The invisible becomes quantifiable in coronary computed tomography angiography exams with CT-FFR

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Coronary Artery Disease (CAD)

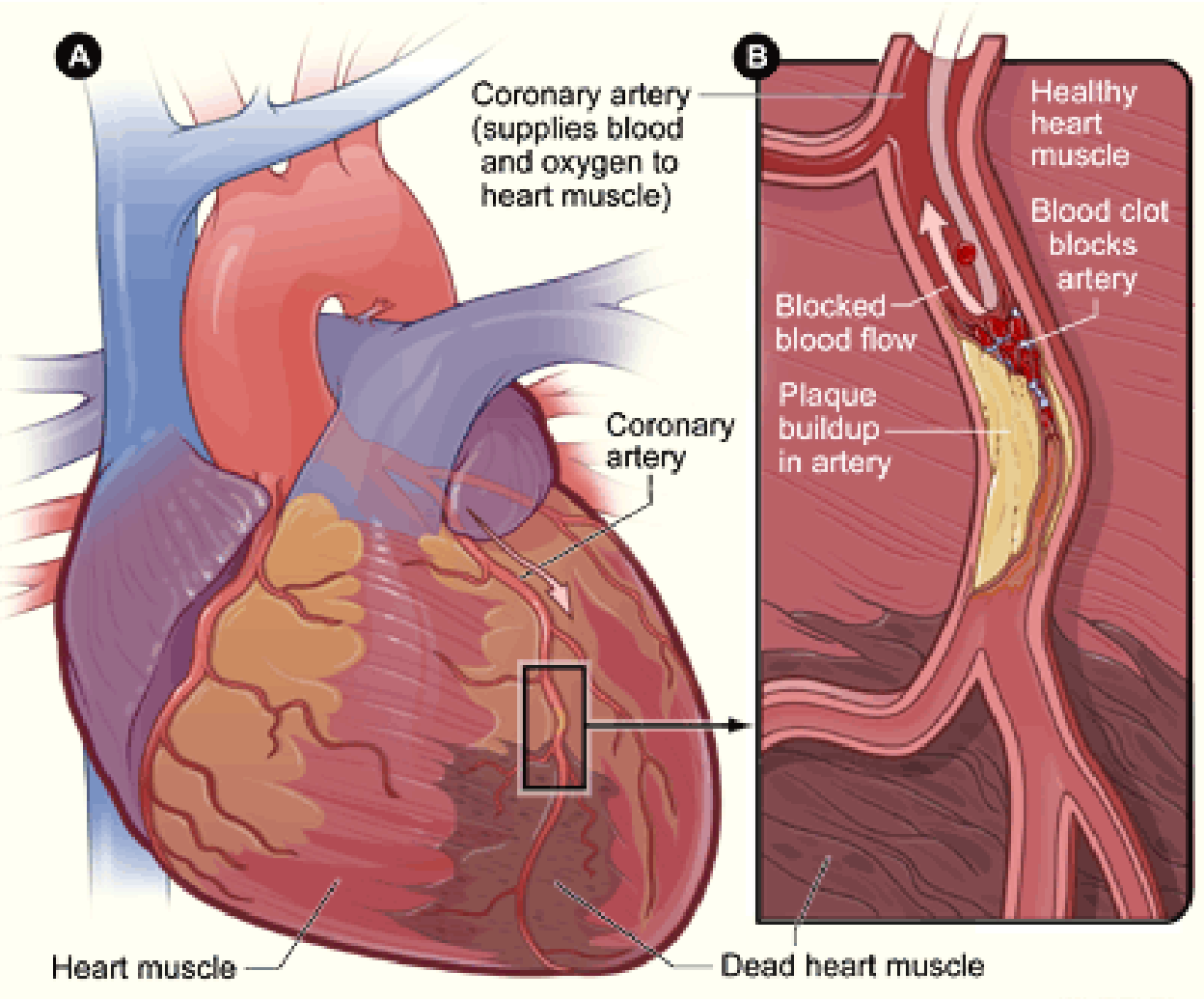

Image source: http://www.nhlbi.nih.gov/health/health-topics/topics/cad/signs

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Evaluating CAD by Coronary Computed Tomography angiography

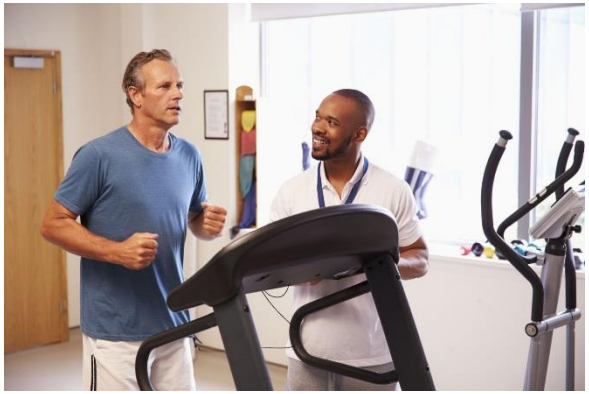

Image source: https://www.health.harvard.edu/heart-disease-overview/cardiac-exercise-stress-testing-what-it-can-and-cannot-tell-you

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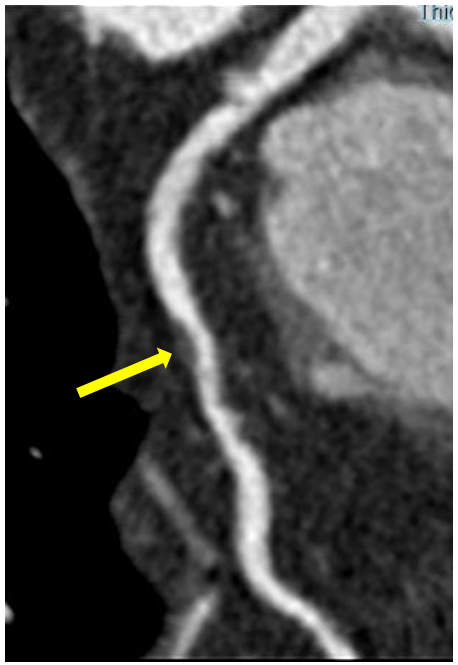
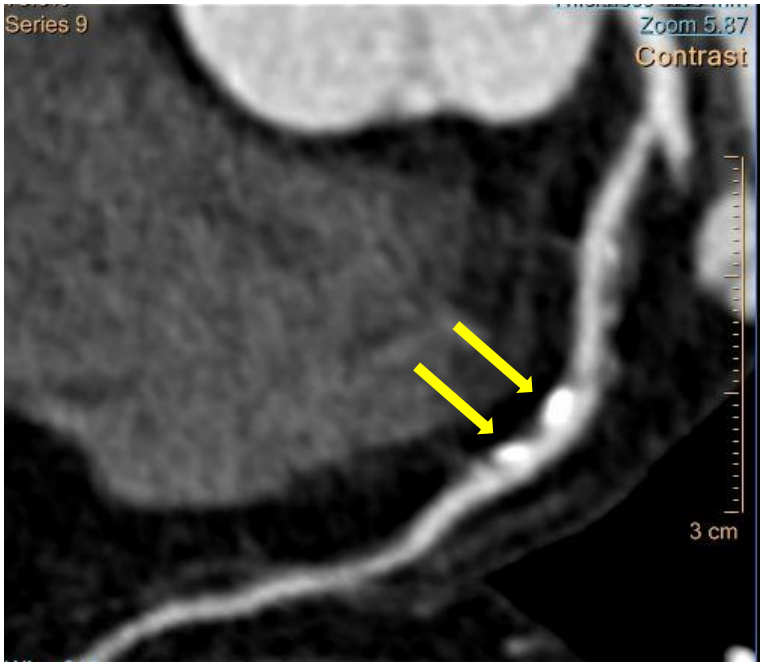
Evaluating chest pain by Coronary Computed Tomography angiography (CCTA)

- Coronary CTA has a high sensitivity and high negative predictive value for diagnosis of obstructive CAD by detecting anatomical narrowing in the coronaries



Soft plaque (darker)



Calcified plaque (brighter)

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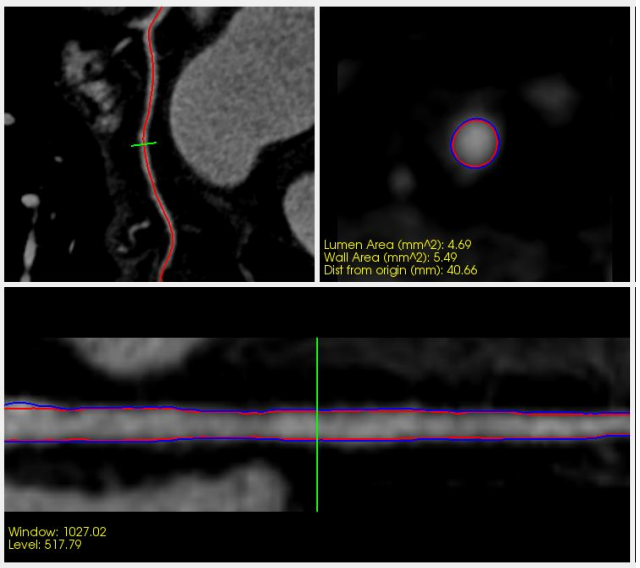
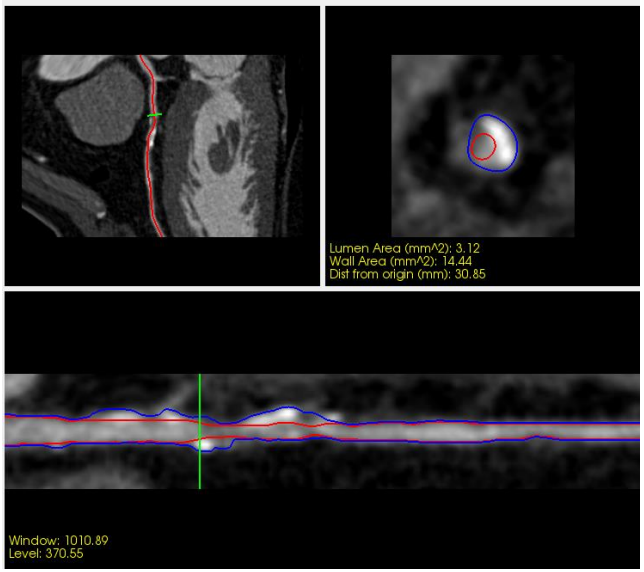
Quantifying coronary artery disease by CCTA

- Stenosis percentage: different clinical definitions
- Recently demonstrated high accuracy: $1 - \frac{\text{lumen cross-sectional area}}{\text{vessel cross-sectional area}}$



Healthy vessel: ~ 0.0



Vessel with CAD: ~ 0.8

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Anatomical assessment of intermediate disease with CCTA is not enough

- >50% of lesions with greater than 50% diameter stenosis by CCTA were not functionally significant

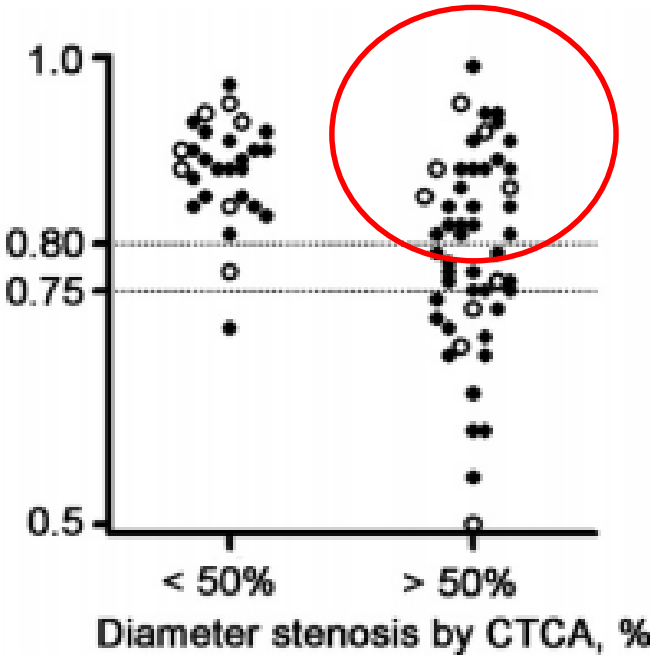

Image source: Meijboom et al. J Am CollCardiol 2008;52:636–43

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Anatomical assessment of intermediate disease with CCTA is not enough

- >50% of lesions with greater than 50% diameter stenosis by CCTA were not functionally significant

Too many unnecessary invasive coronary angiography

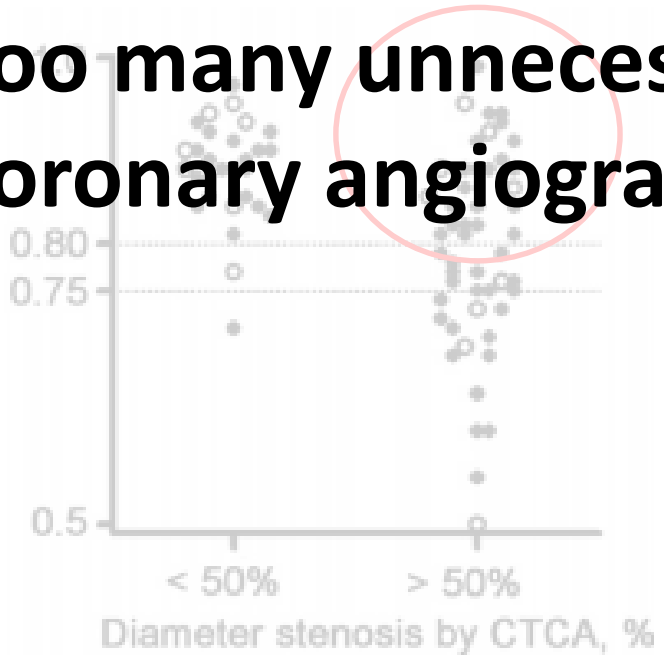

Image source: Meijboom et al. J Am CollCardiol 2008;52:636–43

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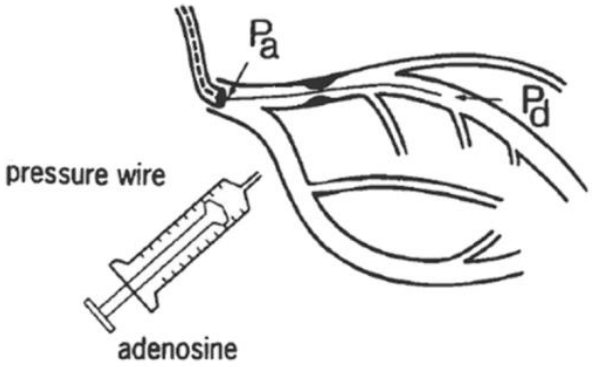
CAD functional significance: Fractional Flow Reserve (FFR)

- FFR = Pd/Pa
- FFR: measured through invasive cathlab procedure through a pressure wire



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Transforming CCTA from anatomical to functional imaging modality with CT-FFR

- CT-FFR: Non-invasive FFR measurement from a routine cardiac CTA scan using a biophysical model

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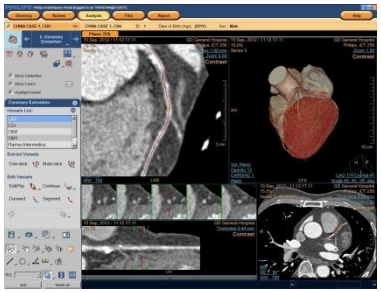
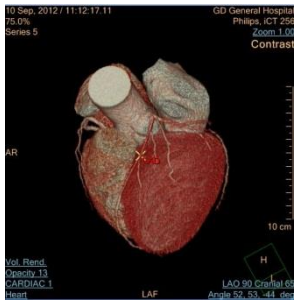
CT-FFR application pipeline

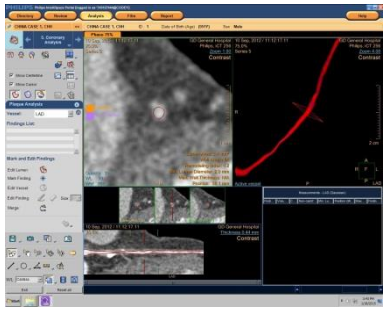
CCTA data



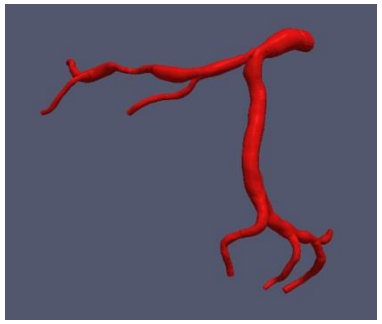
Tree extraction



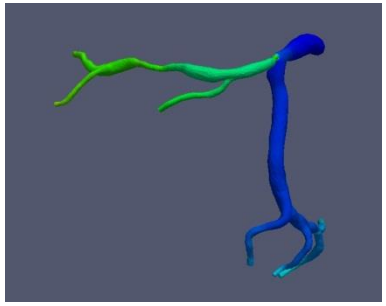
Vessel by vessel segmentation



3D model



Flow simulation



Goal: to improve CCTA specificity by enabling non-invasive CCTA-based functional characterization of coronary stenosis

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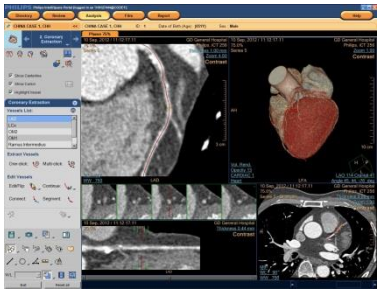
CT-FFR application pipeline

CCTA data



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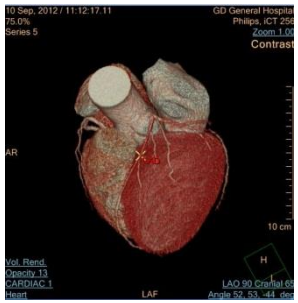

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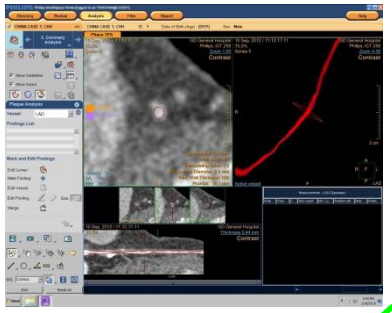

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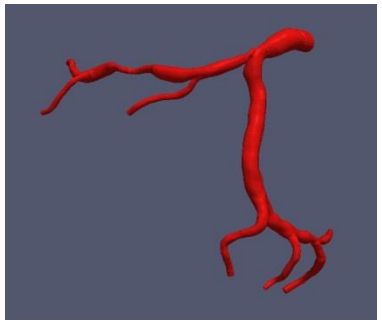

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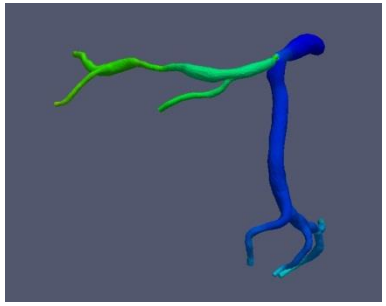

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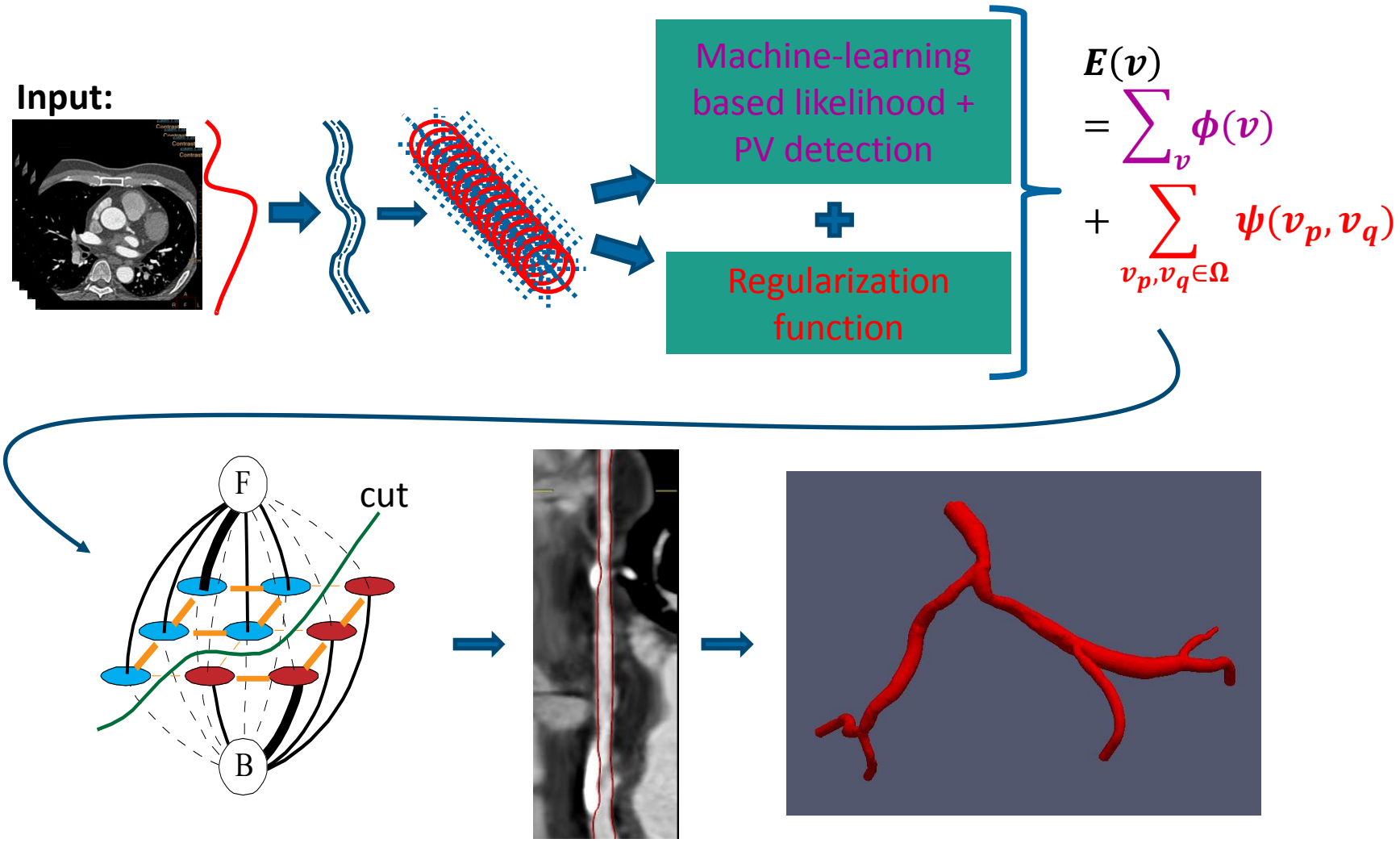
Machine-learning based coronary segmentation algorithm



Freiman et al, Medical Physics 2016

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Approximate K nearest neighbor (L2) likelihood estimation

- Lumen likelihood function:

$$P_{lumen}(\overrightarrow{x_p}): \mathbb{R}^N \rightarrow \mathbb{R}^N$$

Defined as:

$$P_{lumen}(\overrightarrow{x_p}) = \frac{\sum_{k=1}^{K} w\left(I(\overrightarrow{x_p}), I(\overrightarrow{x_k})\right) \cdot S(\overrightarrow{x_k})}{\sum_{k=1}^{K} w\left(I(\overrightarrow{x_p}), I(\overrightarrow{x_k})\right)}$$

where:

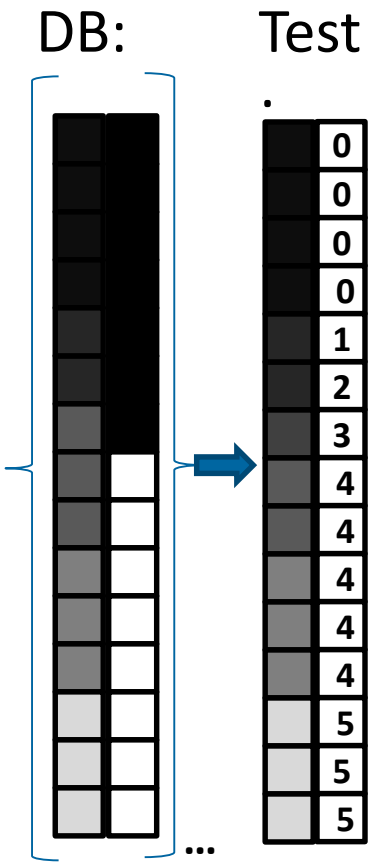
$\overrightarrow{x_p}$: ray to assign likelihood to

$\overrightarrow{x_k}$: similar ray from the database

I: ray HU profile

S: ray expert segmentation

w: weighting function (L2)



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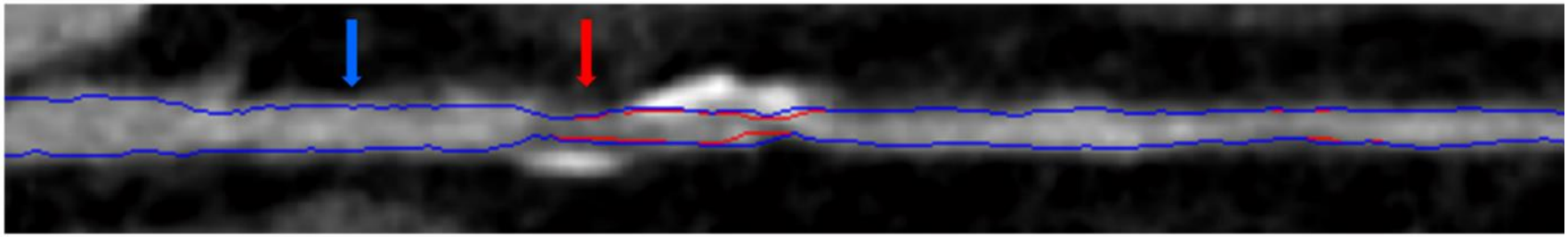
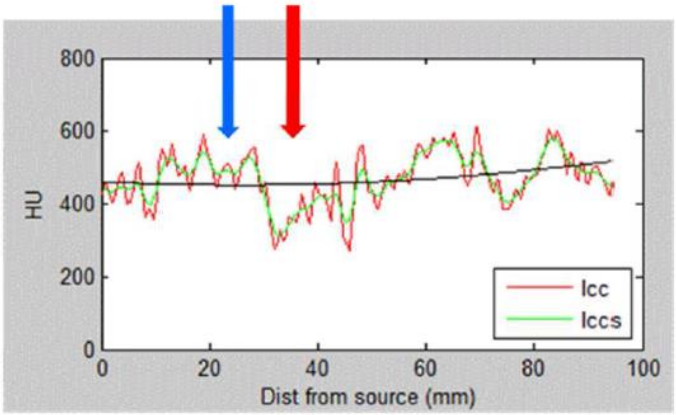
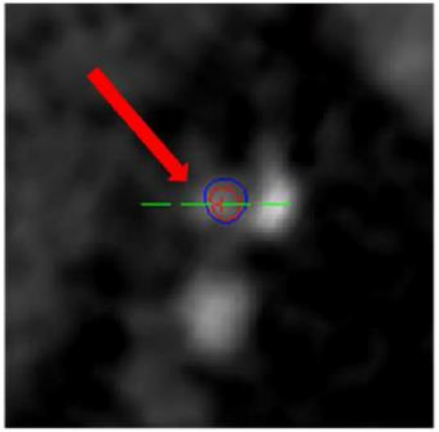
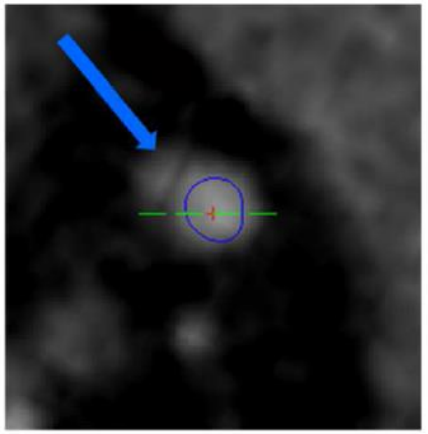
Accounting for partial volume effect (PVE) in small vessels



(a)







Small radius with PVE

No PVE

Freiman et al, Medical Physics 2016

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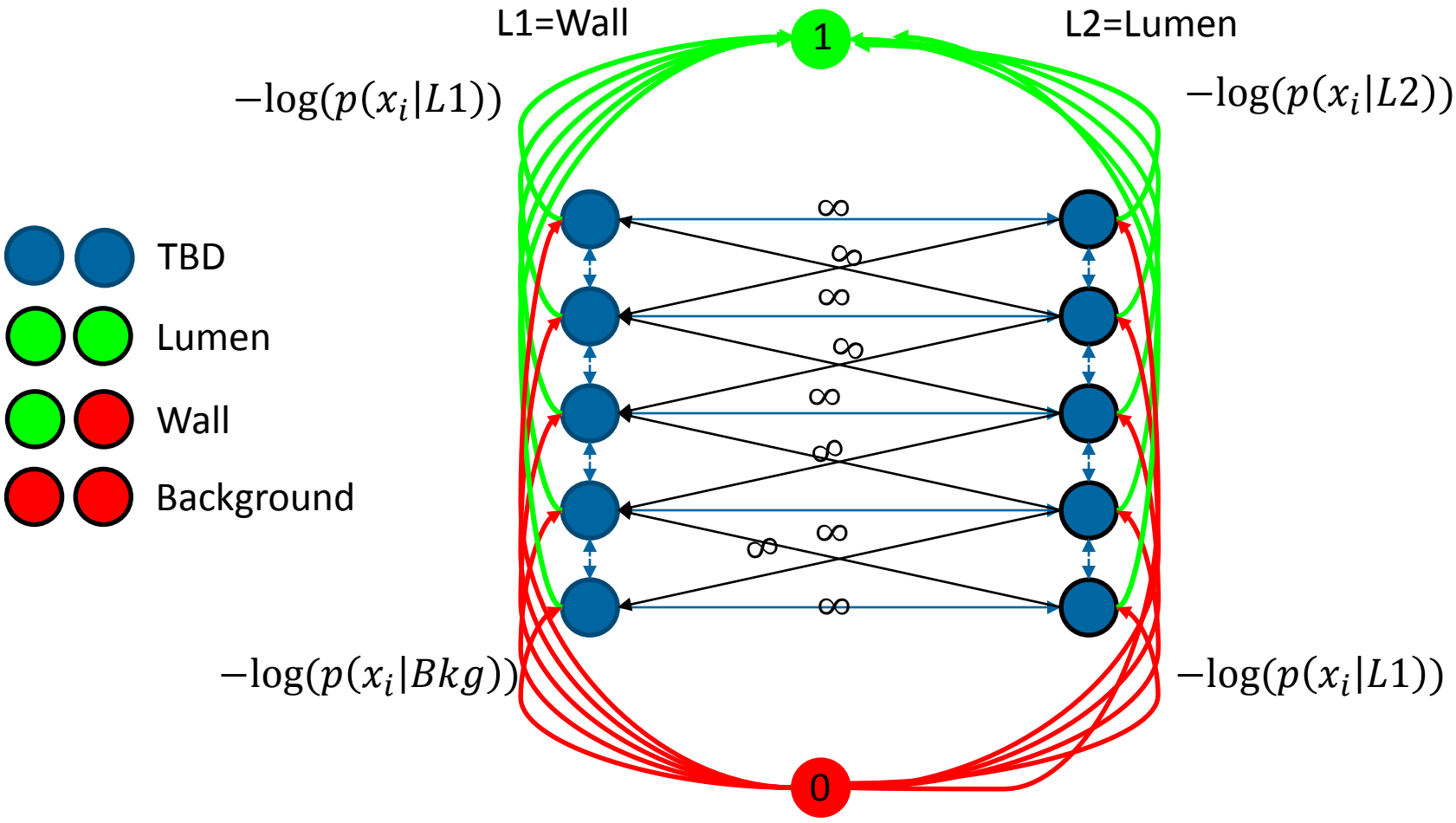
Simultaneous lumen and wall segmentation using hierarchical graph



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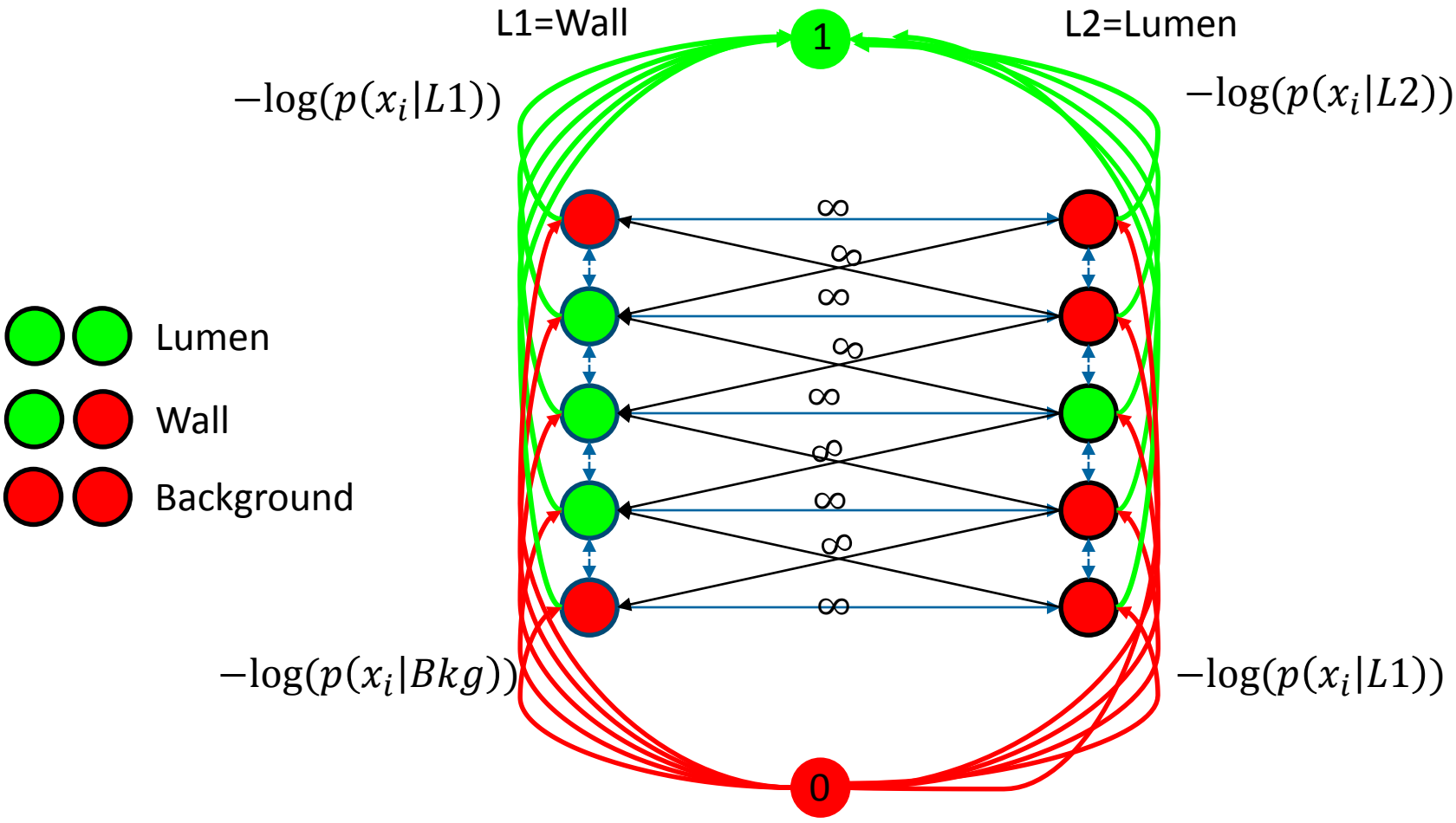
Simultaneous lumen and wall segmentation using hierarchical graph: solution



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Database optimization

- $DB(\vec{N})$: function that create sampled database from the full one according to the parameters $\vec{N}$
- Find $\vec{N} = \{N_i\}_{i=1\ldots5}$ that maximize the CT-FFR AUC:

$$\widehat{DB(\vec{N})} = \arg\max_{\vec{N}} AUC\left(FFR_{CT}\left(DB(\vec{N})\right), FFR_{GT}\right)$$

- Optimization strategy:
  - Optimize FFR-CT AUC over the parameters: $\vec{N}$ using the BOBYQA algorithm (Powell, M. J. D. 2009)
  - For each iter.:
    1. Build a sparsely sampled database for the full database by sampling $\vec{N}$ **percent** samples to the database from each class
    2. Perform lumen segmentation
    3. Calculate FFR-CT values.

Freiman et al, PATCH-MI, MICCAI 2017

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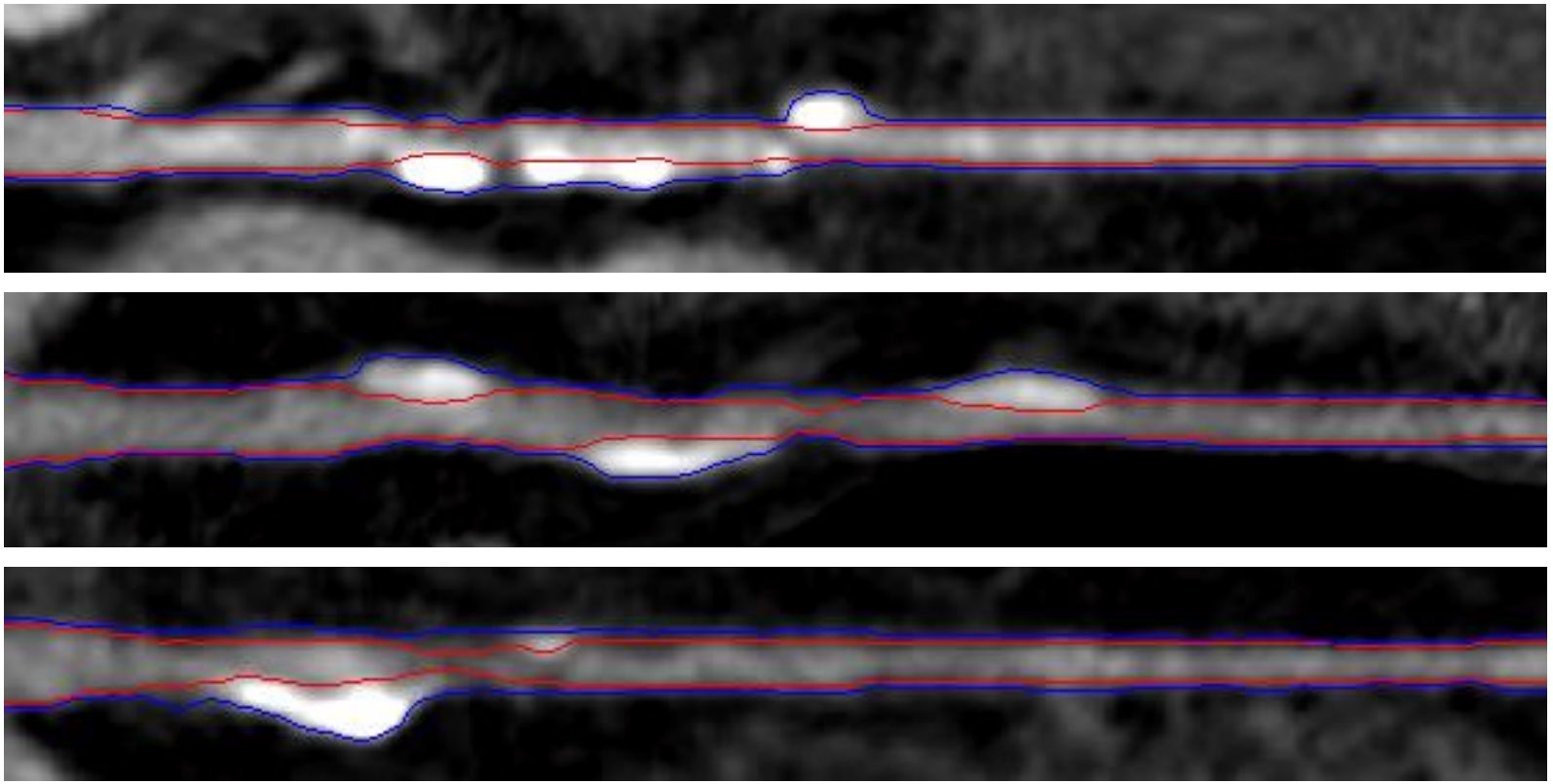
Representative vessel segmentation results



Red: lumen

Blue: wall

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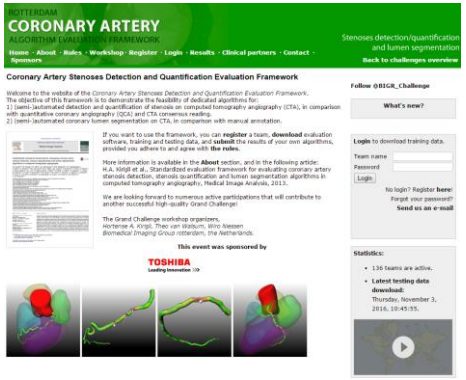
Lumen segmentation evaluation on the MICCAI 2012 database

- Evaluate the impact of database sampling using the publicly available MICCAI 2012 challenge framework

- Website:
  http://coronary.bigr.nl/stenoses/

- Papers:
  Medical Image Analysis, 2013



Summary statistics of coronary lumen segmentation accuracy using the MICCAI 2012 challenge evaluation framework for the training datasets with provided centerlines (18 cases, 78 coronary segments).

Method	Dice (%)		MSD (mm)		MAX SD (mm)	
	Healthy	Disease	Healthy	Disease	Healthy	Disease
Mohr et al.	0.75	0.73	0.45	0.29	3.73	1.87
Ours	0.69	0.74	0.49	0.28	1.69	1.22

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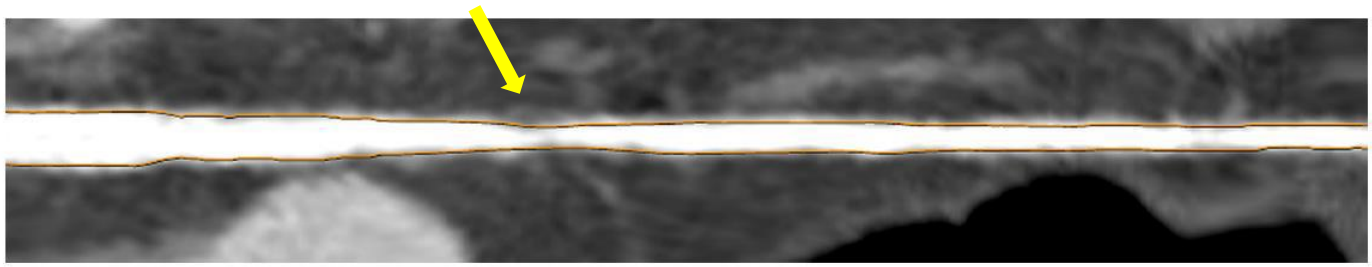
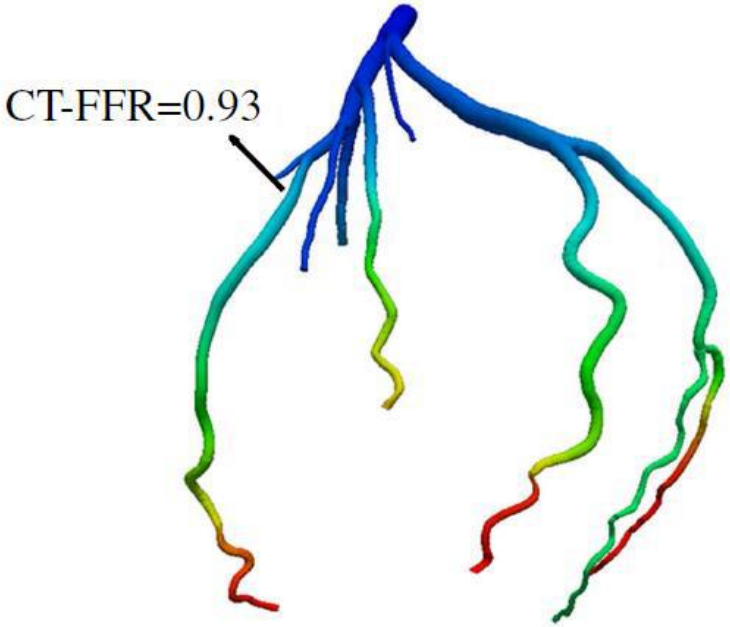
CT-FFR results: non significant lesion

Stenosis: ~40%





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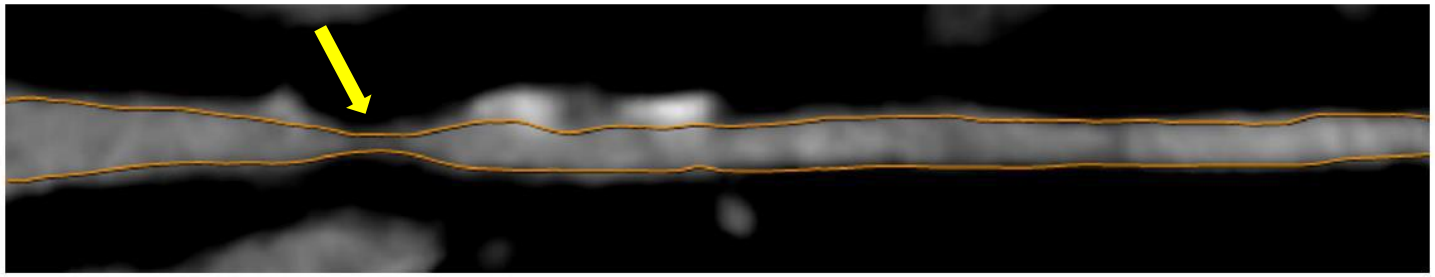
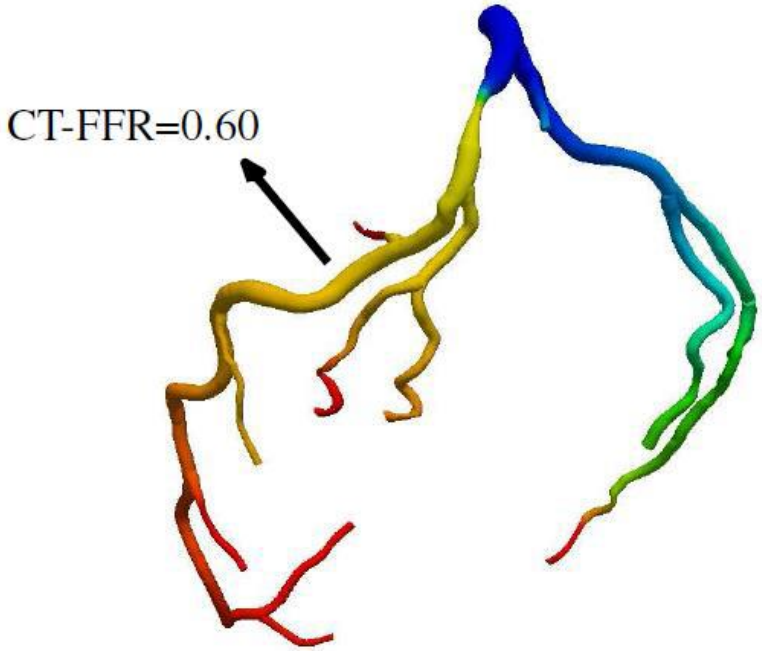
CT-FFR results: significant lesion

Stenosis: ~50%





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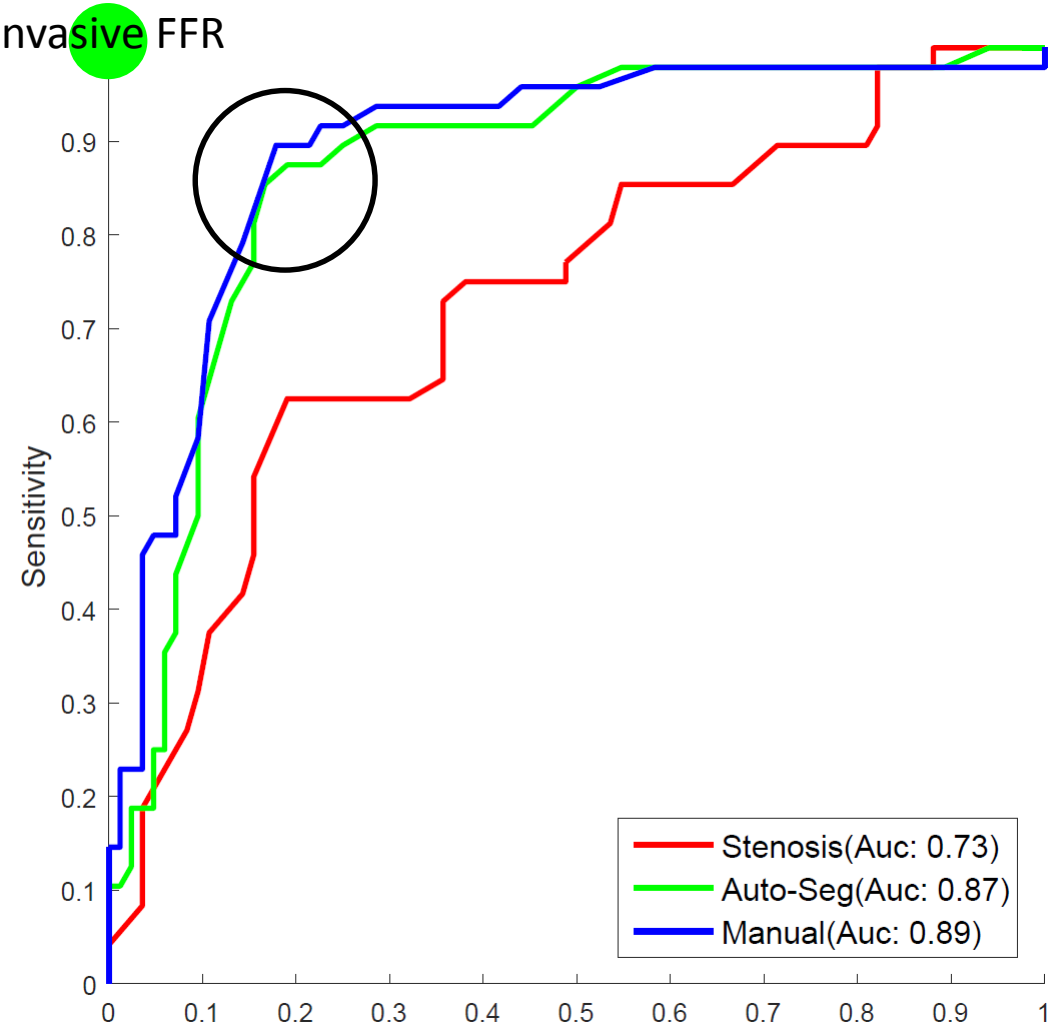
CT-FFR results: automatic segmentation vs. manual



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Summary

- CT-FFR enables on-site non-invasive functional assessment of coronary lesions
- Potential to reduce substantially unnecessary invasive coronary angiography exams
- Automatic coronary segmentation can achieve almost human-level performance by means of CT-FFR accuracy

Participants

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