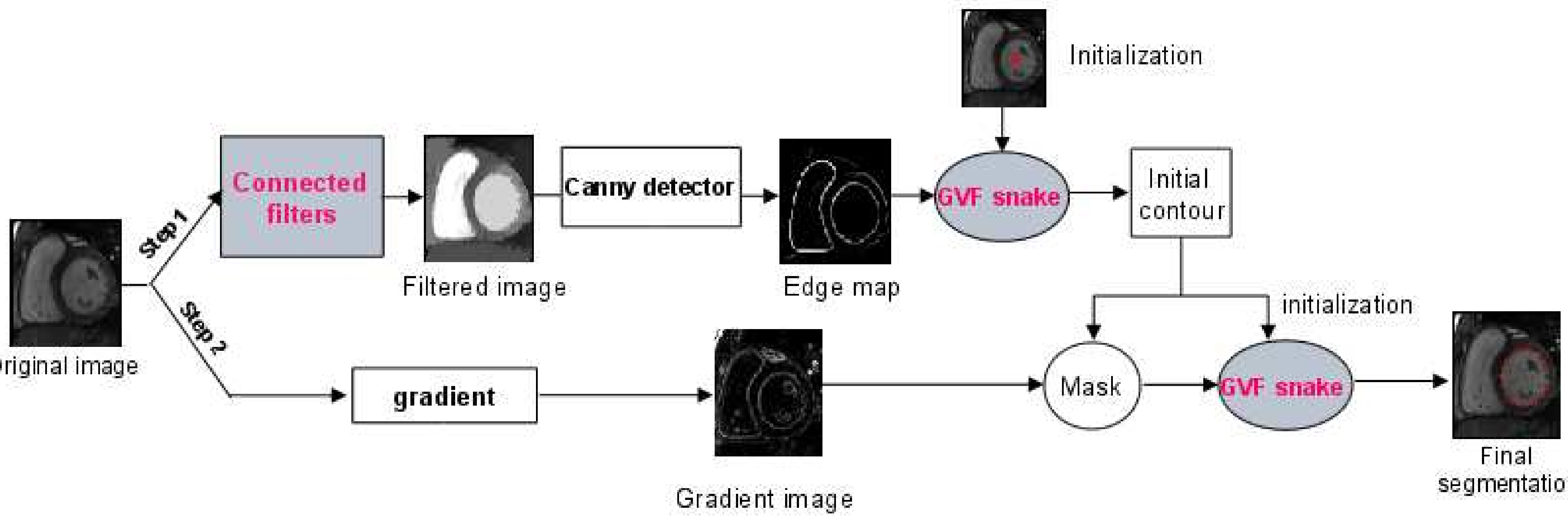
Late enhancement

Segmentation method





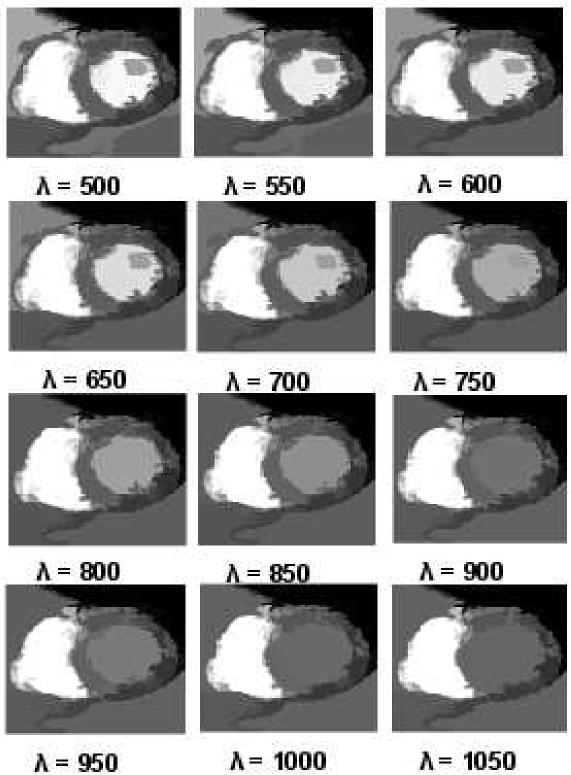


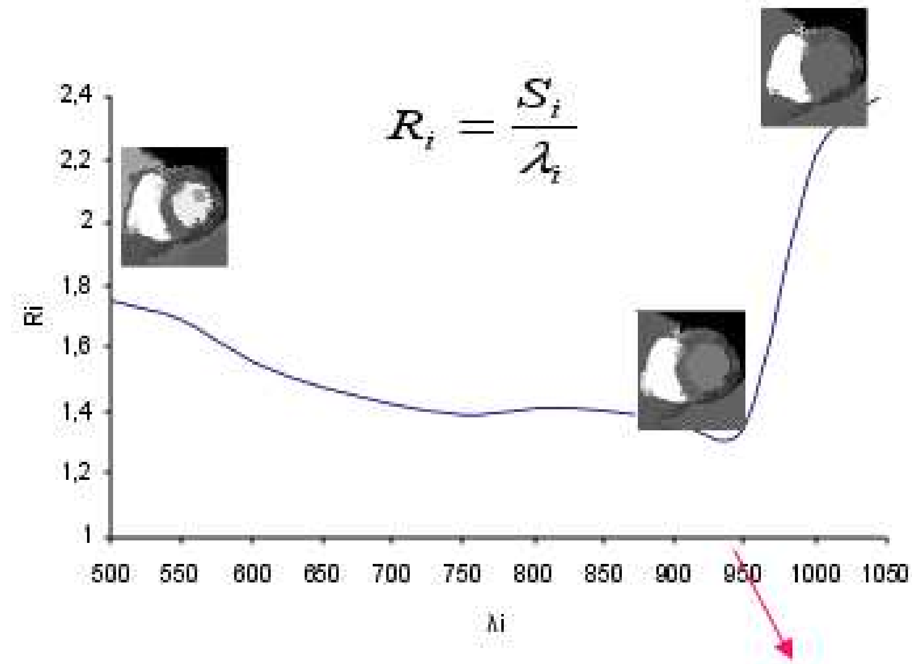


Segmentation method

Endocardium segmentation

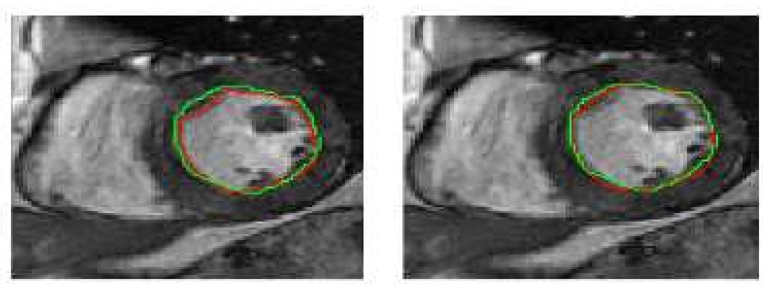
- *First step:*
  Each filtered image → [$\lambda_1, \lambda_2, \ldots \lambda_i$]





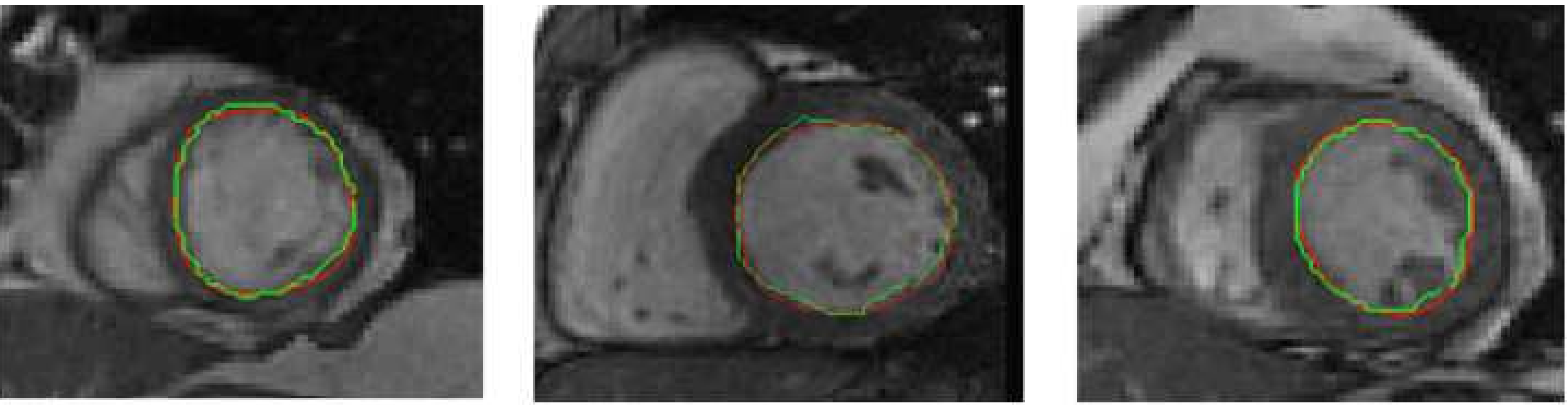
Optimal value of λ

- *Second step:*
  - segmentation refinement



Step 1 **Step 2**

Results



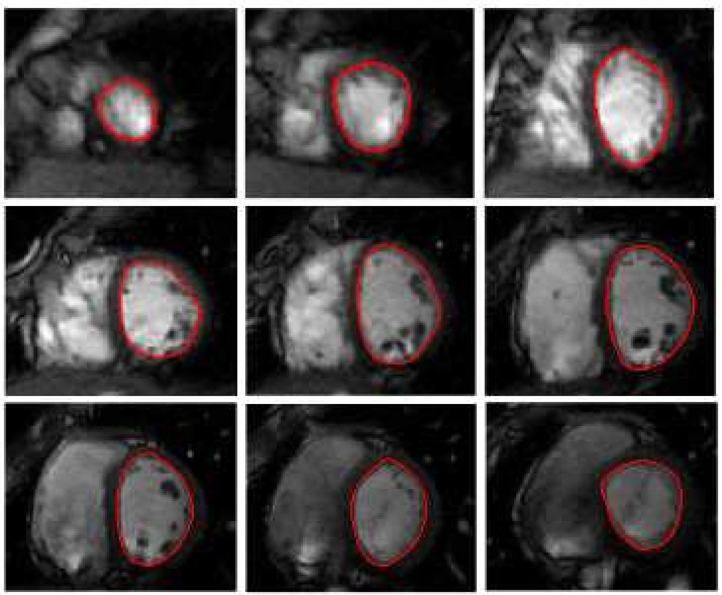
Red: automated segmentation – Green: manual expert segmentation

Results

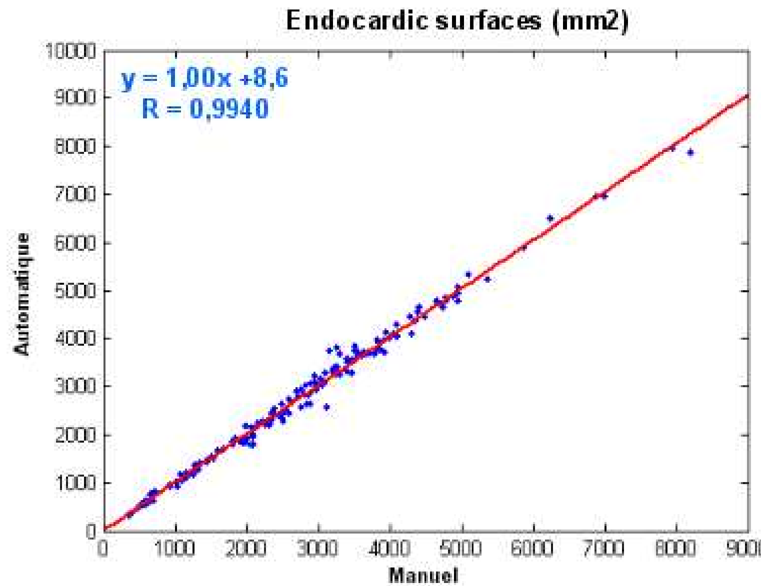
Evaluation

BDD1: 13 subjects, 39 slices
BDD2: 36 normal subjects, 293 slices

Comparison with manual tracing on 20 cases of BDD2



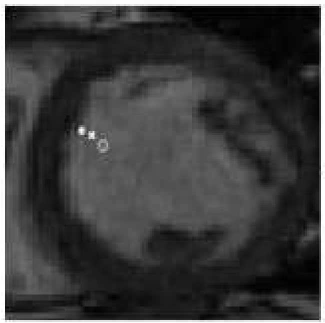
From apex to base

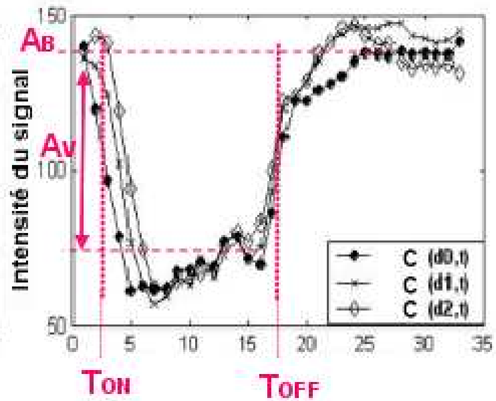


M_s (%)	D_{max} (mm)	D_{moy} (mm)
91 ± 4	2.8 ± 1.1	1.1 ± 1.0

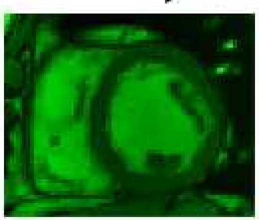
Results

Parametric Analysis of Main Movement





$$P(x,y,t) = A_B(x,y) - A_V(x,y).g(t, T_{ON}(x,y), T_{OFF}(x,y)) + e(x,y,t)$$



AB image

AV image

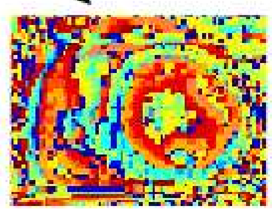


Image TON

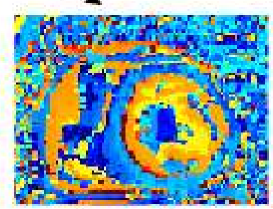
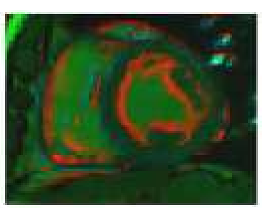


Image TOFF



Trichromatic image

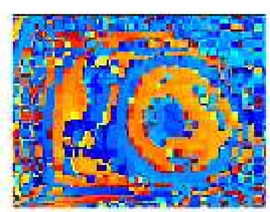
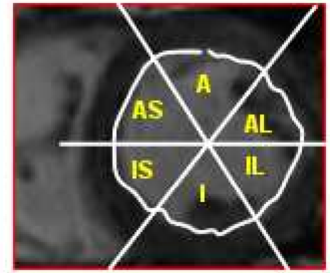


Image TM

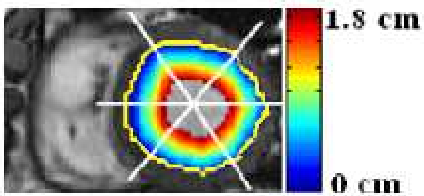
Results

Estimation of functional parameters

- Segment analysis



- Estimation of radial distances:



Distance map

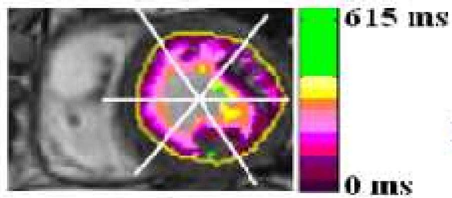
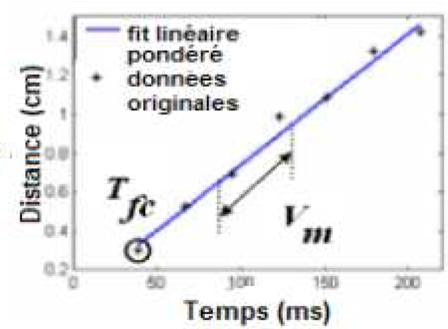


Image T+ON



-Estimation of mean contraction time:

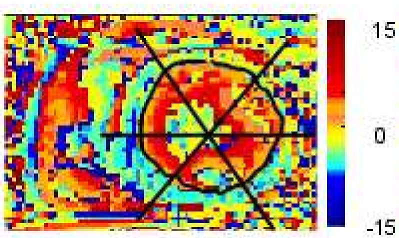


Image TON

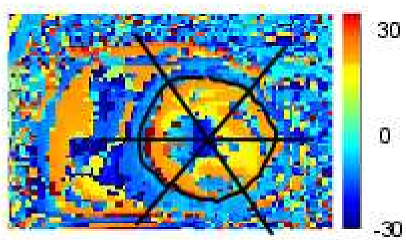
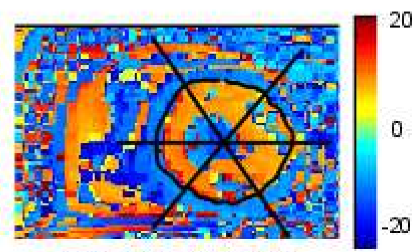


Image TOFF

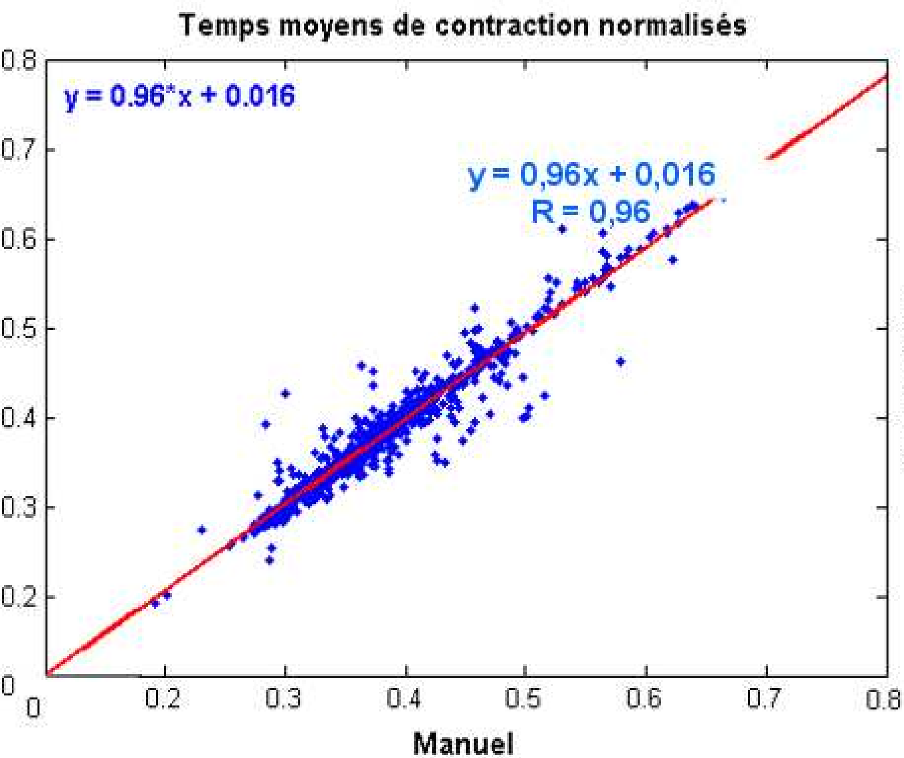


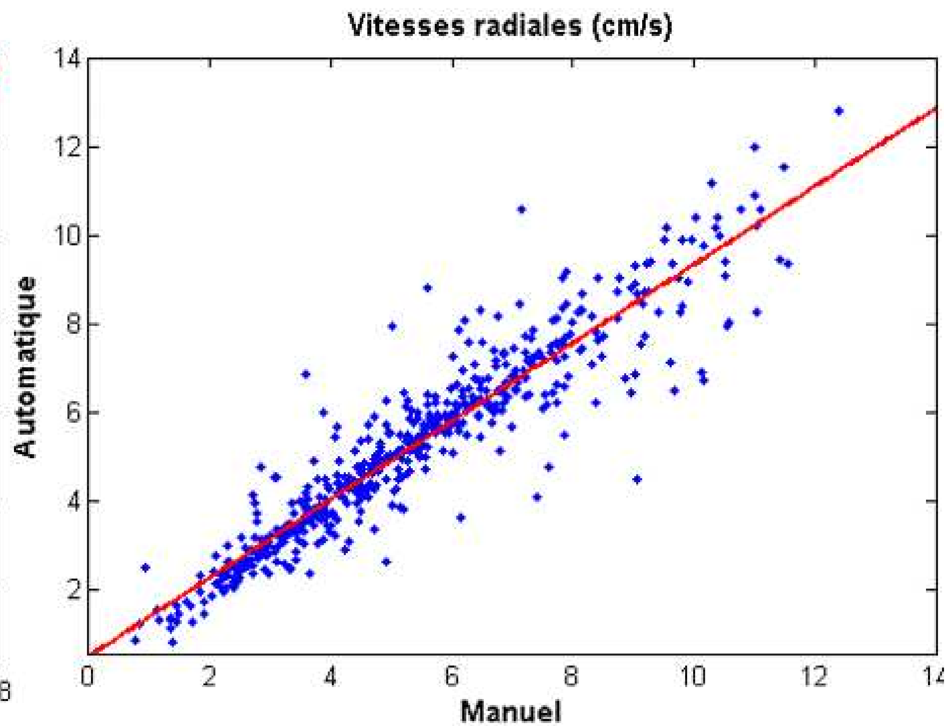
TM = (TON + TOFF) /2

Results

Evaluation

BDD2: 20 normal subjects with manual tracing (984 segments)

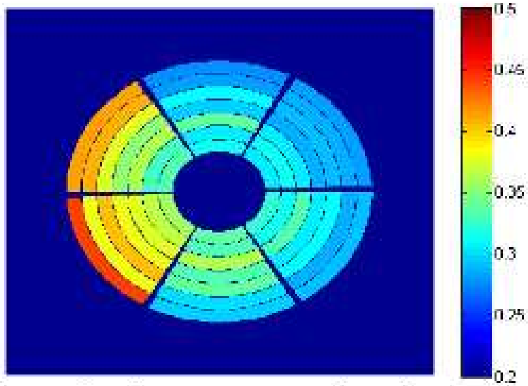




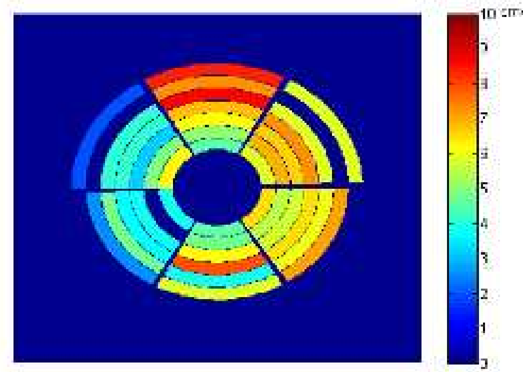
Results

Global results

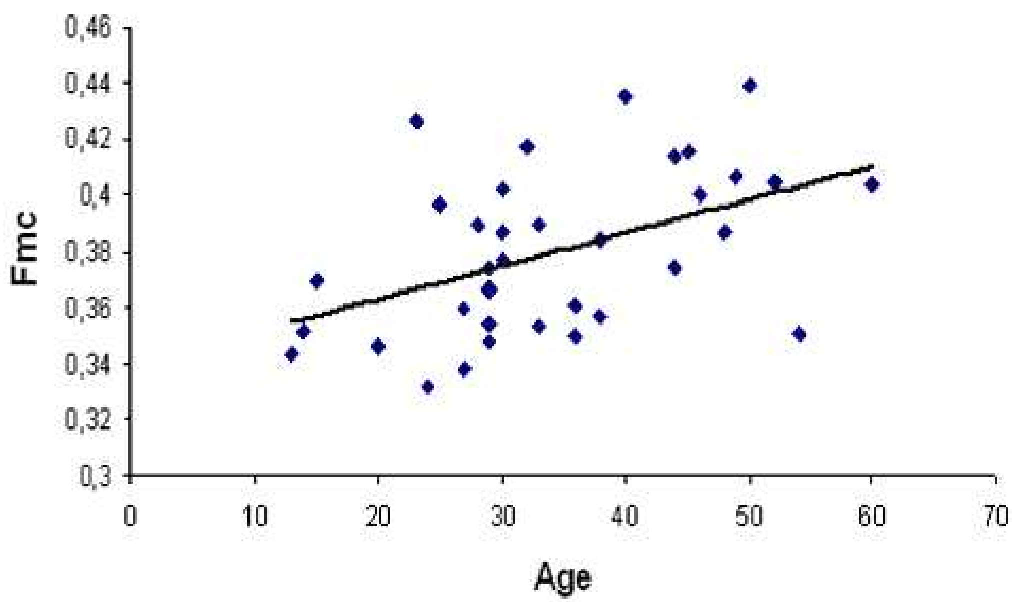
BDD2: 36 normal subjects (1752 segments)



Normalized mean contraction time
Fmc (Bull eye visualization)



Radial velocity
Vm (cm/s)

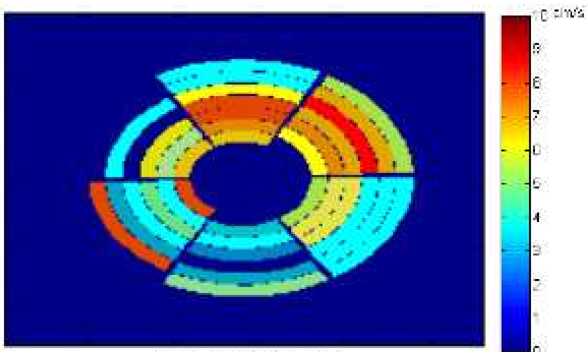


Results

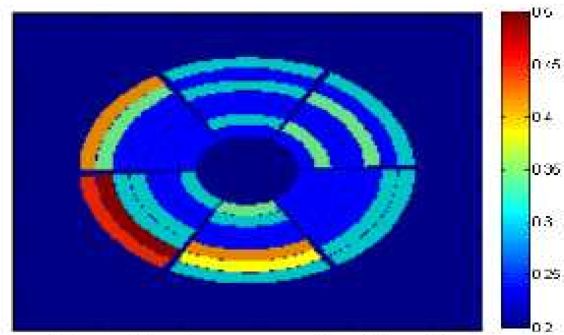
BDD3:

10 normal subjects + 10 pathological ones with infarctus

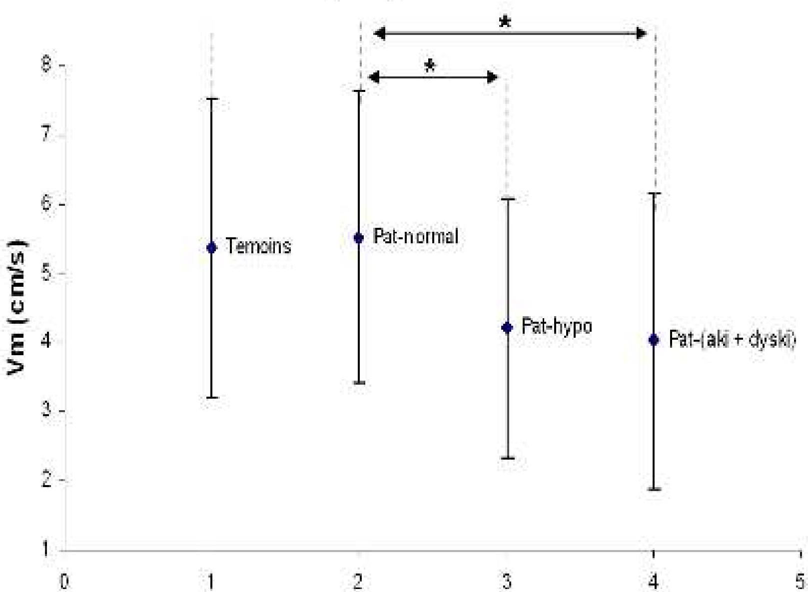
(444 segments + 408 segments)

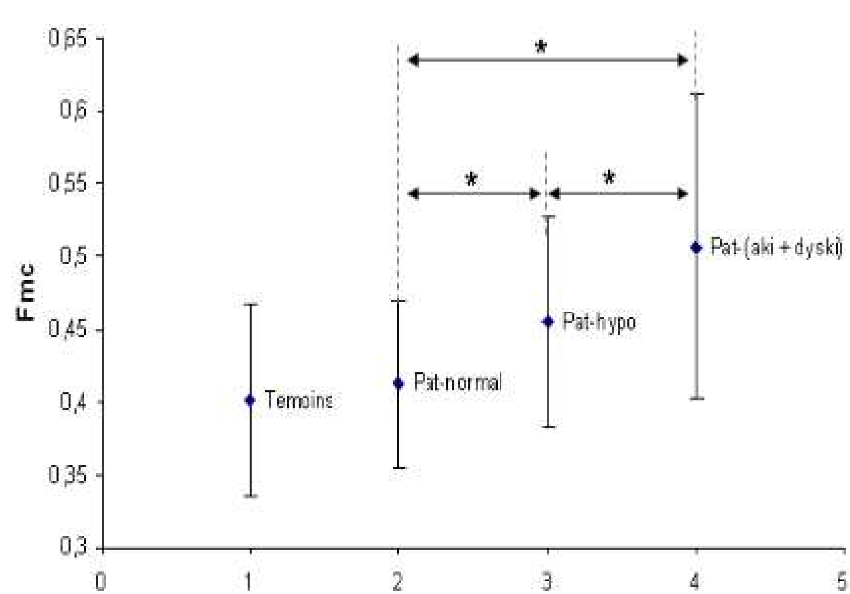


Radial velocity
Vm (cm/s)

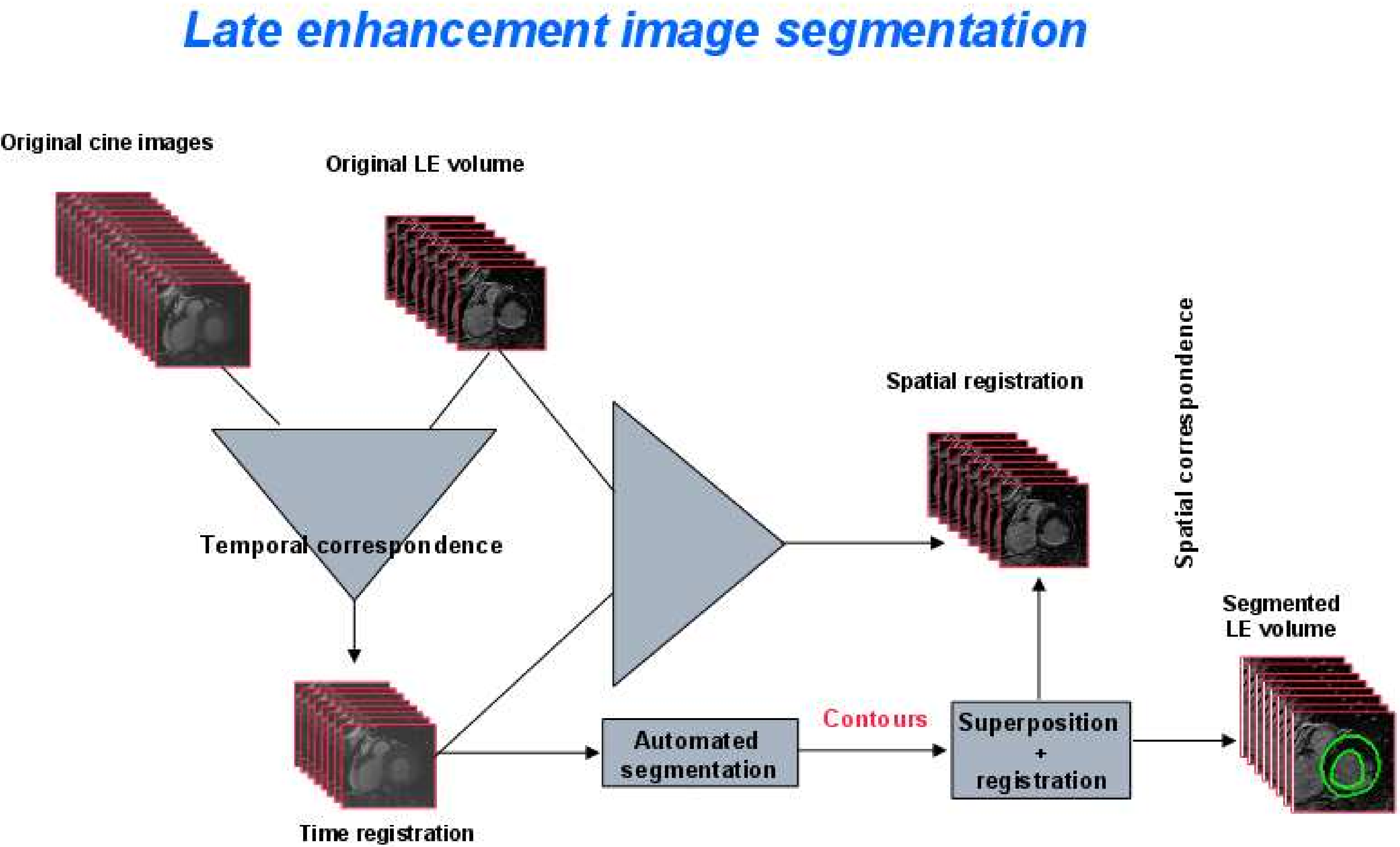


Normalized mean contraction time
F_{mc}

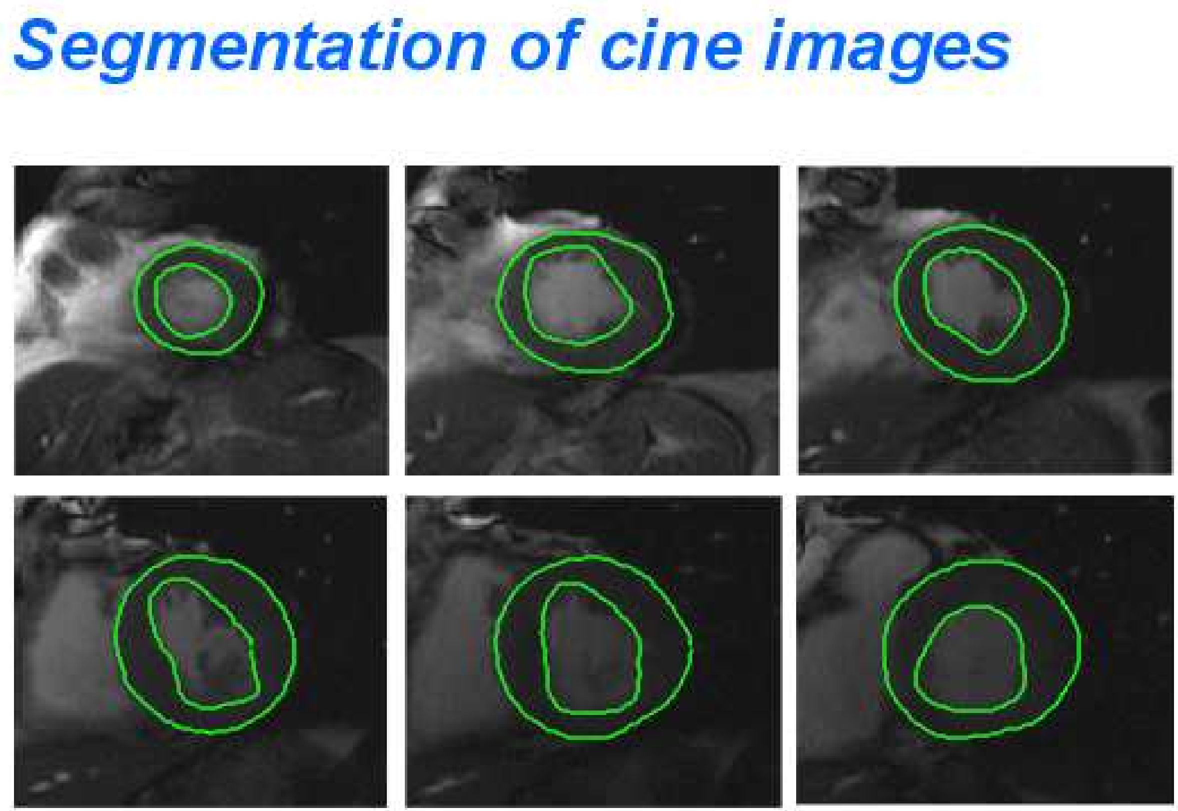




Late enhancement images

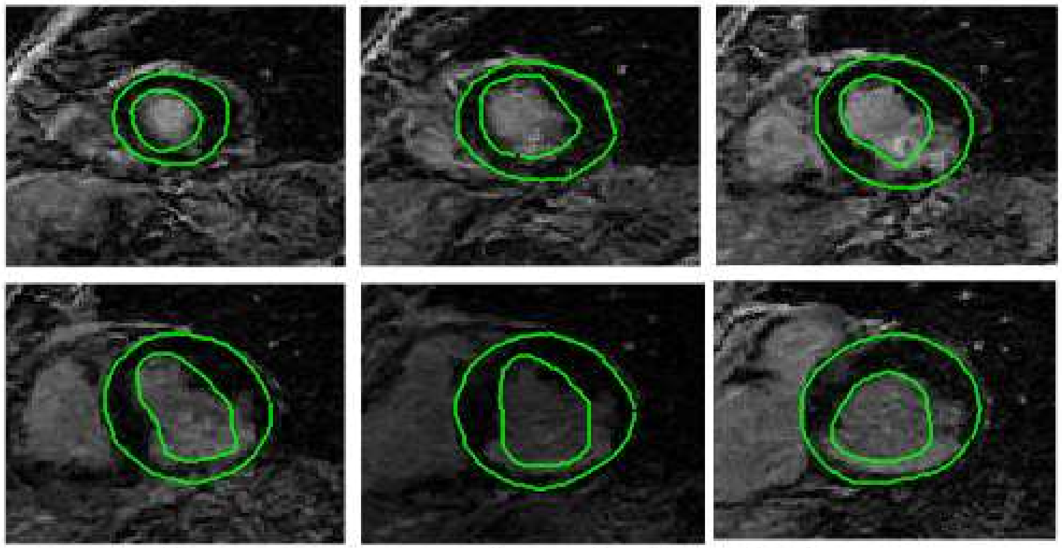


Late enhancement images



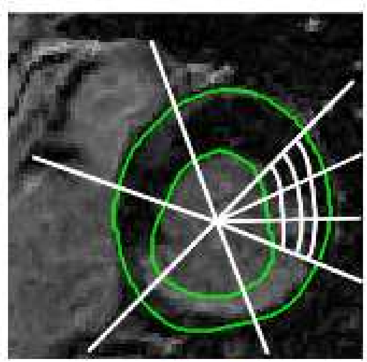
Late enhancement images

uperposition and registration of contours on LE images



Myocardium segmentation on six slices of LE images

Quantification of infarctus transmurality



Late enhancement images

Evaluation

BDD4:

9 pathological subjects (921 sub-segments)

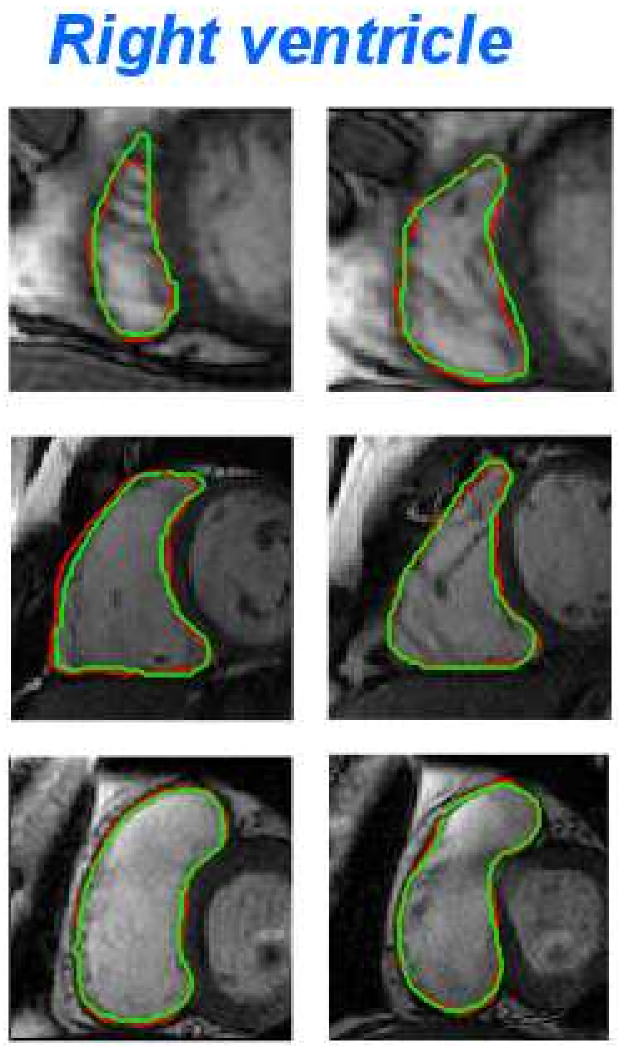
- class 0: no enhancement
- class 1: enhancement from 0 to 25 % of myocardium thickness
- class 2: 26 - 50 %
- class 3: 51 - 75 %
- class 4: 76 - 100 %

Quantitative \ Visual	0	1	2	3	4
0	584	13	9	2	1
1	40	24	12	-	1
2	4	12	47	35	6
3	2	-	7	13	40
4	-	-	-	2	67

Absolute agreement = 80%
Relative agreement up to 1 degree = 97%
Relative agreement up to 2 degrees = 99%

Kappa $\kappa = 0.815$

Extensions

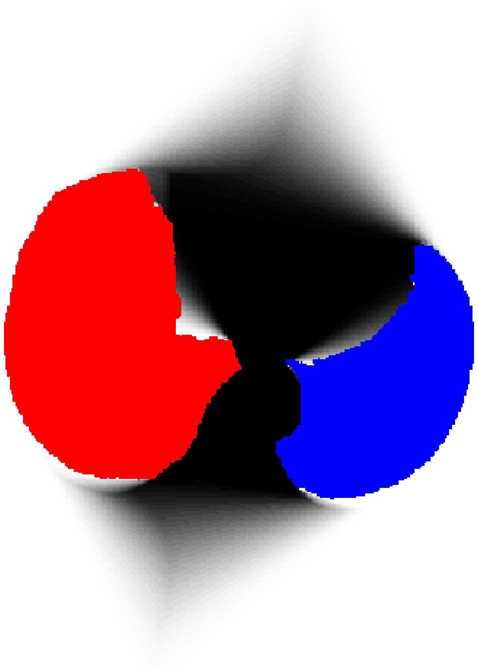


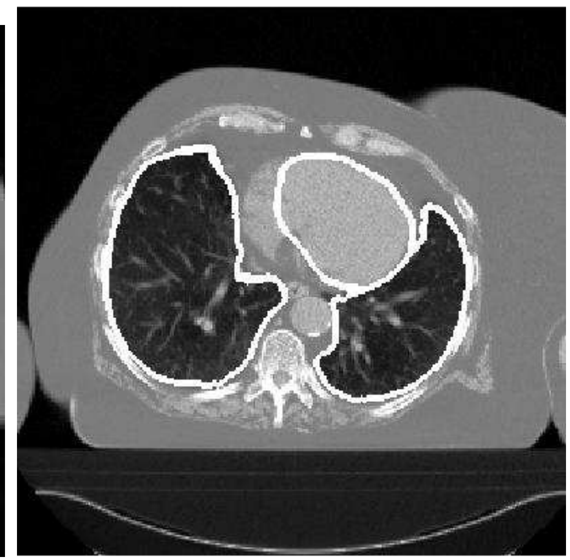
Red: automated segmentation – Green: manual expert segmentation

Others: multi-centric evaluation...

Heart segmentation for oncology applications (A. Moreno, J. Wojak)

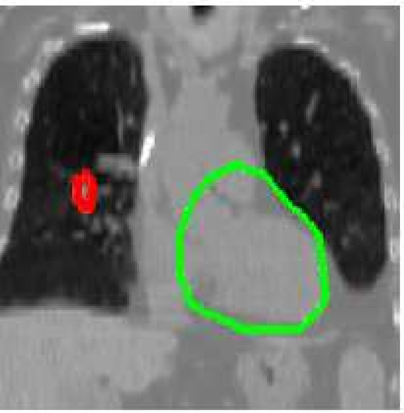
Using structural constraints

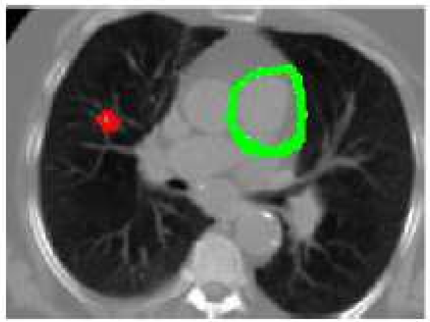


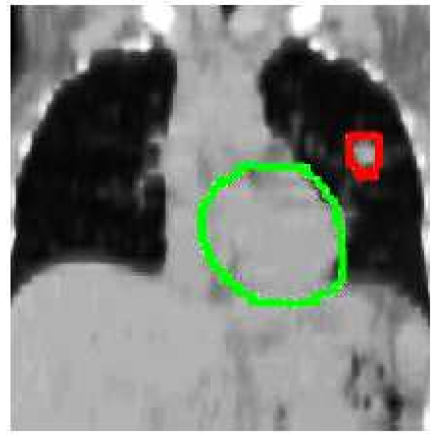


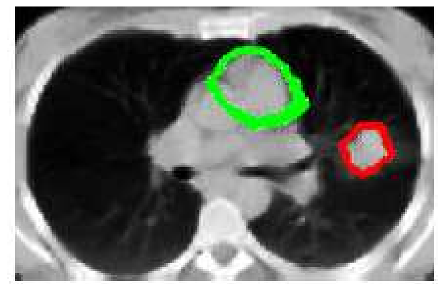
Heart segmentation for oncology applications (A. Moreno, J. Wojak)

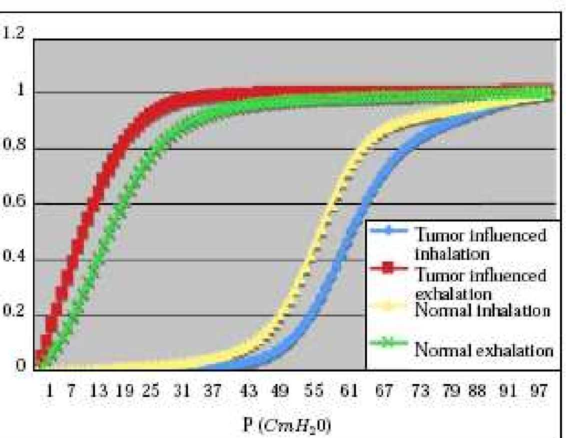
Using structural constraints and a breathing model



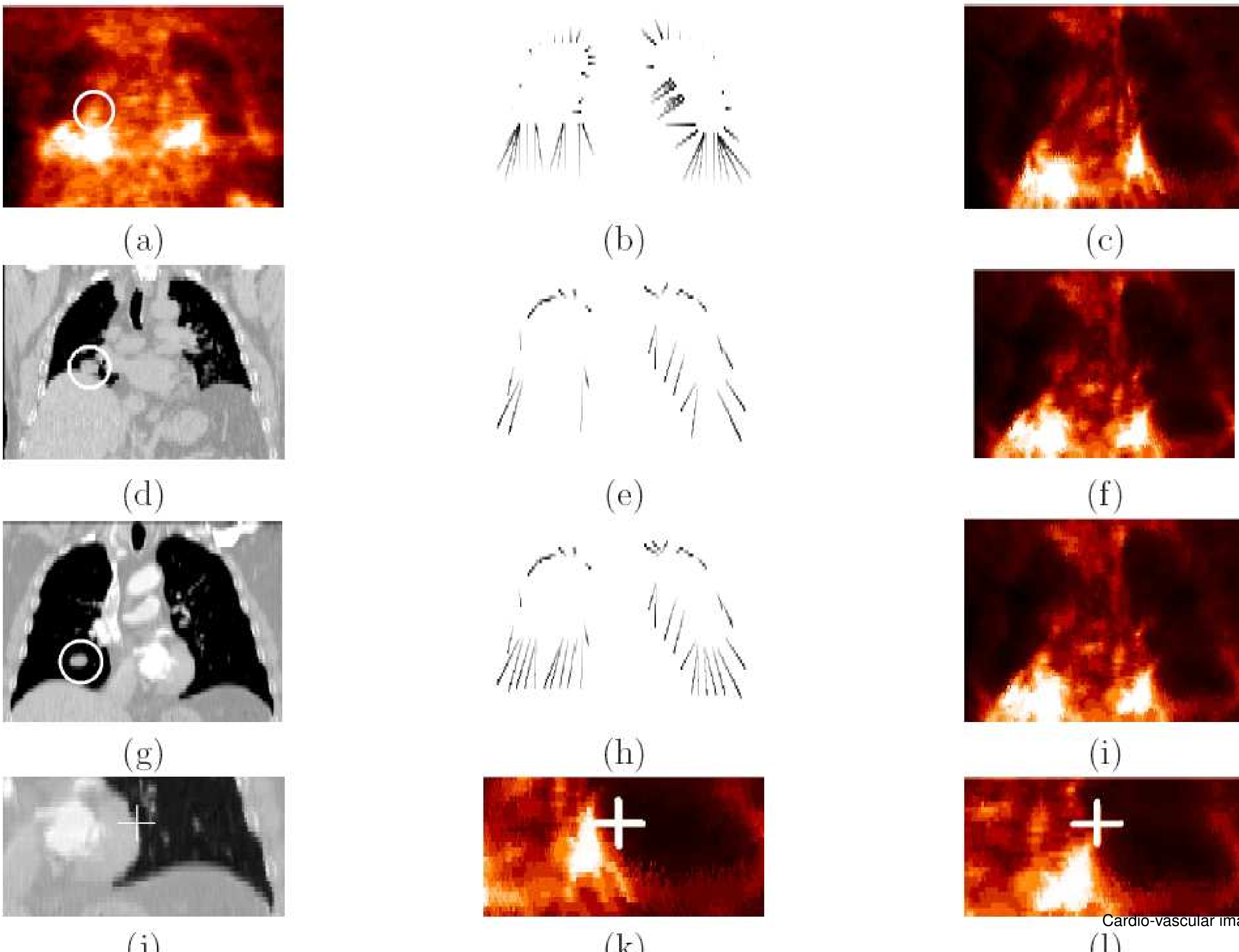






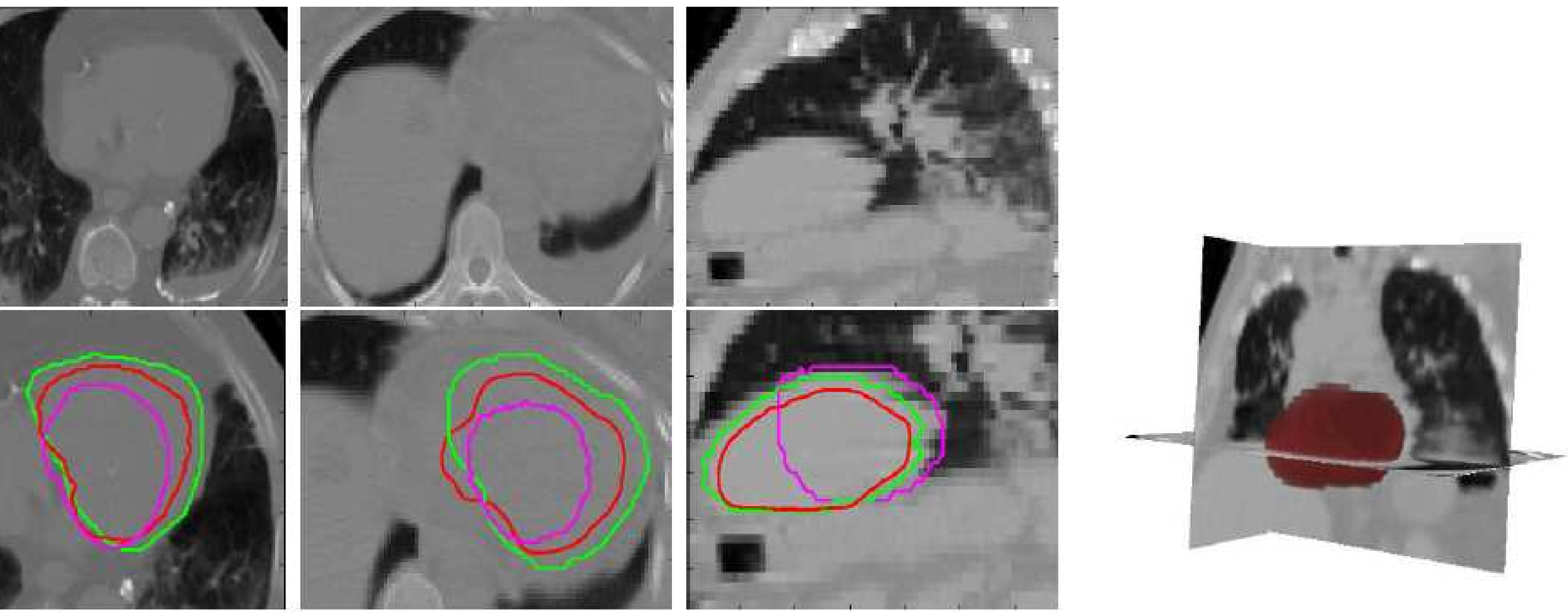


Heart segmentation for oncology applications (A. Moreno, J. Wojak)



Heart segmentation for oncology applications (A. Moreno, J. Wojak)

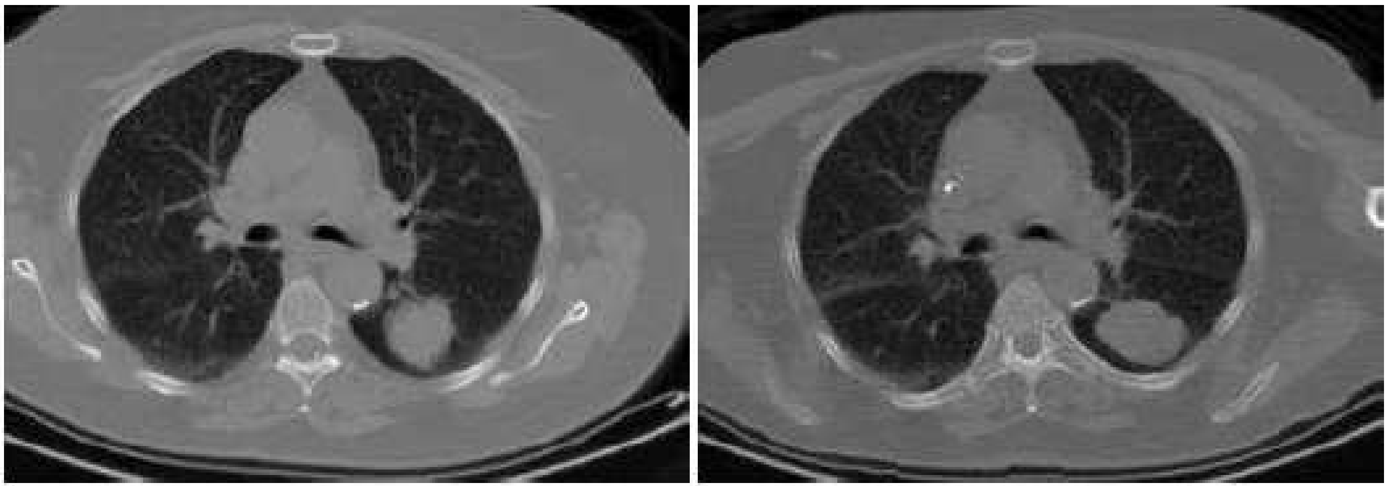
Using shape constraints



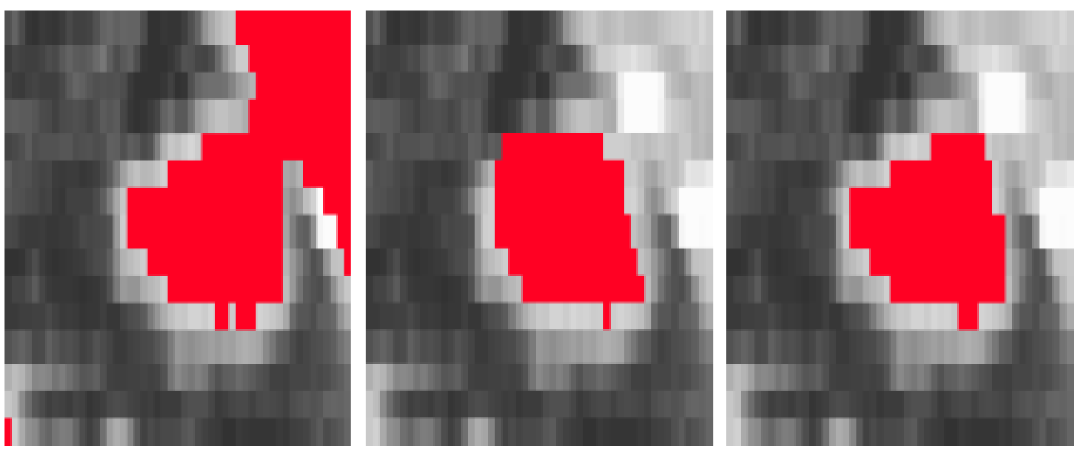
Magenta = structural constraints, red = shape constraints, green = manual

Heart segmentation for oncology applications (A. Moreno, J. Wojak)

Follow-up



CT in 2007 CT in 2008

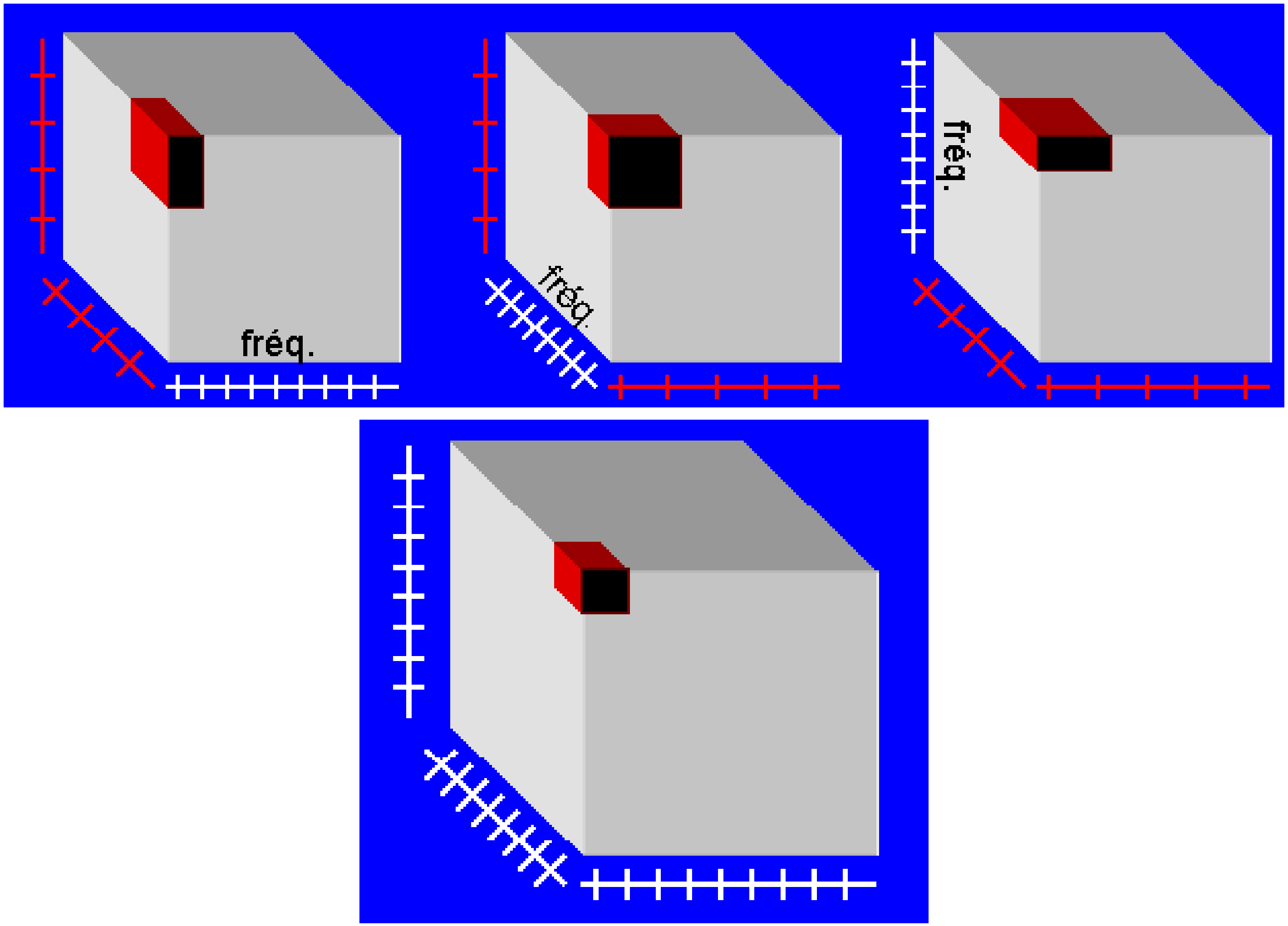


Output: Weak prior | Output: Strong prior | Output: medium prior

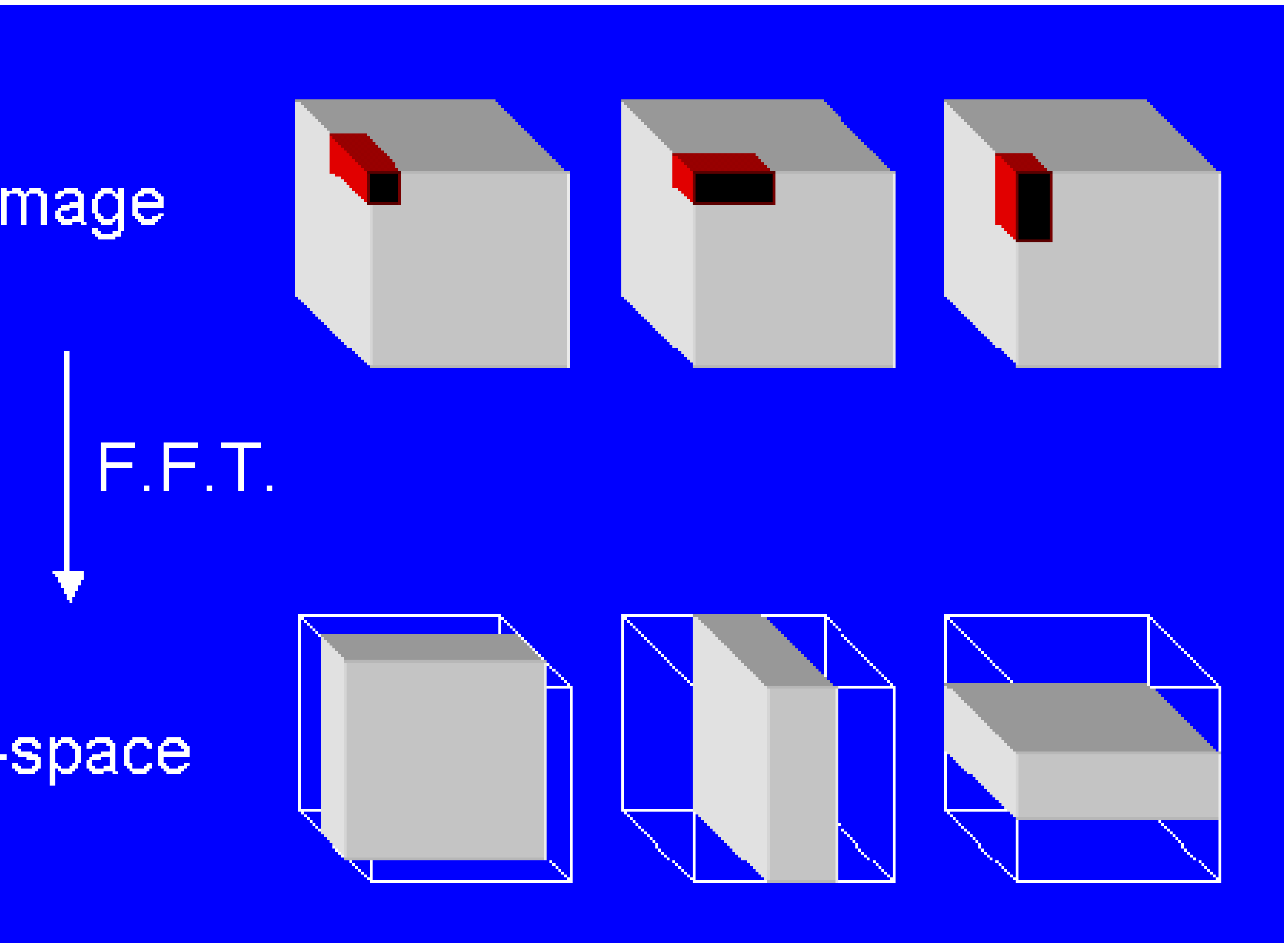
Image processing for vascular imaging

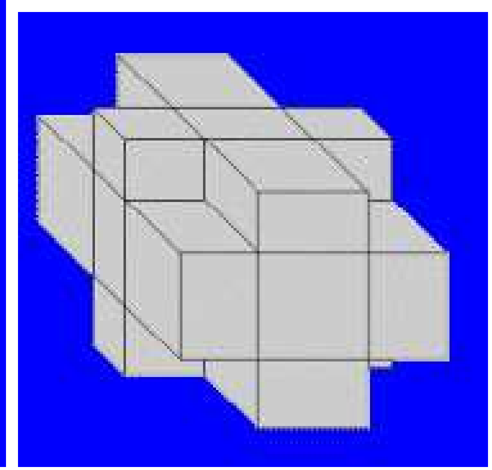
1. High quality reconstruction from multiple MRI acquisitions.
2. Segmentation of brain vessels from MRA.
3. Segmentation of coronary vessels from high resolution CT.

High quality reconstruction from multiple MRI acquisitions (E. Roullot)

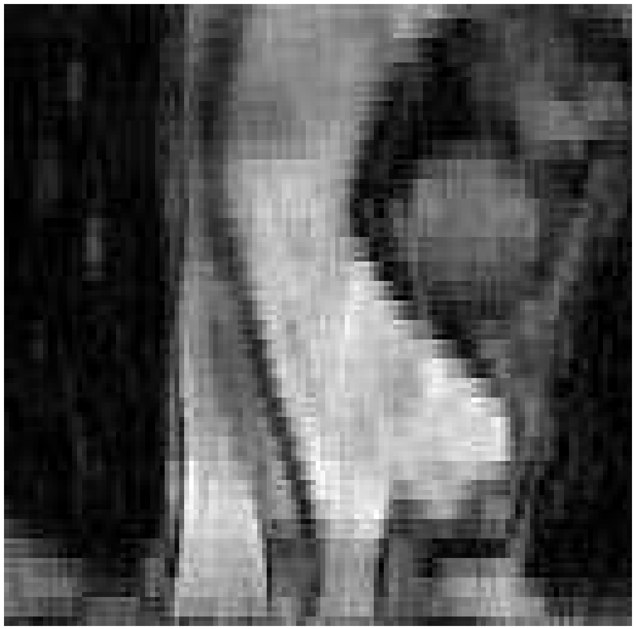


High quality reconstruction from multiple MRI acquisitions (E. Roullot)

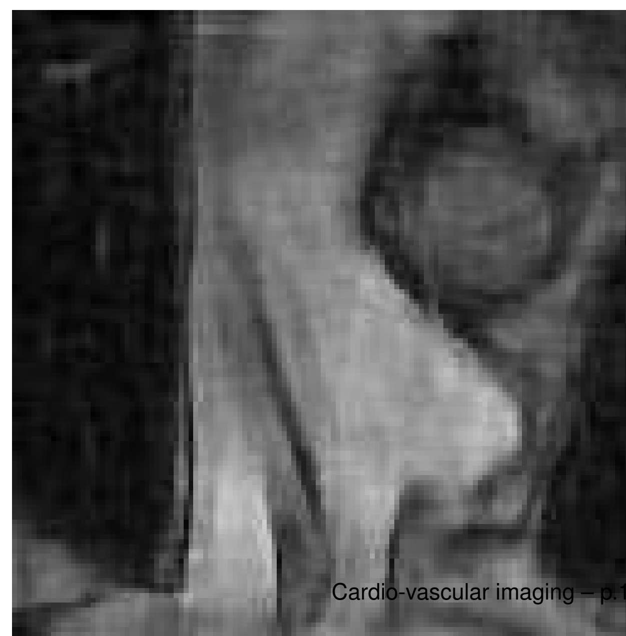




High quality reconstruction from multiple MRI acquisitions (E. Roullot)



result_anime



Vessel segmentation for...

- better visualization,
- diagnosis assistance (detection, quantification),
- virtual endoscopy...

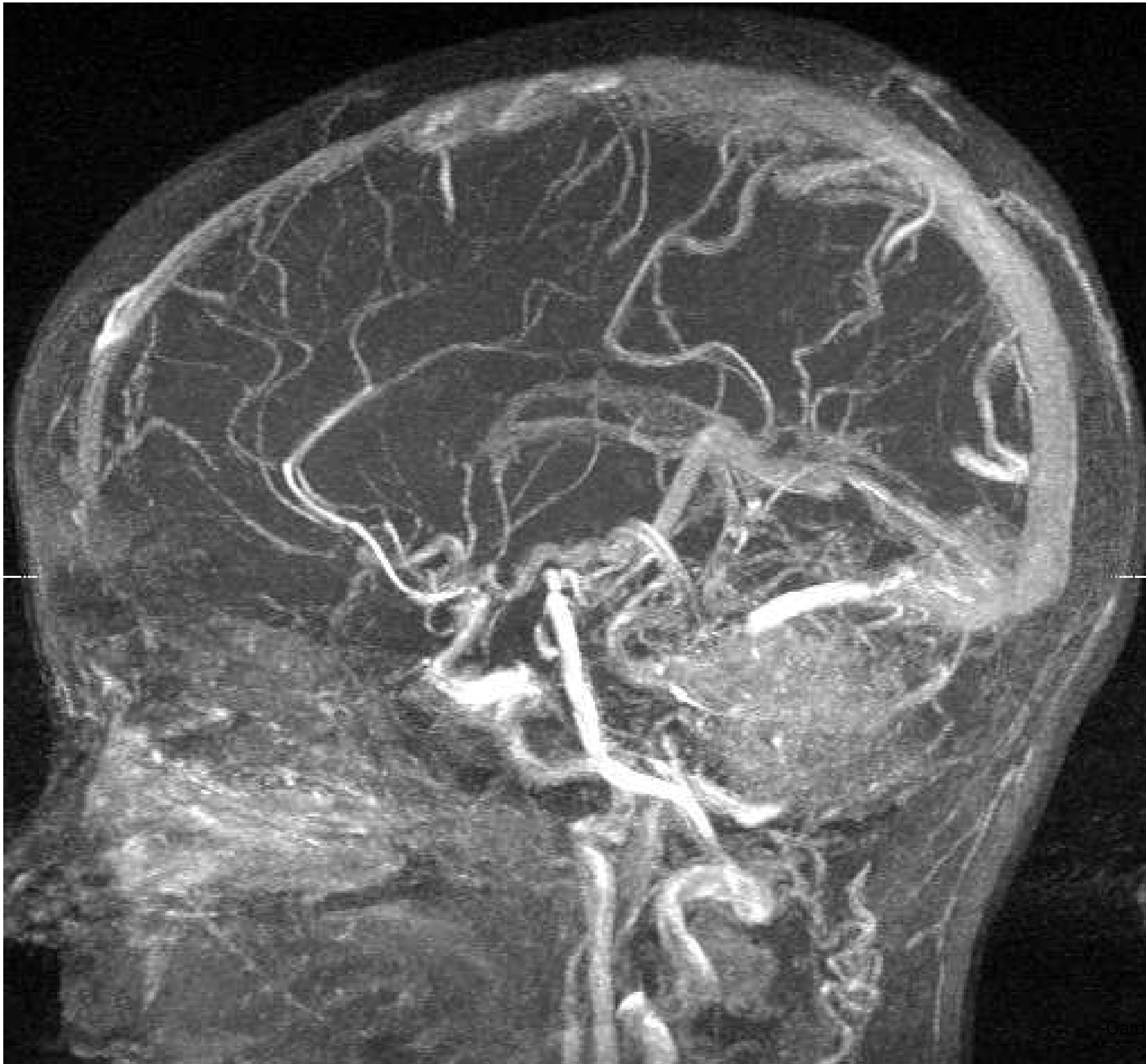
Some issues:

- classical ones: resolution, noise, partial volume effect...
- vessel specific: thin structures, bifurcations, anomalies...

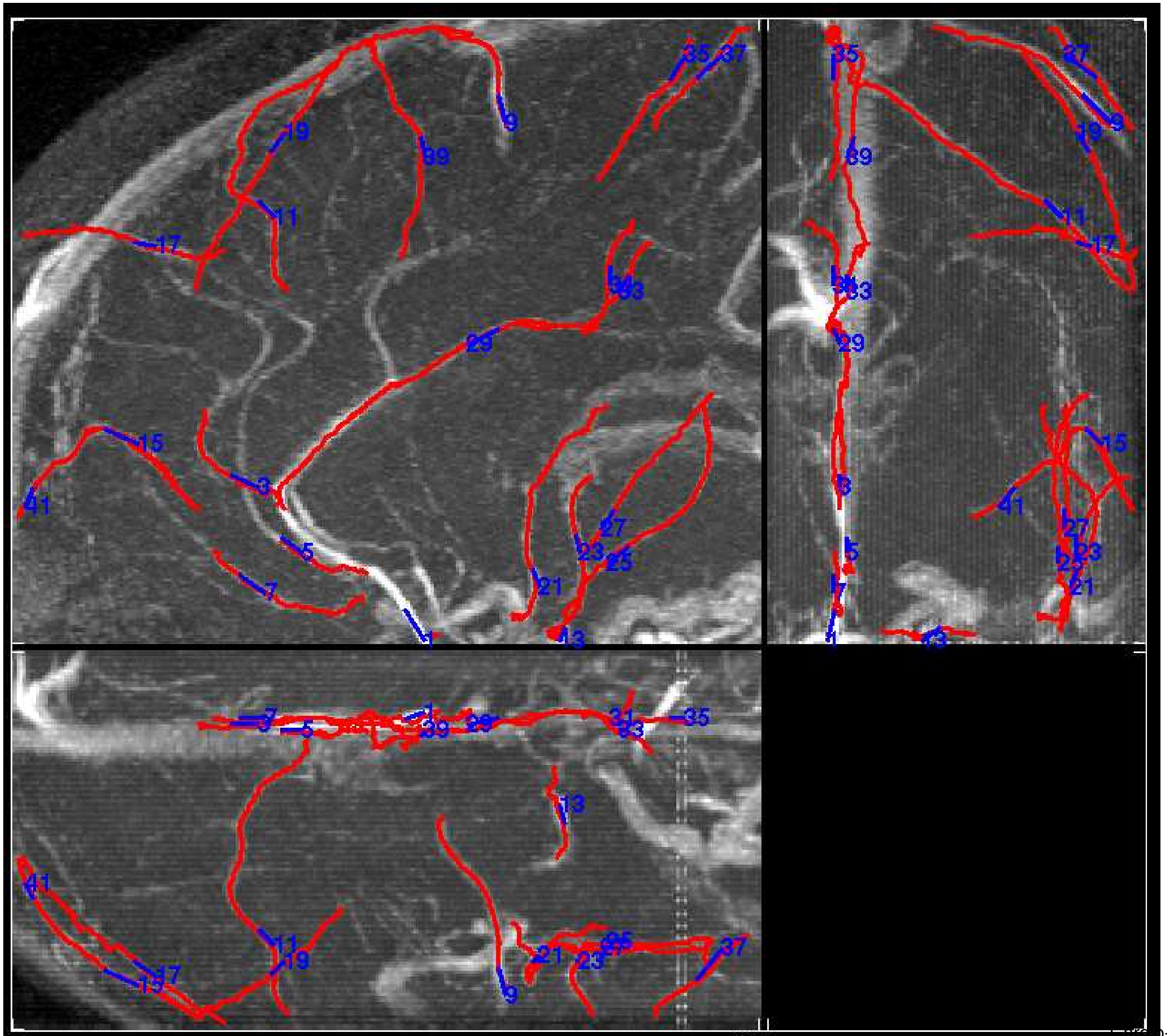
Three important components

- models (hypotheses),
- features (image information),
- extraction techniques.

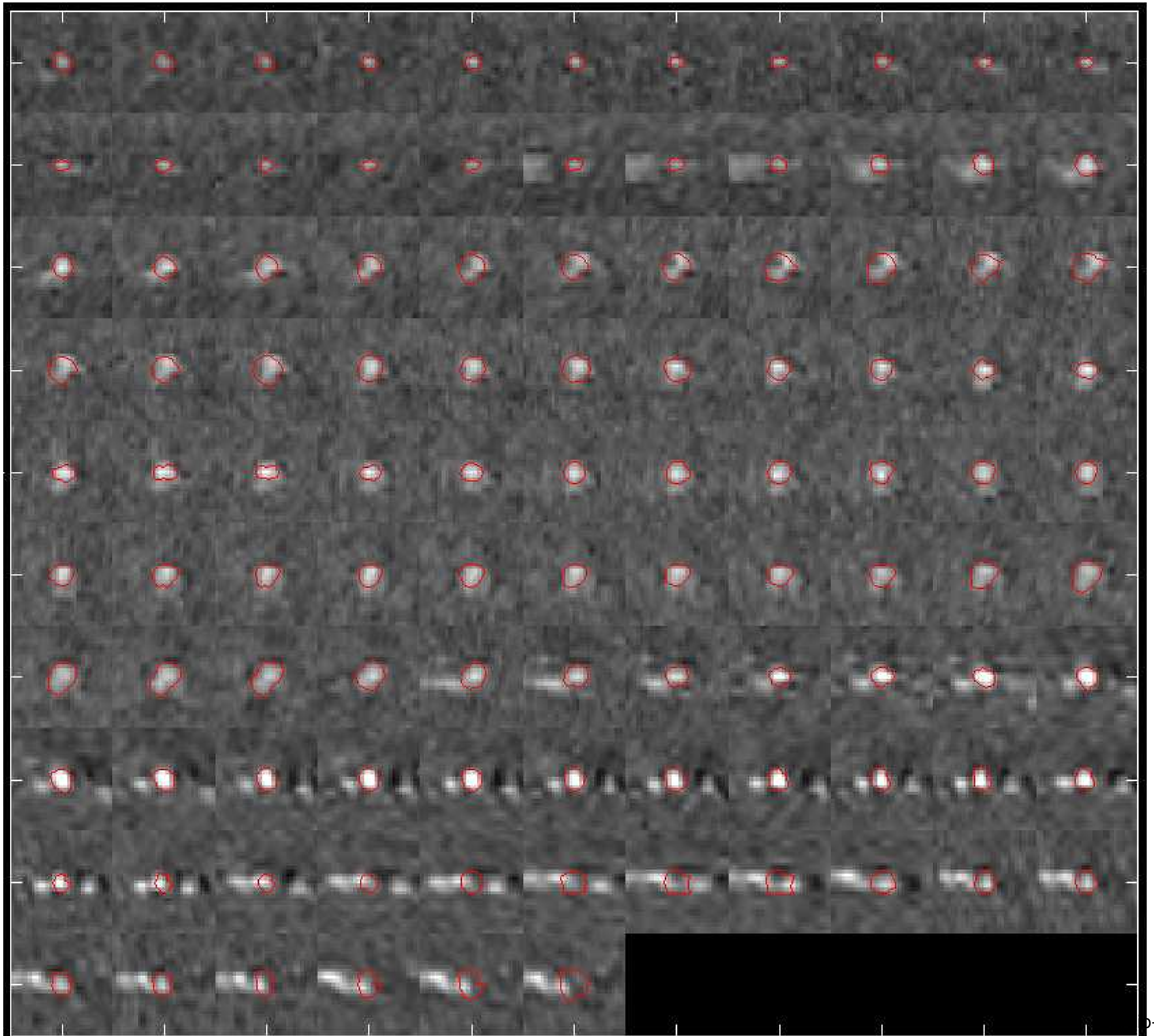
Segmentation of brain vessels from MRA (B. Verdonck)



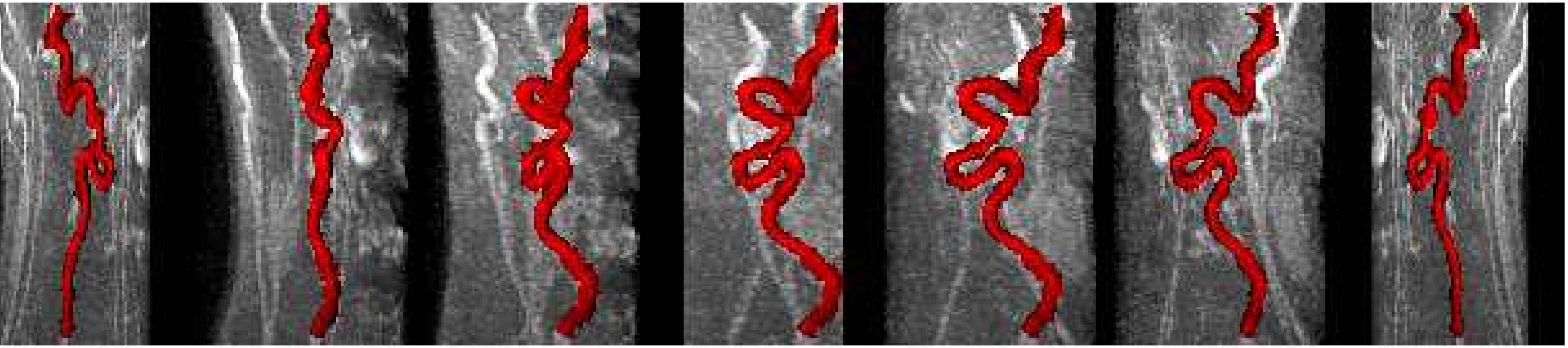
Segmentation of brain vessels from MRA (B. Verdonck)



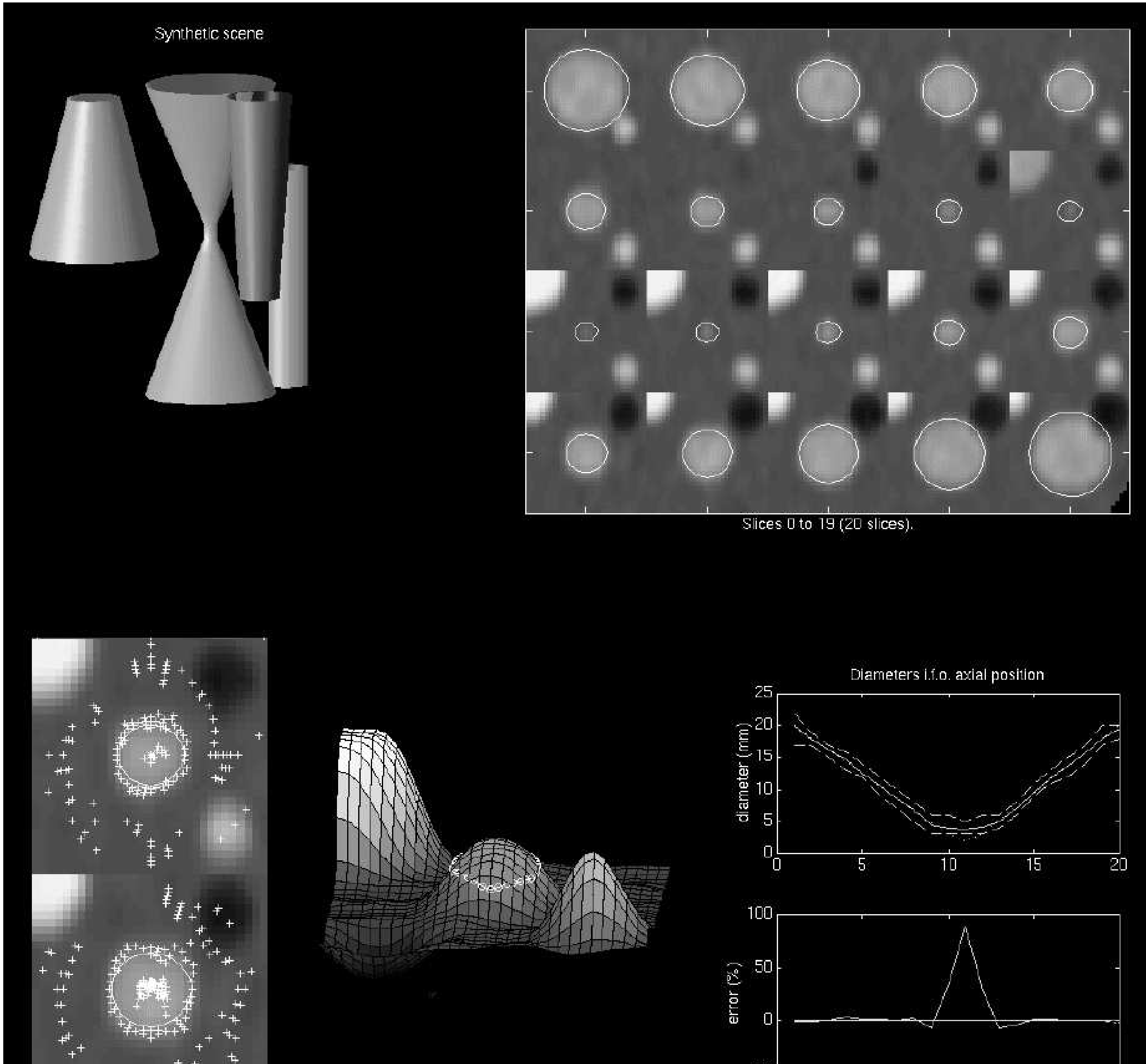
Segmentation of brain vessels from MRA (B. Verdonck)



Segmentation of brain vessels from MRA (B. Verdonck)



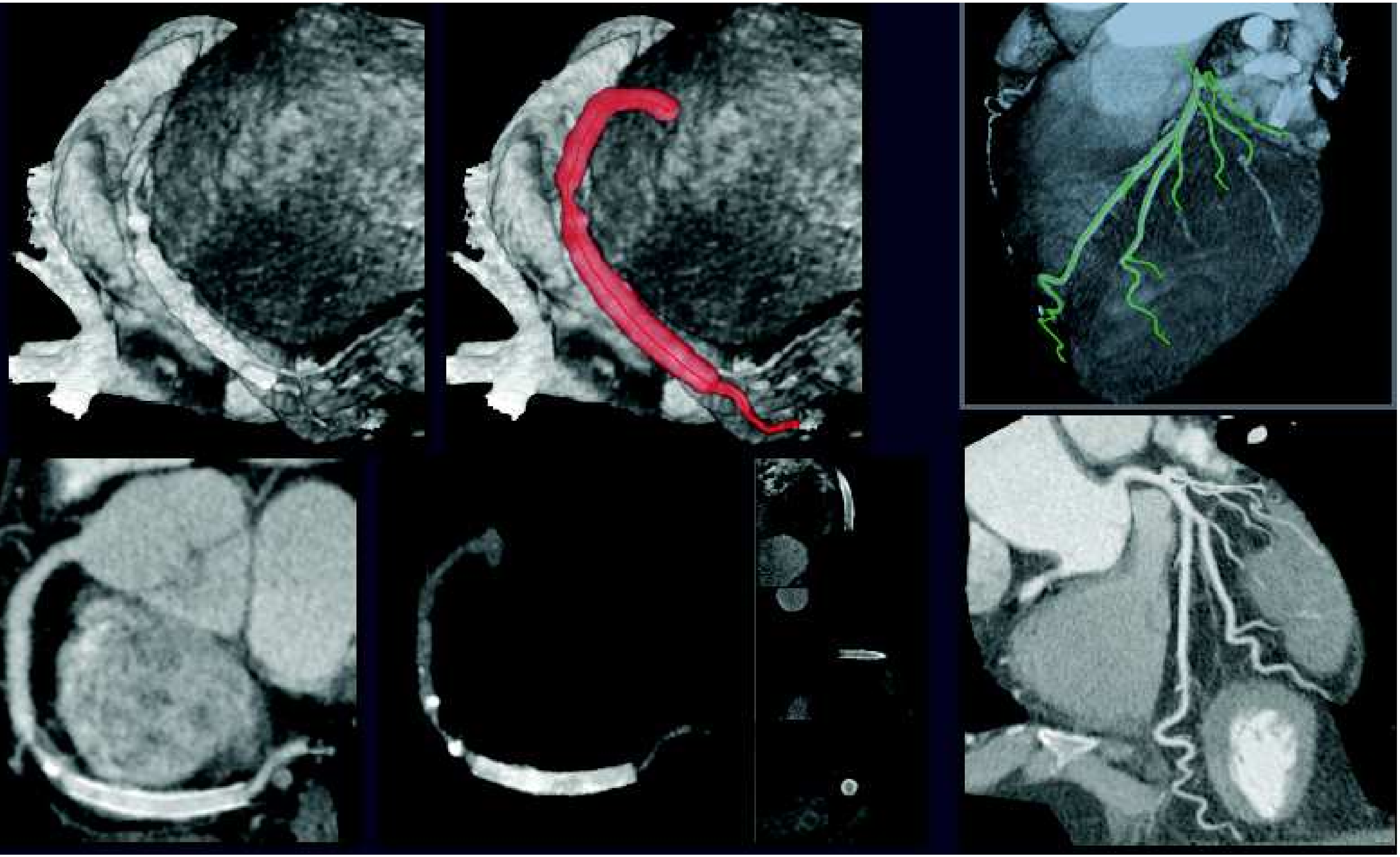
Segmentation of brain vessels from MRA (B. Verdonck)



Segmentation of coronary vessels from high resolution CT (D. Lesage)

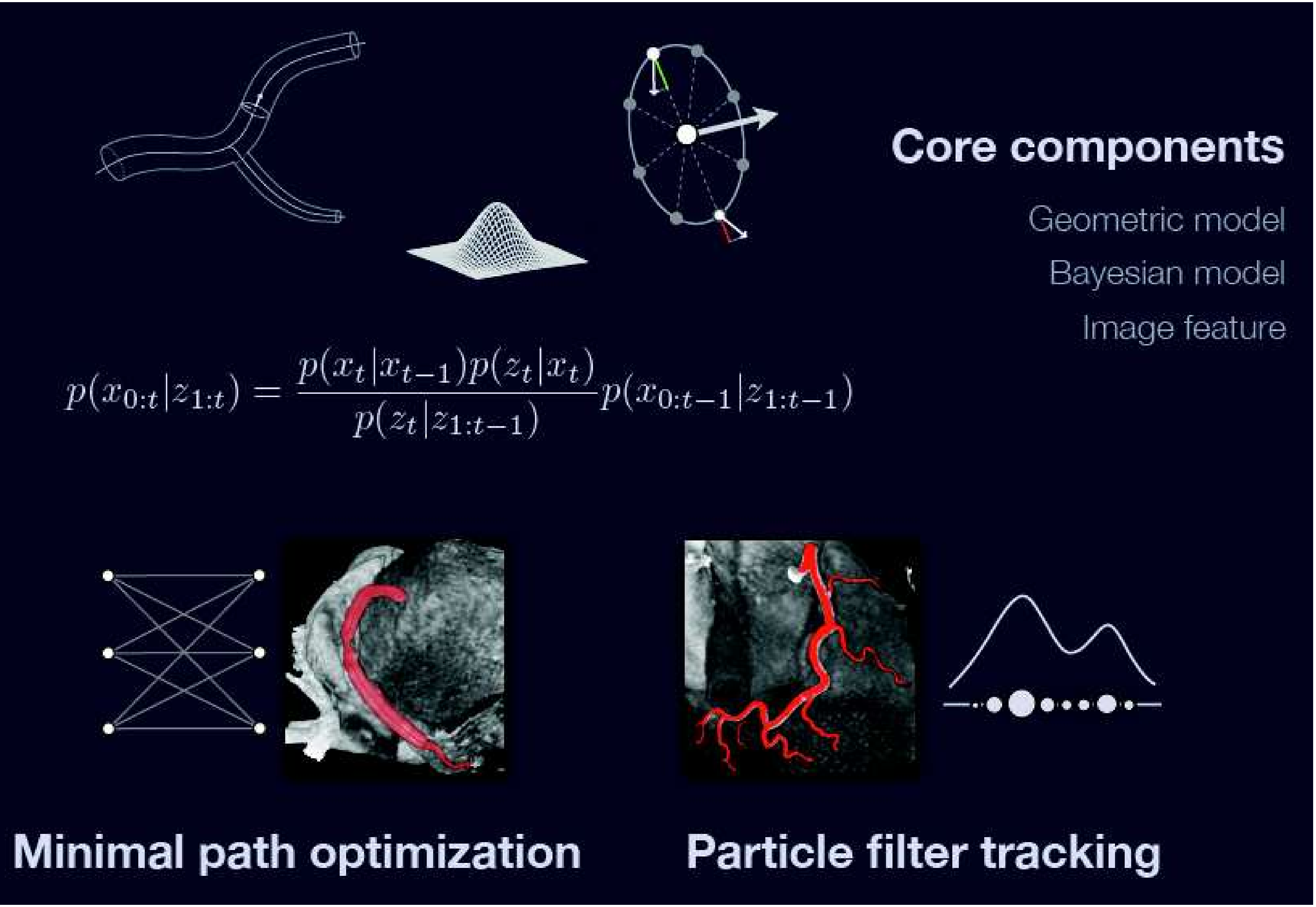
- Collaboration with Siemens Corporate Research.
- High resolution CT: $\sim$ 0.33 mm.
- Vessel model.
- Local features and measurements (flux).
- Segmentation expressed as a tracking process in a Bayesian framework, solved by:
  - minimal path,
  - particle filter.

Segmentation of coronary vessels from high resolution CT (D. Lesage)

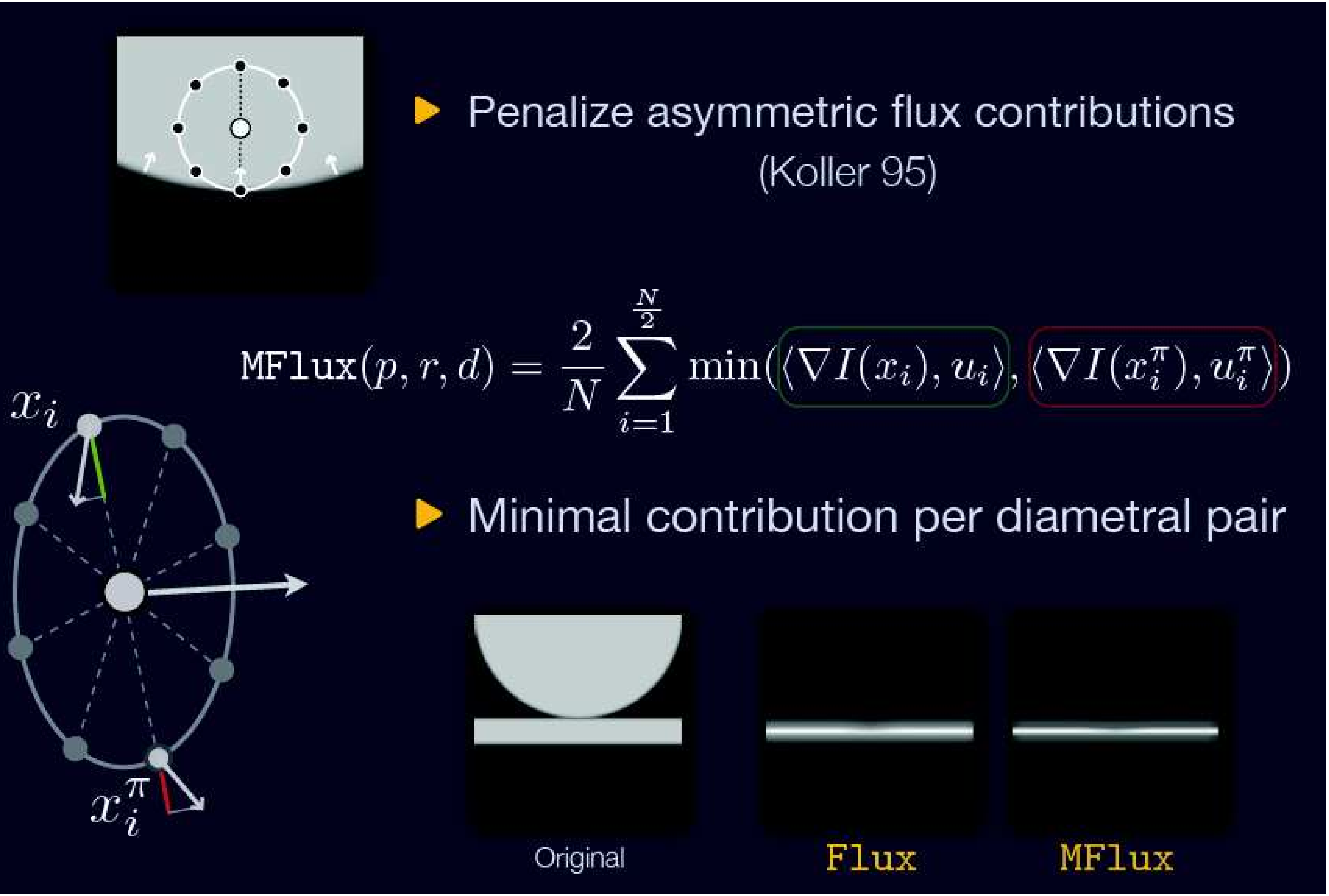


Tracking based approach

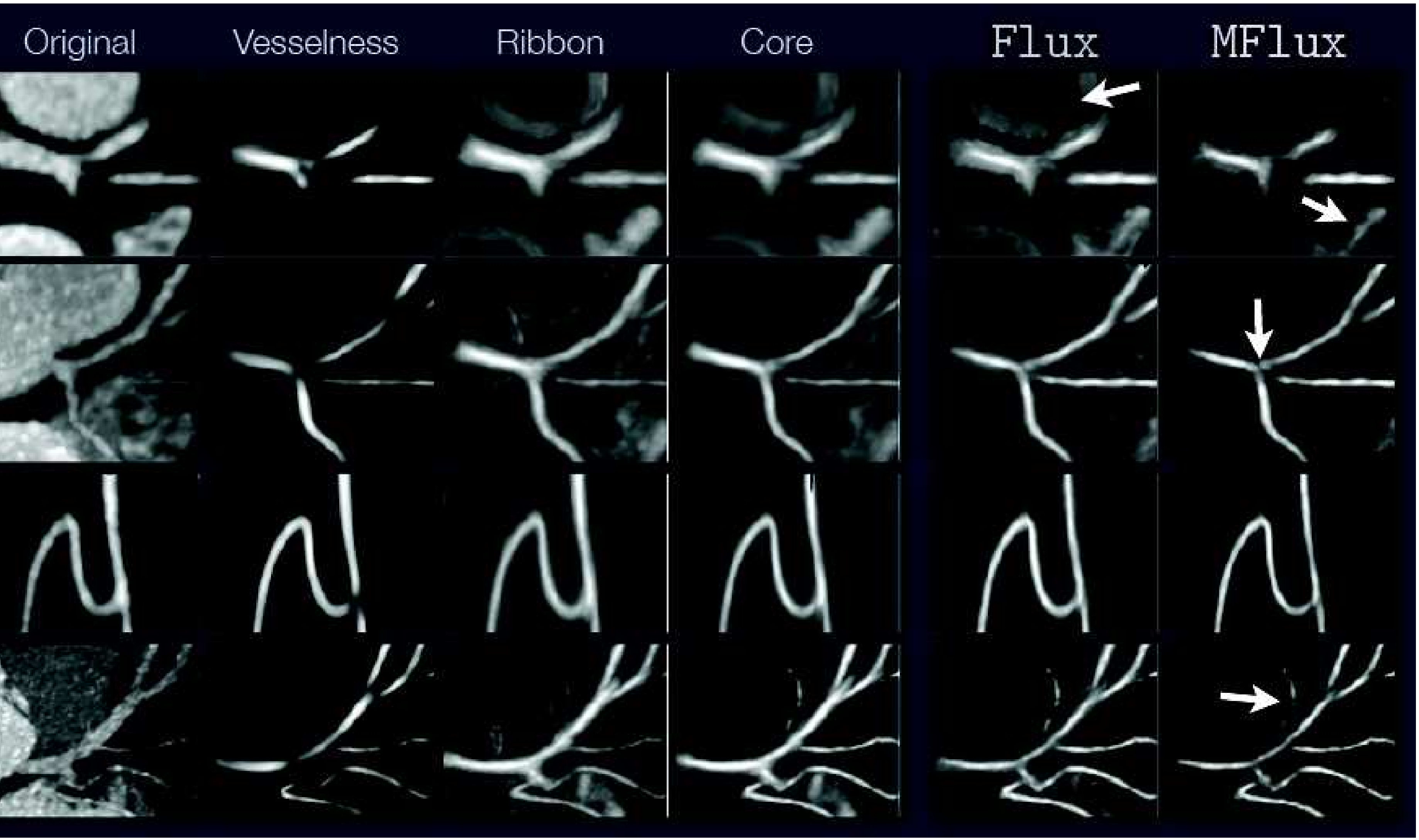
Overview


Core components
Geometric model
Bayesian model
Image feature
$$p(x_{0:t}|z_{1:t}) = \frac{p(x_t|x_{t-1})p(z_t|x_t)}{p(z_t|z_{1:t-1})}p(x_{0:t-1}|z_{1:t-1})$$
Minimal path optimization
Particle filter tracking

Flux based measure

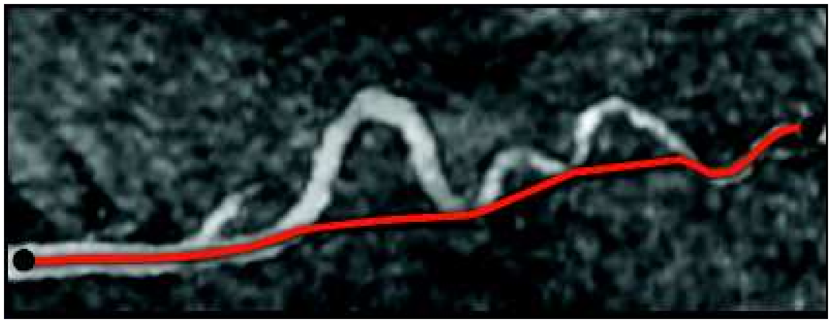


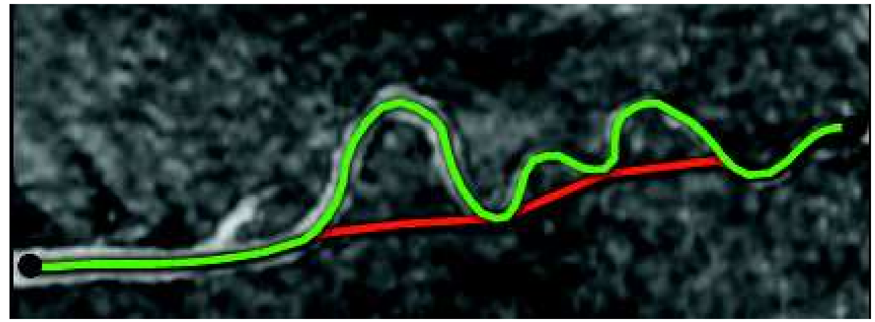
Comparison with other measures



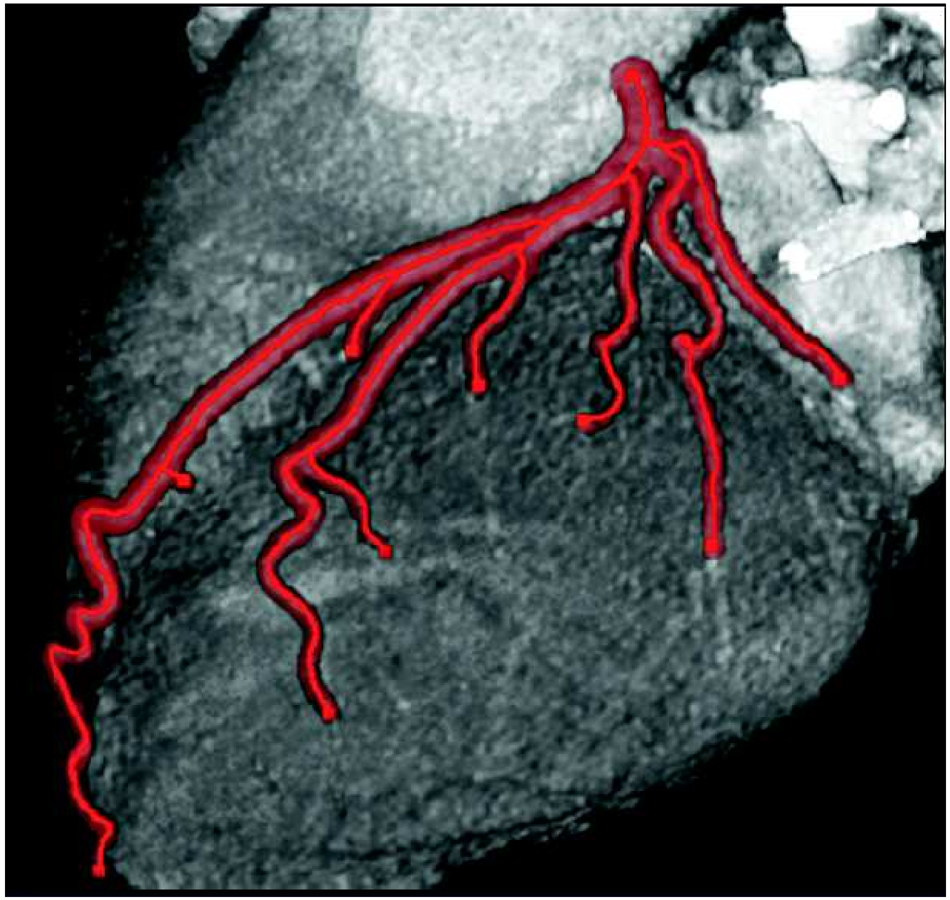
Minimal path approach

Metric choice

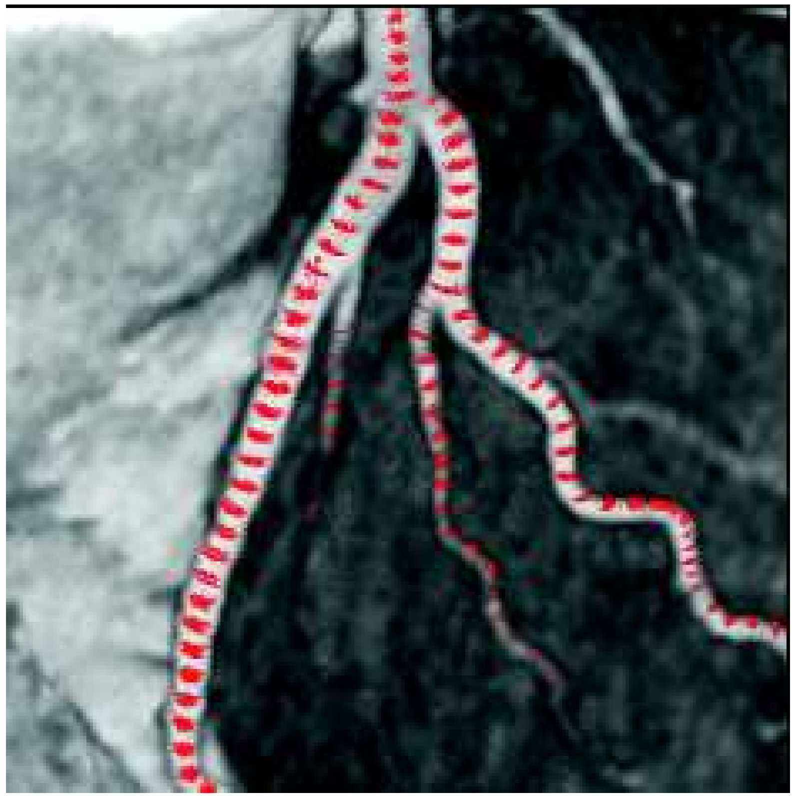




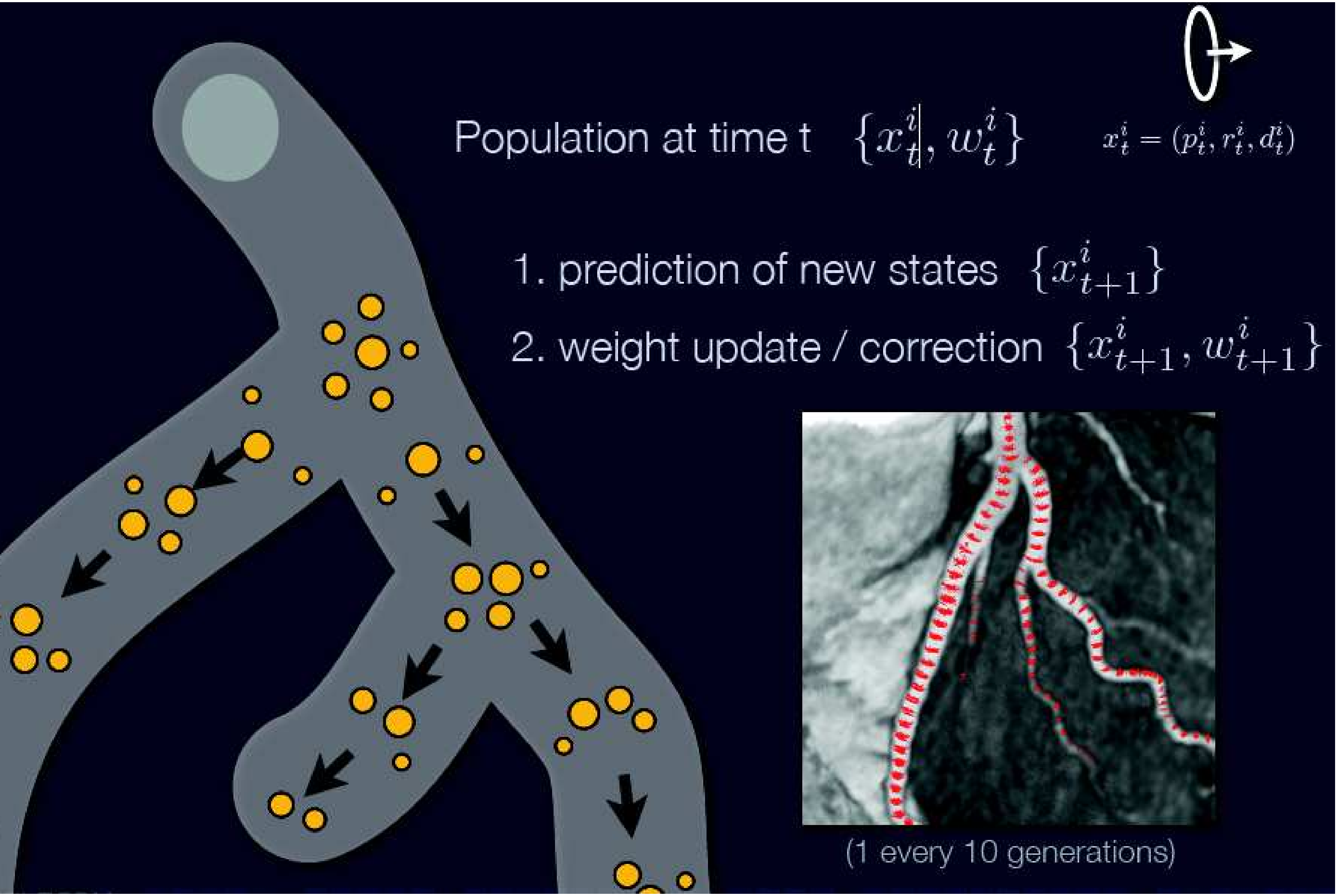
Result example



Particle filter

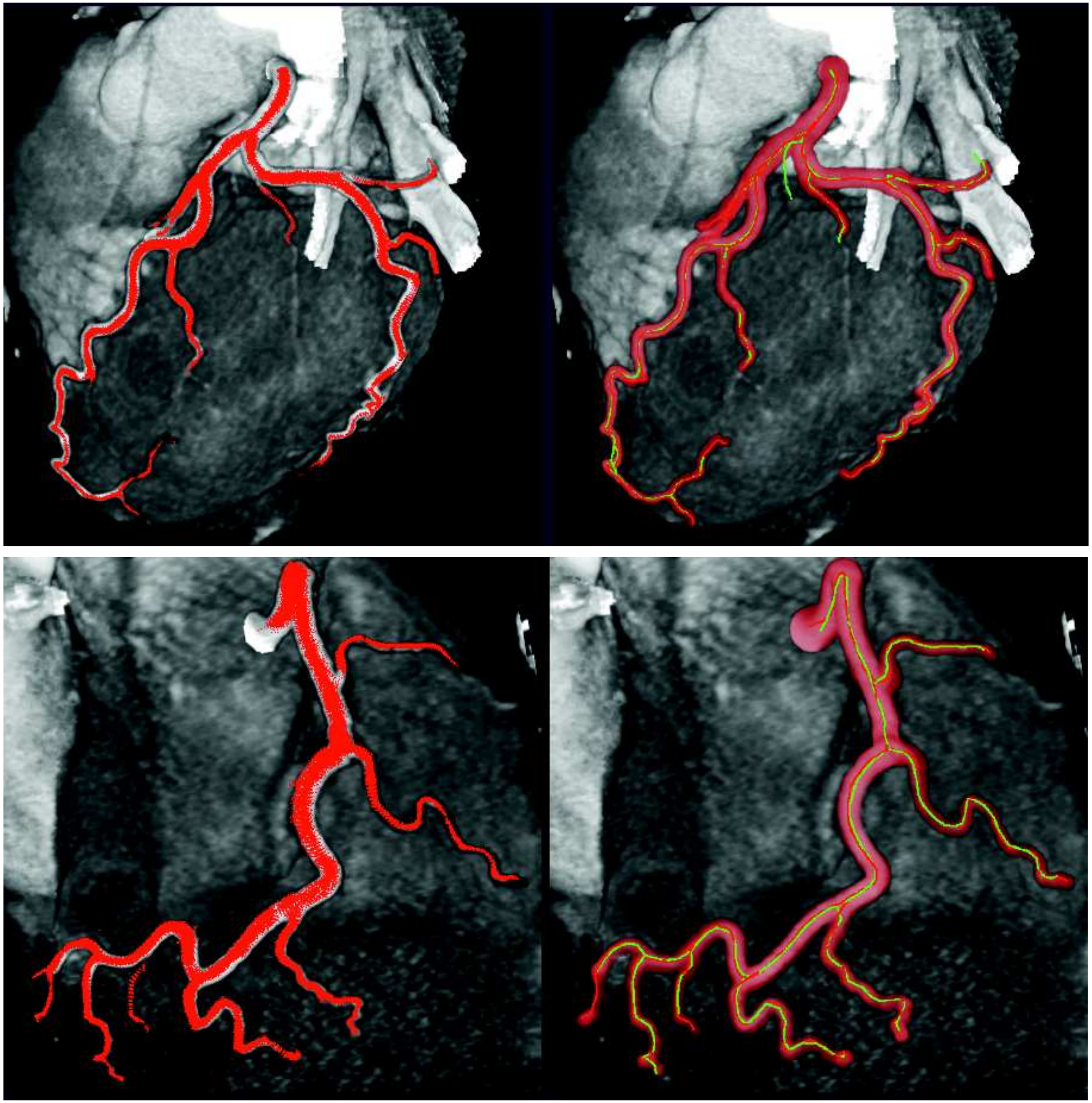


Evolution

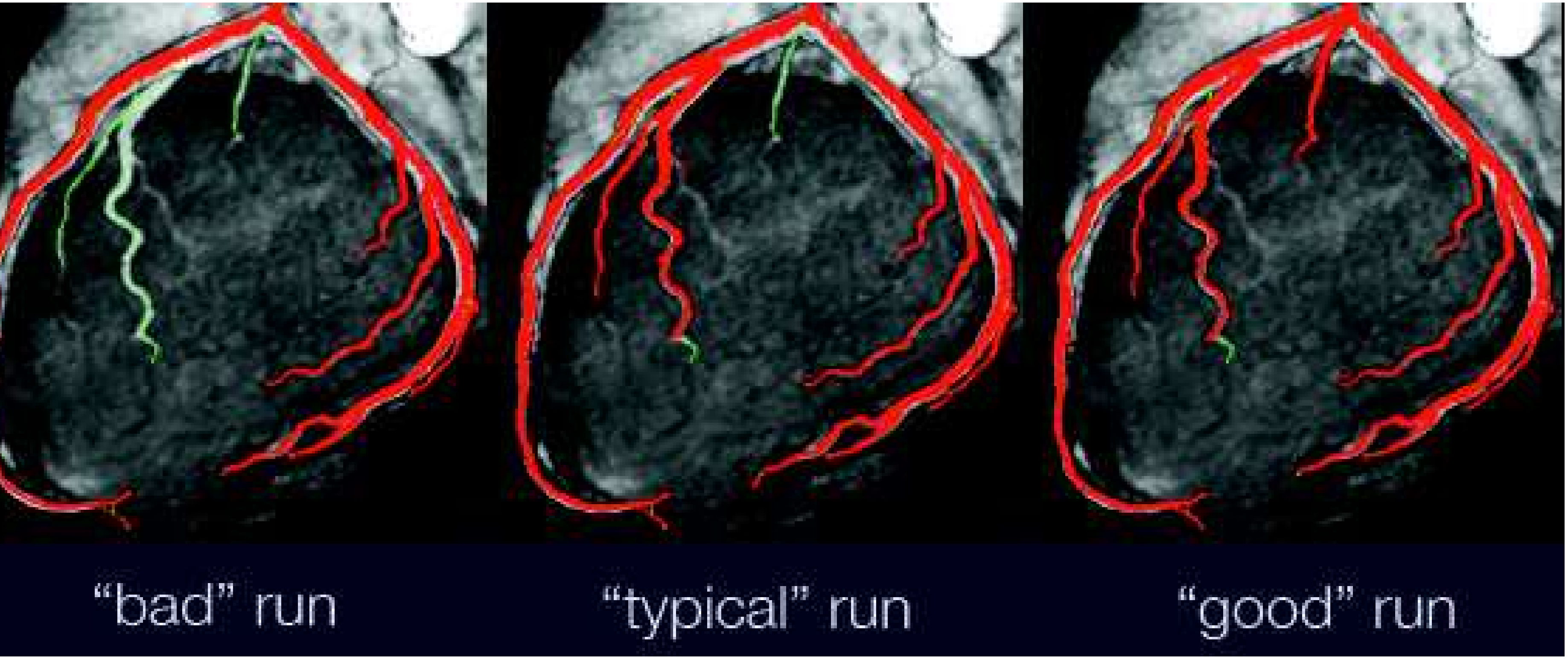


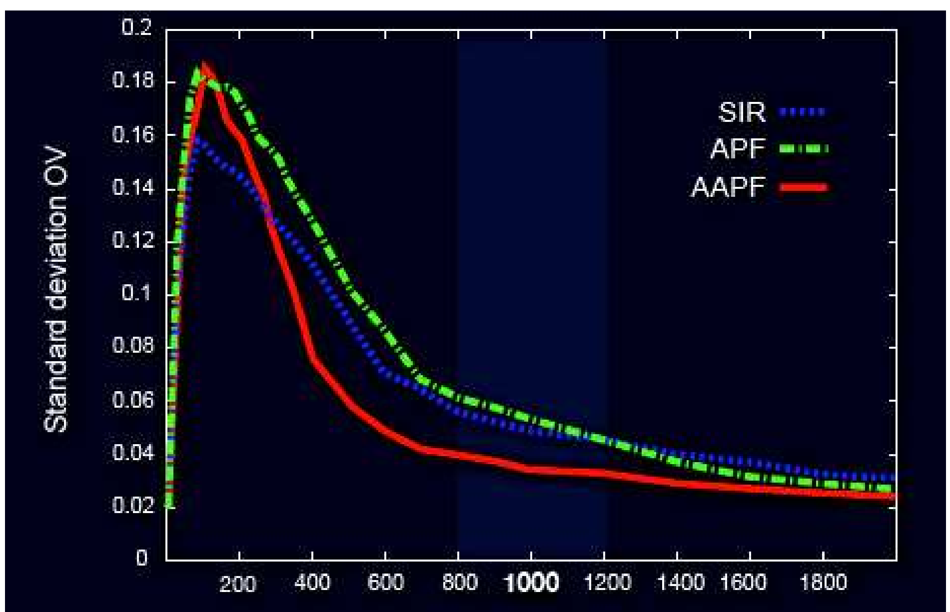
Population at time t $\{x_t^i, w_t^i\}$
$x_t^i = (p_t^i, r_t^i, d_t^i)$
1. prediction of new states $\{x_{t+1}^i\}$
2. weight update / correction $\{x_{t+1}^i, w_{t+1}^i\}$
(1 every 10 generations)

Result examples and evaluation



Result examples and evaluation





Comparison of the two approaches

Evaluation on the Rotterdam database (http://coronary.bigr.nl).

Measure	Minimal path (H = 4)	Particle filter (N = 1000)
Overlap	85 %	86.2 %
Distance to the central line (mm)	0.31	0.25
Error on radius (mm)	0.2	0.2
Computation time	1 min	4 min

- FP: less false positives (more robust stopping criterion).
- FP: more precise (no discretization of space).
- MP: less false negative (missing branches).

Conclusion

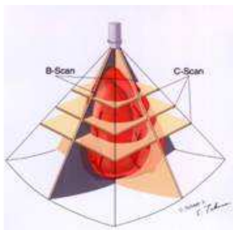
- Segmentation depends on:
  - imaging data,
  - available knowledge,
  - requirements and final objective.
- Derived quantitative measures answering clinical needs.
- Importance of evaluation.
- Normal / pathological cases.
- Temporal / multi-modality images.
- Bifurcations and distal information (still open).

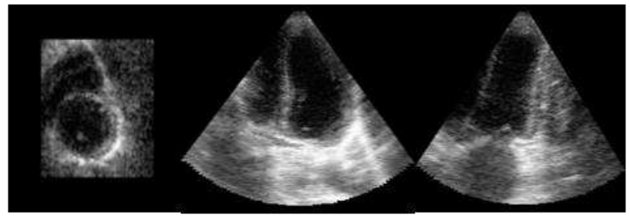
Other applications and examples:

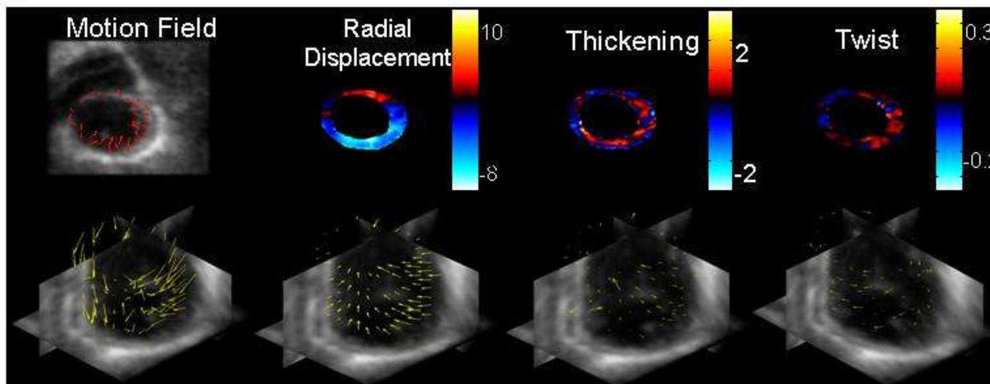
- other modalities (US, Doppler US, tagged MRI, DTI, TEP...),
- T1/T2 distribution,
- movement analysis,
- perfusion dynamics,
- 3D + t + multi-modal modeling of the heart,
- ...

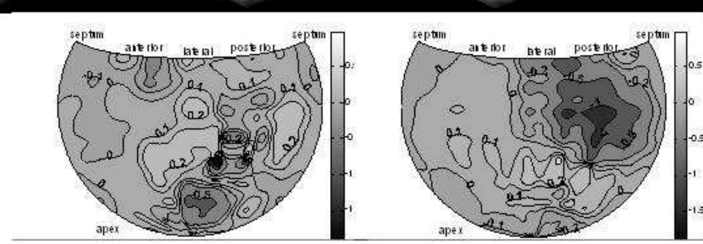
A few images

US









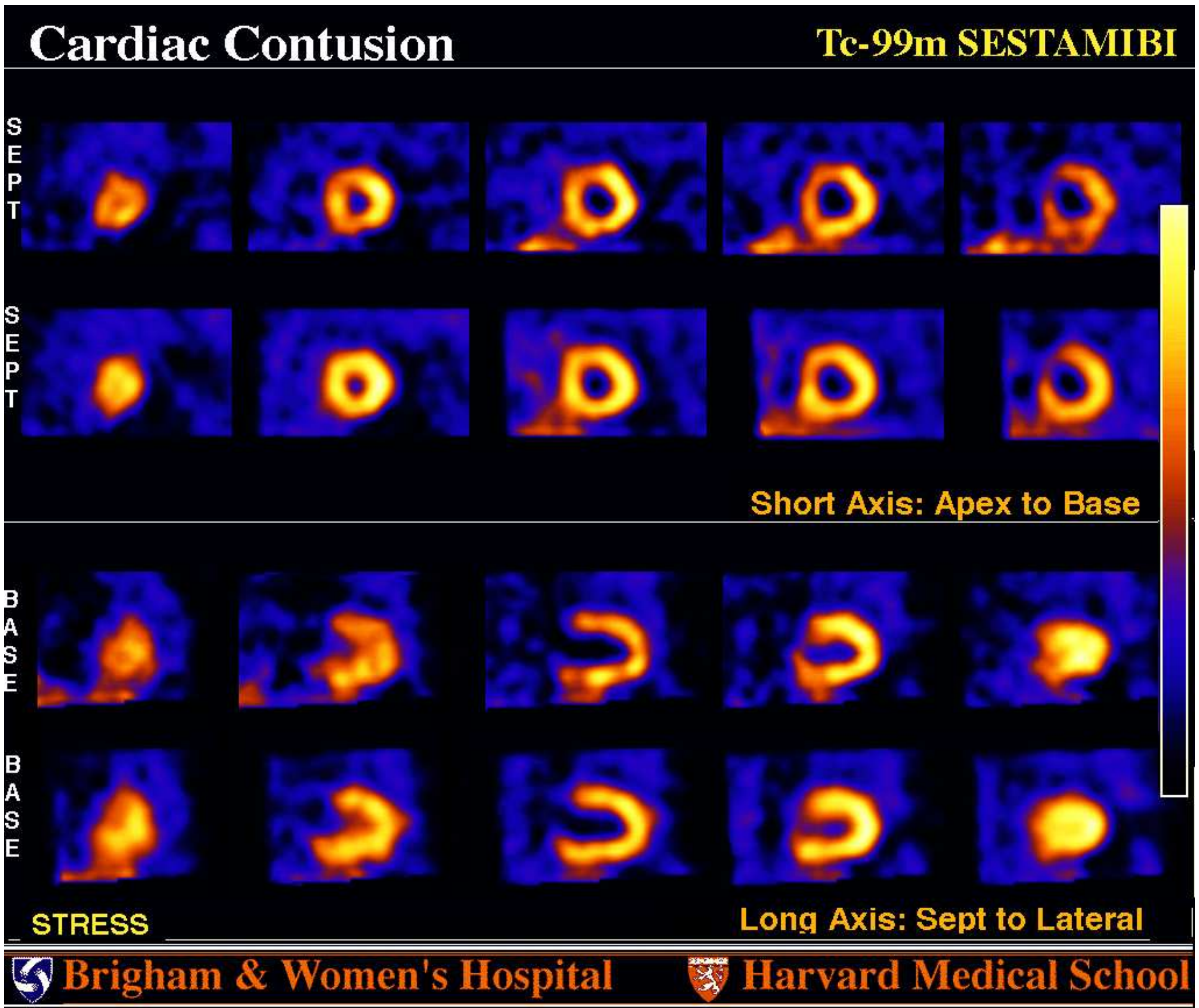
OF vs. manual tracing

OF vs. QLAB© segmentation

E. Angelini

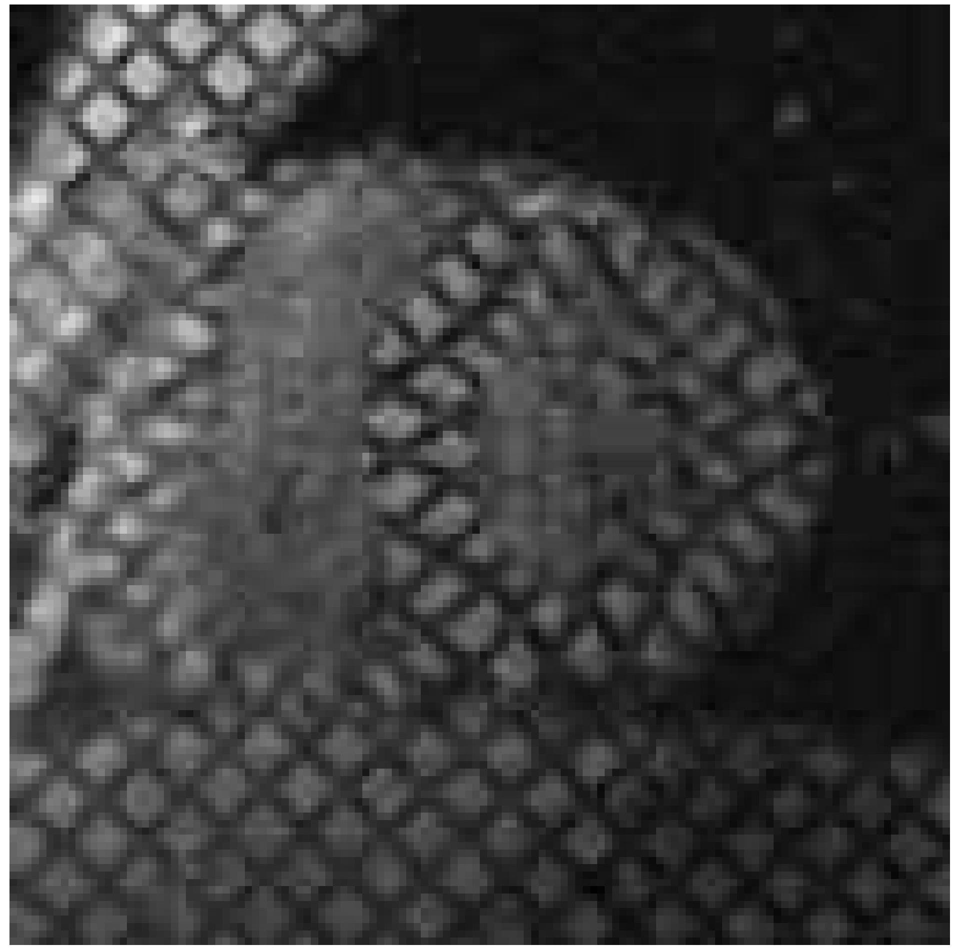
A few images

TEP



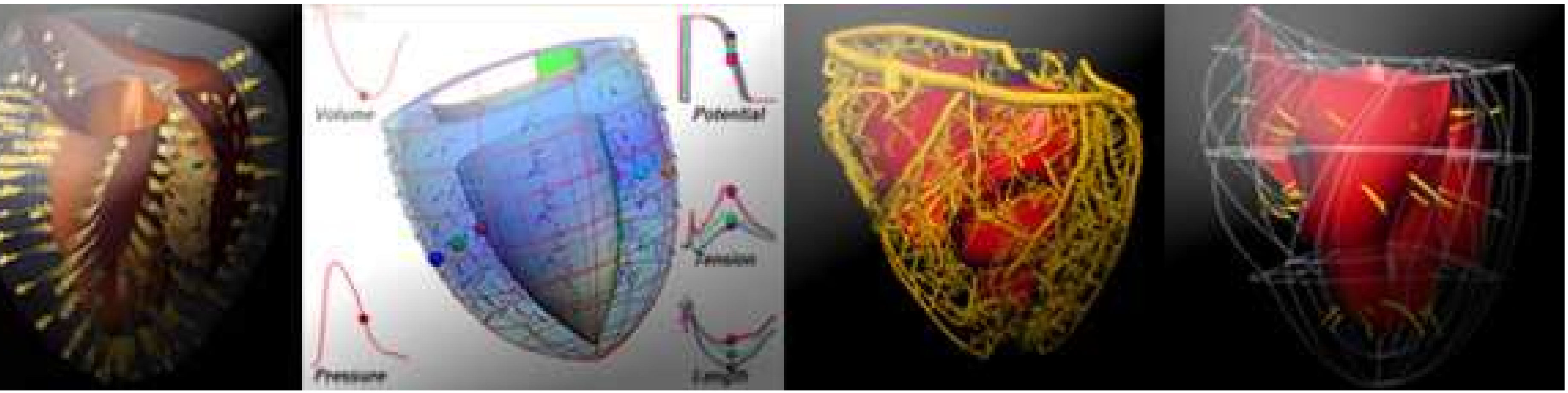
A few images

Tagged MRI



A few images

Whole heart model: Physiome project



Models of electrical activation and myocardial mechanics at the whole organ level - http://www.physiome.ox.ac.uk/