

Automatic coronary lumen segmentation with partial volume modeling improves lesions' hemodynamic significance assessment

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Coronary Artery Disease

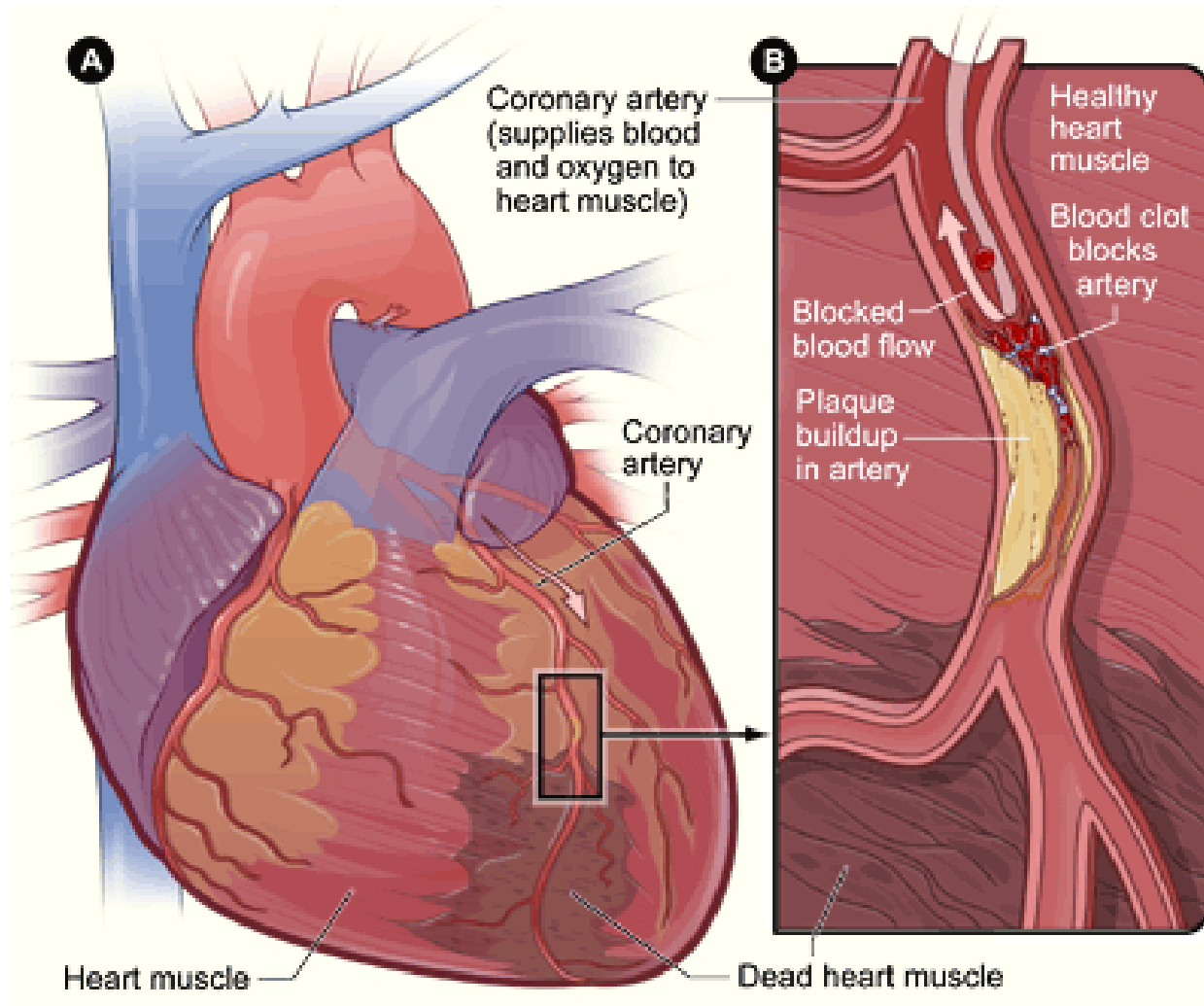


Image source: <http://www.nhlbi.nih.gov/health/health-topics/topics/cad/signs>

Clinical motivation: from anatomy to function

- Current gold standard for CAD stenting: hemodynamic significant stenosis (i.e. pressure drop (FFR) below 0.8).

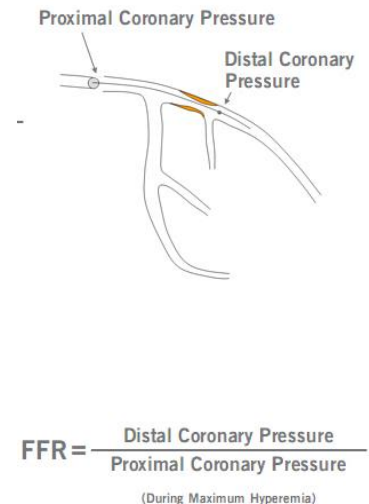
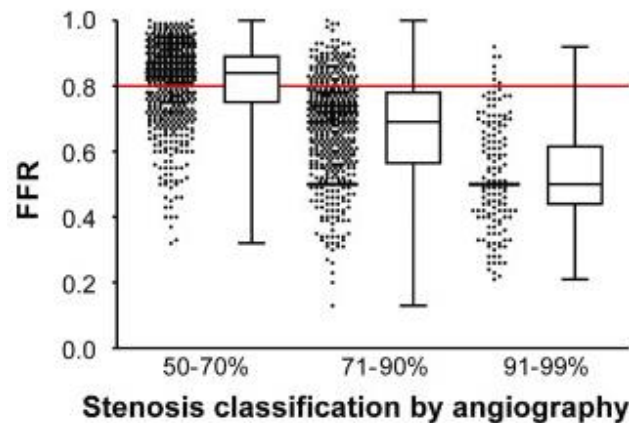
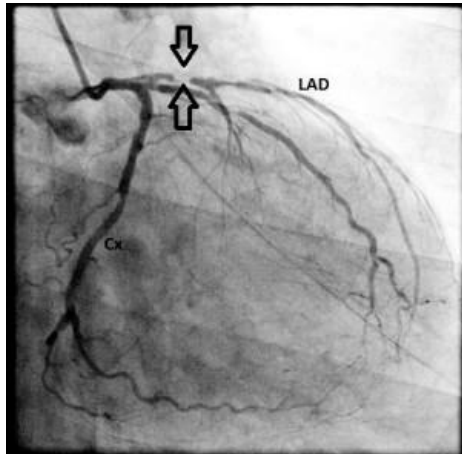
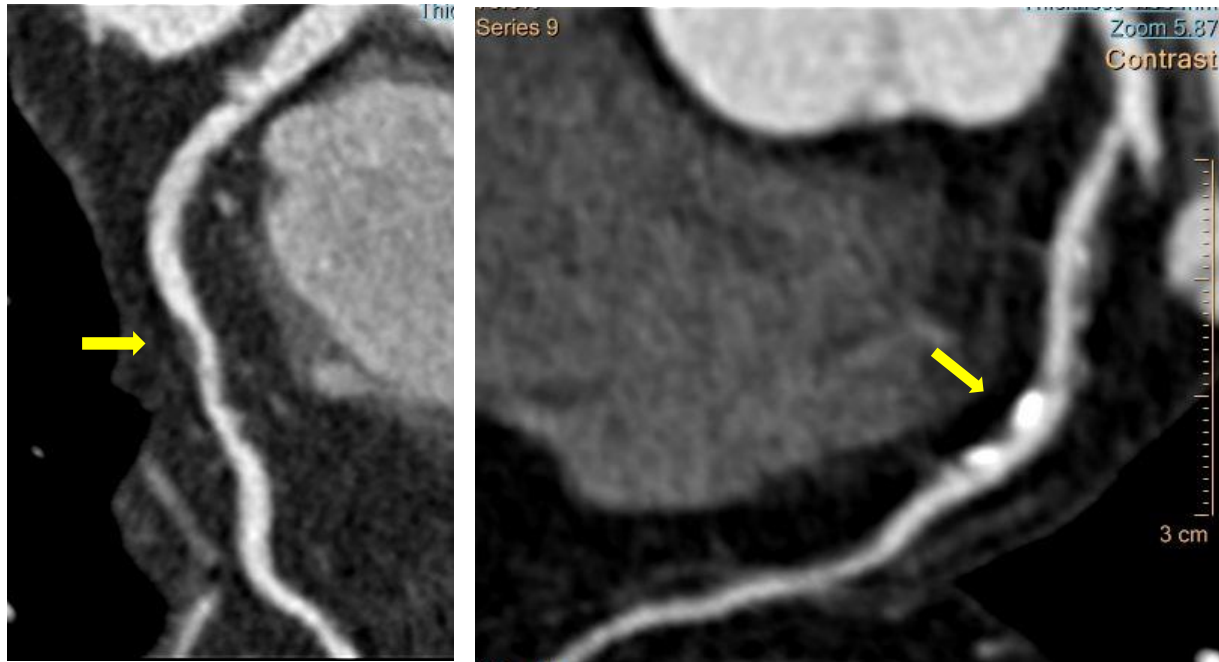


Image sources:

1. <http://westjem.com/case-report/red-flags-in-electrocardiogram-for-emergency-physicians-remembering-wellens-syndrome-and-upright-t-wave-in-v1.html>
2. Tonino et al, JACC 2010;55:2816-21

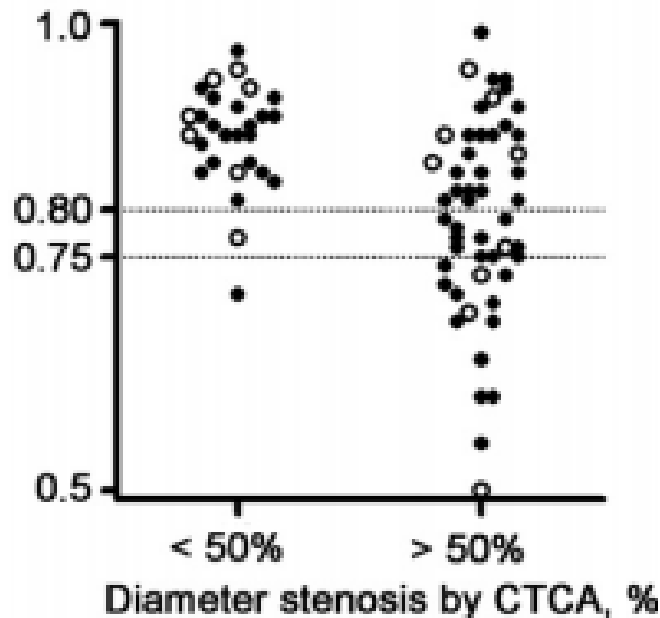
CCTA for Coronary Artery Disease

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



Anatomical assessment of lesion's significance with CCTA is not enough

- CCTA is currently limited to anatomical information about luminal narrowing in the coronaries

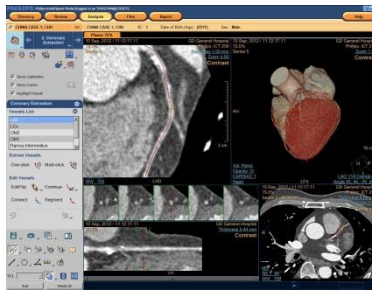


>50% of lesions
with greater than
50% diameter
stenosis by CCTA
have FFR>0.8

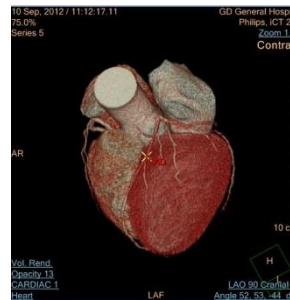
Image source: Meijboom et al. J Am CollCardiol 2008;52:636–43

Flow simulation enable lesion's hemodynamic significance assessment from CCTA

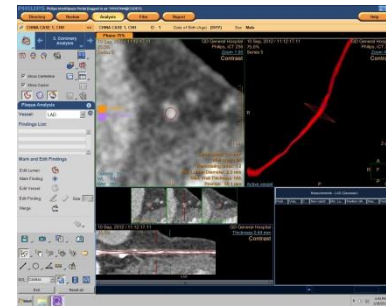
CCTA data



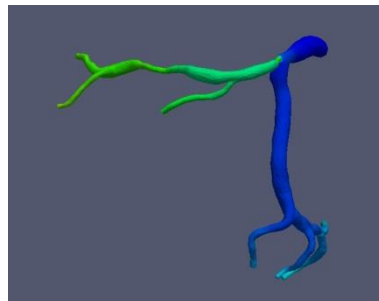
Tree extraction



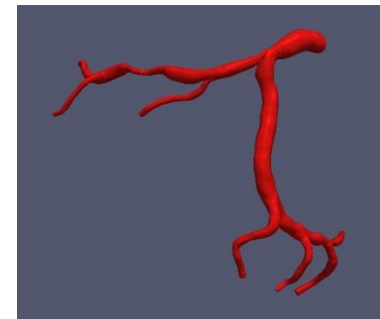
Vessel by vessel segmentation



CFD simulation



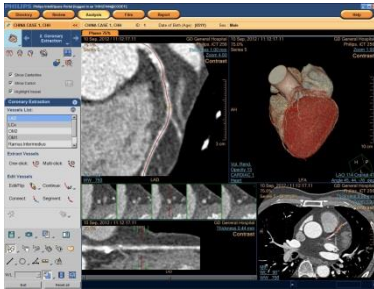
3D model



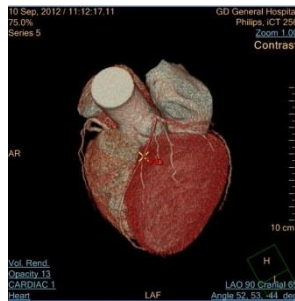
Goal: to improve CCTA specificity by enabling non-invasive CCTA-based functional hemodynamic characterization of coronary stenosis

Key enabler of accurate CCTA flow simulation: **Accurate Automatic Coronary lumen segmentation**

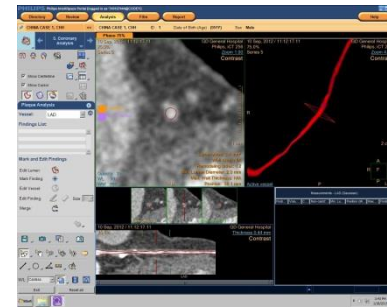
ISP CCA



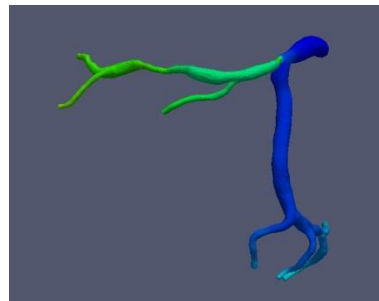
Tree extraction



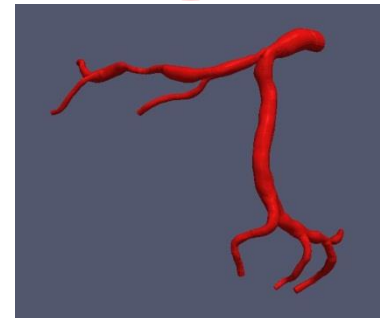
Vessel by vessel
segmentation



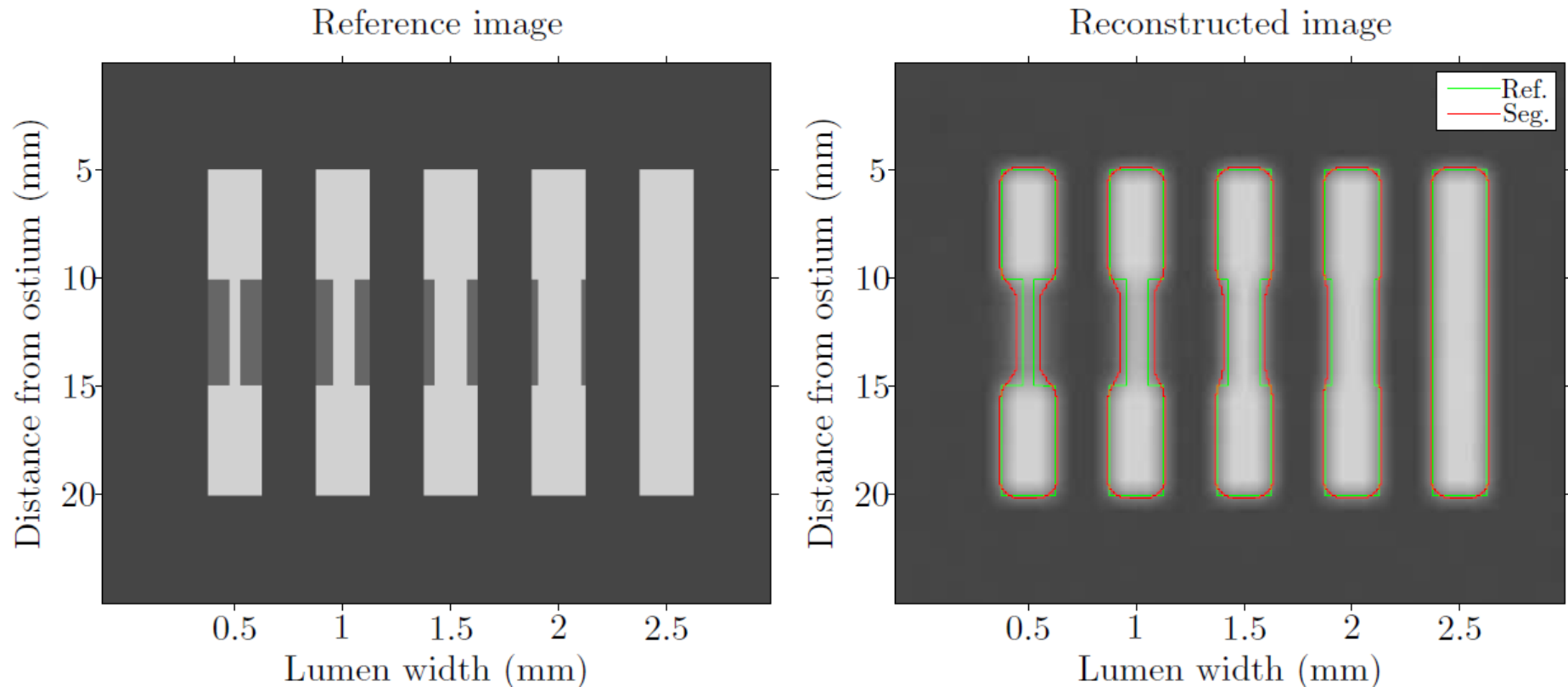
CFD simulation



3D model



Partial volume effect on small-radius vessels

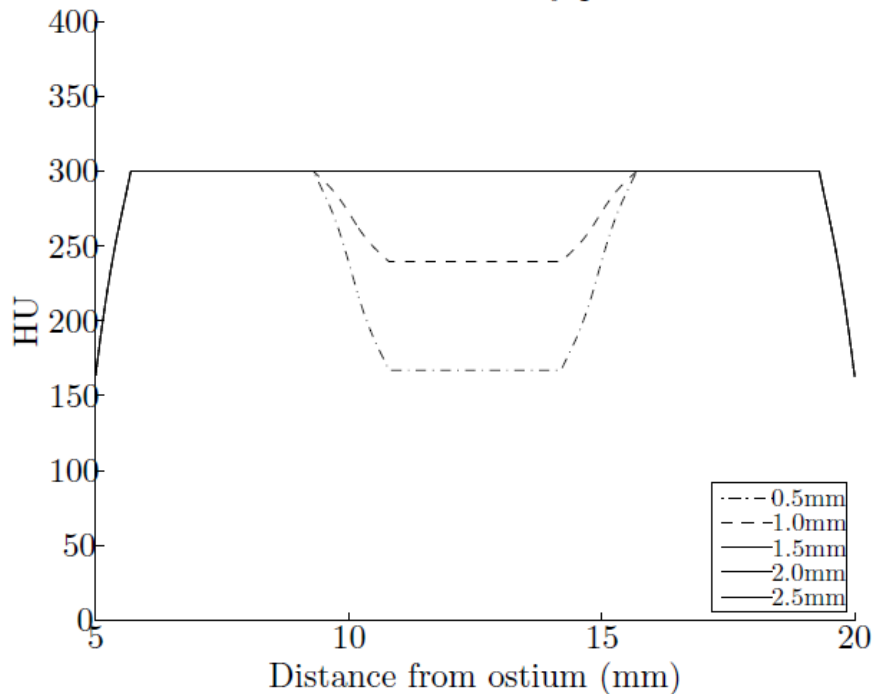


Small vessel diameters can be overestimated due to the overall system PSF¹ and significantly impact flow simulation results

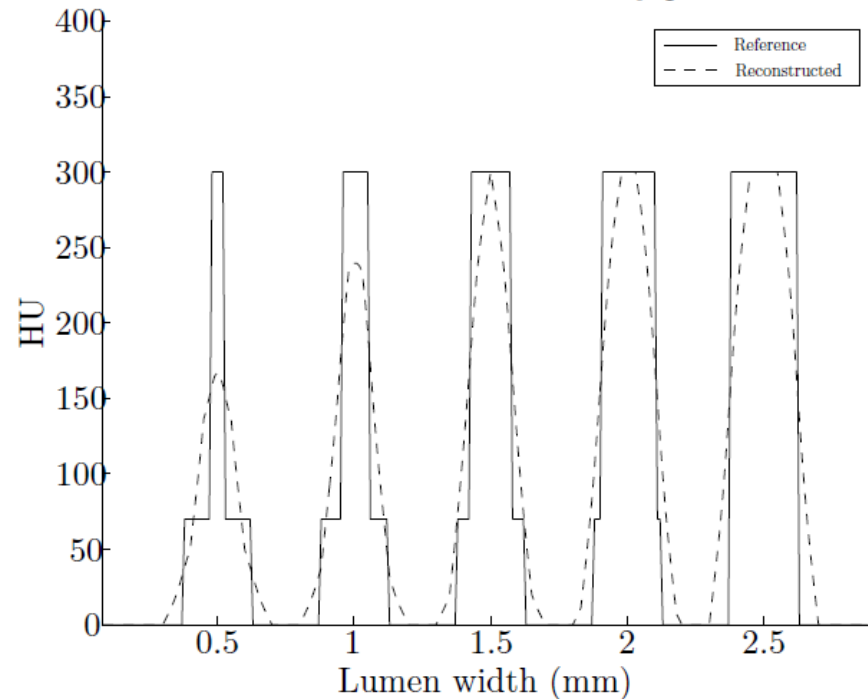
1. Sato et al, MICCAI 2004

Partial volume effect on small-radius vessels

Centerline intensity profile



Lumen cross-section intensity profile



Small vessel diameters can be overestimated due to the overall system PSF¹ and significantly impact flow simulation results

1. Sato et al, MICCAI 2004

Previous works: MICCAI 2012 workshop

The screenshot shows the homepage of the 'ROTTERDAM CORONARY ARTERY ALGORITHM EVALUATION FRAMEWORK'. The header is green with white text. Below the header, there's a navigation bar with links: Home, About, Rules, Workshop, Register, Login, Results, Clinical partners, Contact, Sponsors. The main content area is white. It starts with the title 'Coronary Artery Stenoses Detection and Quantification Evaluation Framework'. Below this, there's a welcome message and the objective of the framework. It lists two main tasks: 1) (semi-)automated detection and quantification of stenosis on computed tomography angiography (CTA), in comparison with quantitative coronary angiography (QCA) and CTA consensus reading. 2) (semi-)automated coronary lumen segmentation on CTA, in comparison with manual annotation. There's a section for 'What's new?' and a 'Login to download training data.' section with fields for team name and password, and a 'Login' button. Below the login section, there's a 'Statistics' section showing '94 teams are active' and 'Latest testing data download: Monday, January 12, 2015, 9:51:03.' There's also a world map showing the locations of participating teams. At the bottom, there's a section for 'This event was sponsored by' with the Toshiba logo and four 3D visualizations of coronary arteries.

ROTTERDAM
CORONARY ARTERY
ALGORITHM EVALUATION FRAMEWORK

Home · About · Rules · Workshop · Register · Login · Results · Clinical partners · Contact · Sponsors

Stenoses detection/quantification and lumen segmentation
[Back to challenges overview](#)

Coronary Artery Stenoses Detection and Quantification Evaluation Framework

Welcome to the website of the *Coronary Artery Stenoses Detection and Quantification Evaluation Framework*. The objective of this framework is to demonstrate the feasibility of dedicated algorithms for:

- 1) (semi-)automated detection and quantification of stenosis on computed tomography angiography (CTA), in comparison with quantitative coronary angiography (QCA) and CTA consensus reading.
- 2) (semi-)automated coronary lumen segmentation on CTA, in comparison with manual annotation.

If you want to use the framework, you can **register** a team, **download** evaluation software, training and testing data, and **submit** the results of your own algorithms, provided you adhere to and agree with **the rules**.

More information is available in the **About** section, and in the following article:
H.A. Kirgılı et al., Standardized evaluation framework for evaluating coronary artery stenosis detection, stenosis quantification and lumen segmentation algorithms in computed tomography angiography, *Medical Image Analysis*, 2013.

We are looking forward to numerous active participations that will contribute to another successful high-quality Grand Challenge!

The Grand Challenge workshop organizers,
Hortense A. Kirgılı, Theo van Walsum, Wiro Niessen
Biomedical Imaging Group rotterdam, the Netherlands.

This event was sponsored by

TOSHIBA
Leading Innovation >>>

What's new?

Login to download training data.

Team name
Password

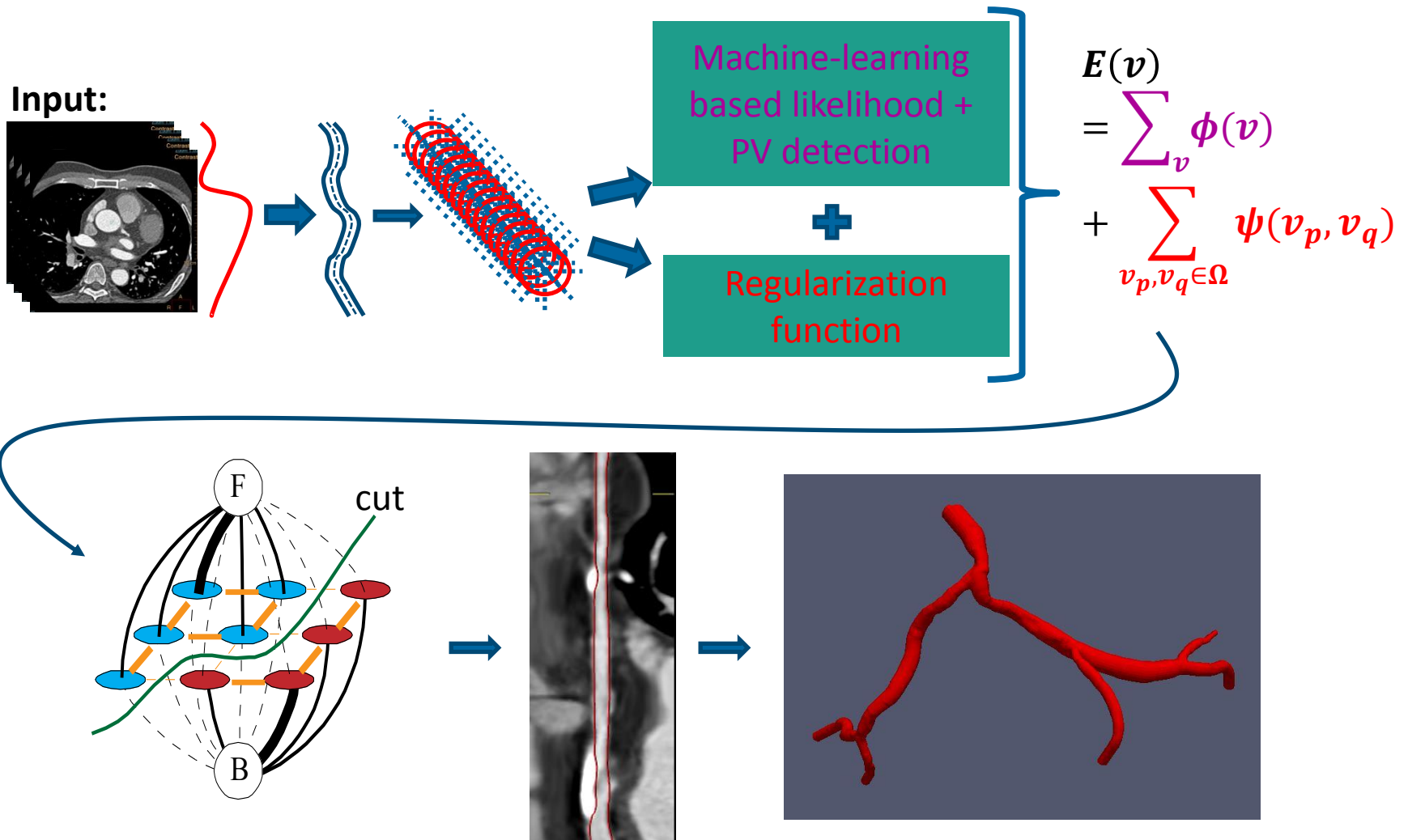
No login? Register **here!**
Forgot your password?
Send us an e-mail

Statistics:

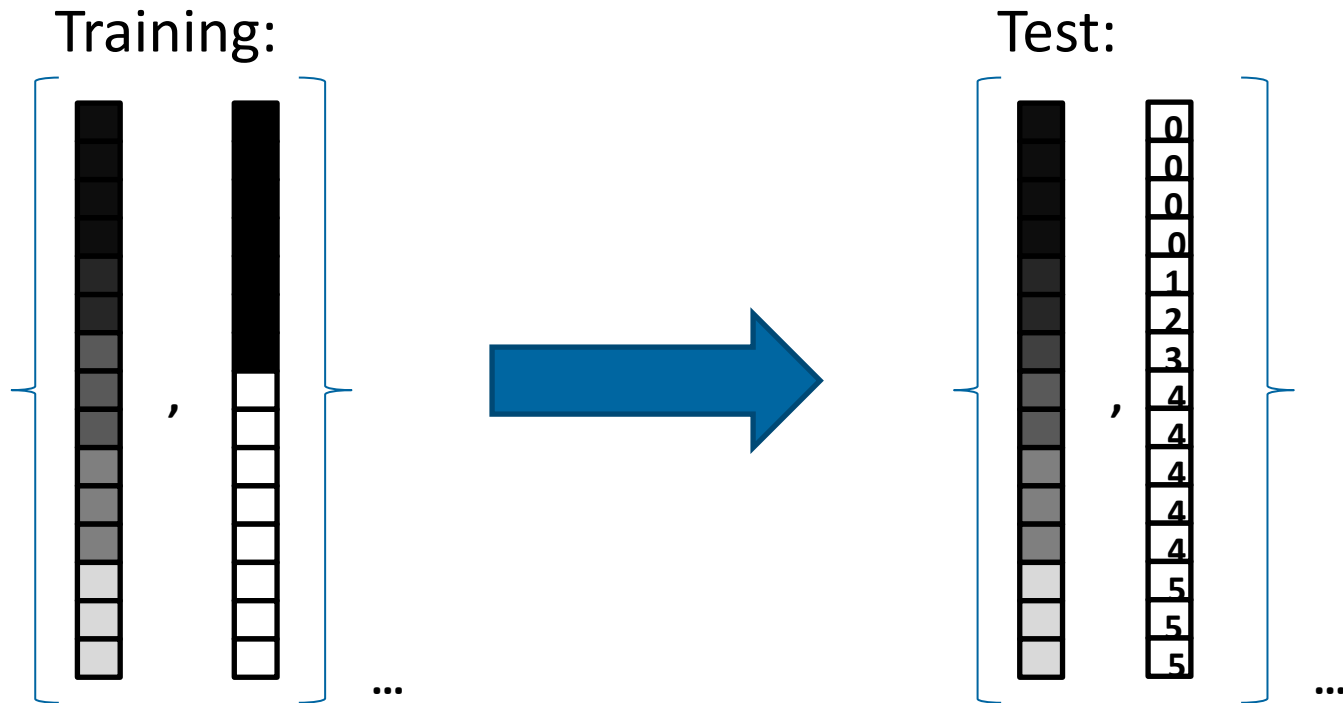
- 94 teams are active.
- Latest testing data download:
Monday, January 12, 2015,
9:51:03.

- Evaluation was limited to anatomical agreement with manual segmentation without assessing impact on flow simulation accuracy
- Most methods did not consider the PV effect on small vessels diameters

Our solution: Automatic coronary segmentation algorithm that accounts for the partial volume effect

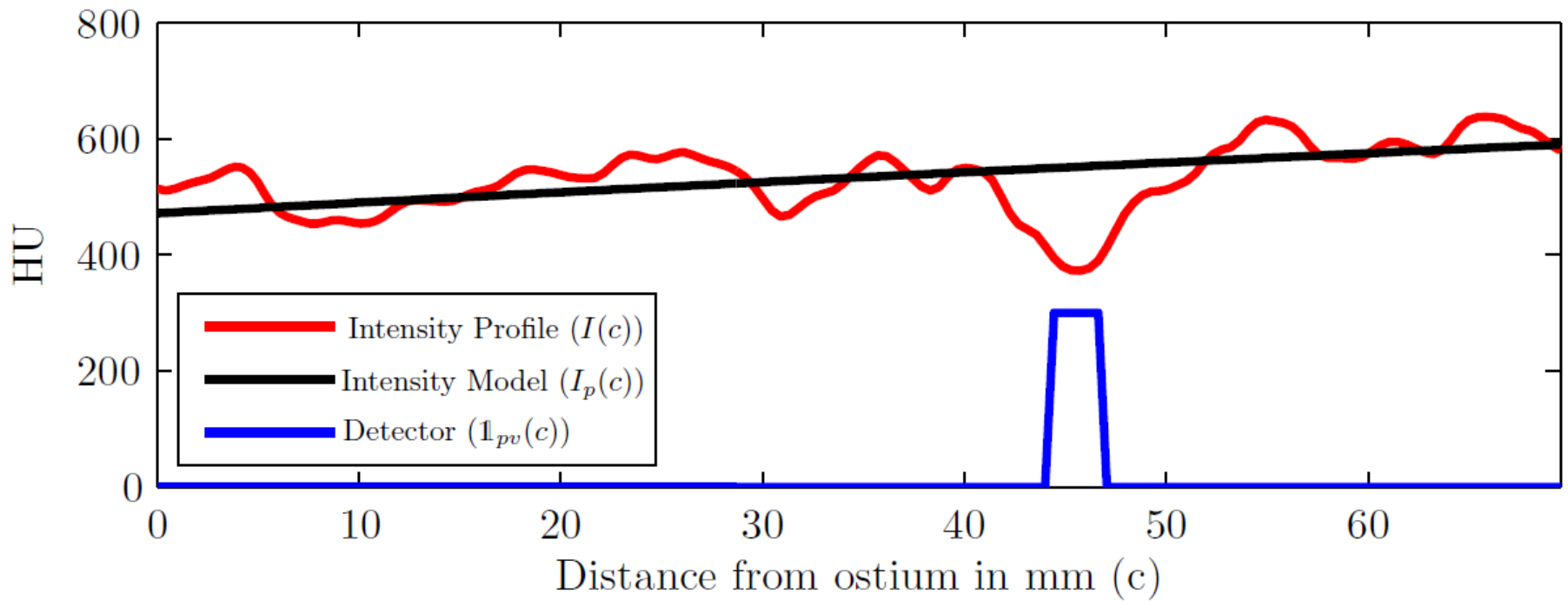


Approximate K nearest neighbor (L2) likelihood estimation



$$\Pr_d(x_p \in \text{Lumen}) = \frac{\sum_{k=1}^K w(I(i^{x_p}, \theta^{x_p}, R), I'(i^k, \theta^k, R)) \cdot \delta(x_p, S(i^k, \theta^k, R))}{\sum_{k=1}^K w(I(i, \theta^{x_p}, R^{x_p}), I'(i^k, \theta^k, R))}$$

Partial Volume detection



Partial Volume detection: Algorithm steps

Input: Coronary centerline, Coronary centerline intensity profile

1. Robust intensity model fitting:

$$\widehat{I_p(C)} = \operatorname{argmin}_{I_p(C)} \sum_{c \in C} \left(I(c) - I_p(c) \right)^2$$

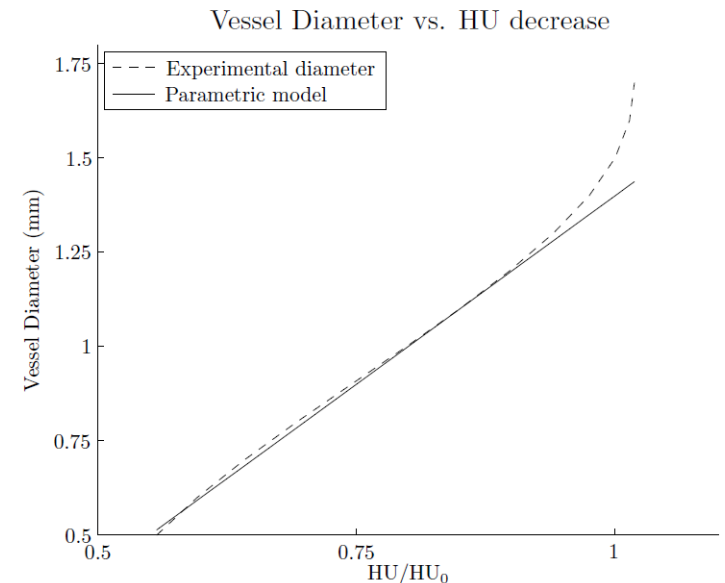
2. Detection of significant reduction in observed intensity compared to the model:

$$\mathbb{1}_{pv}(c) = \begin{cases} 1, & I(c) > (I_p(c) - 2\sigma_{I_c}) \\ 0, & I(c) \leq (I_p(c) - 2\sigma_{I_c}) \end{cases}$$

3. Underlying radius estimation based on pre-calculated model:

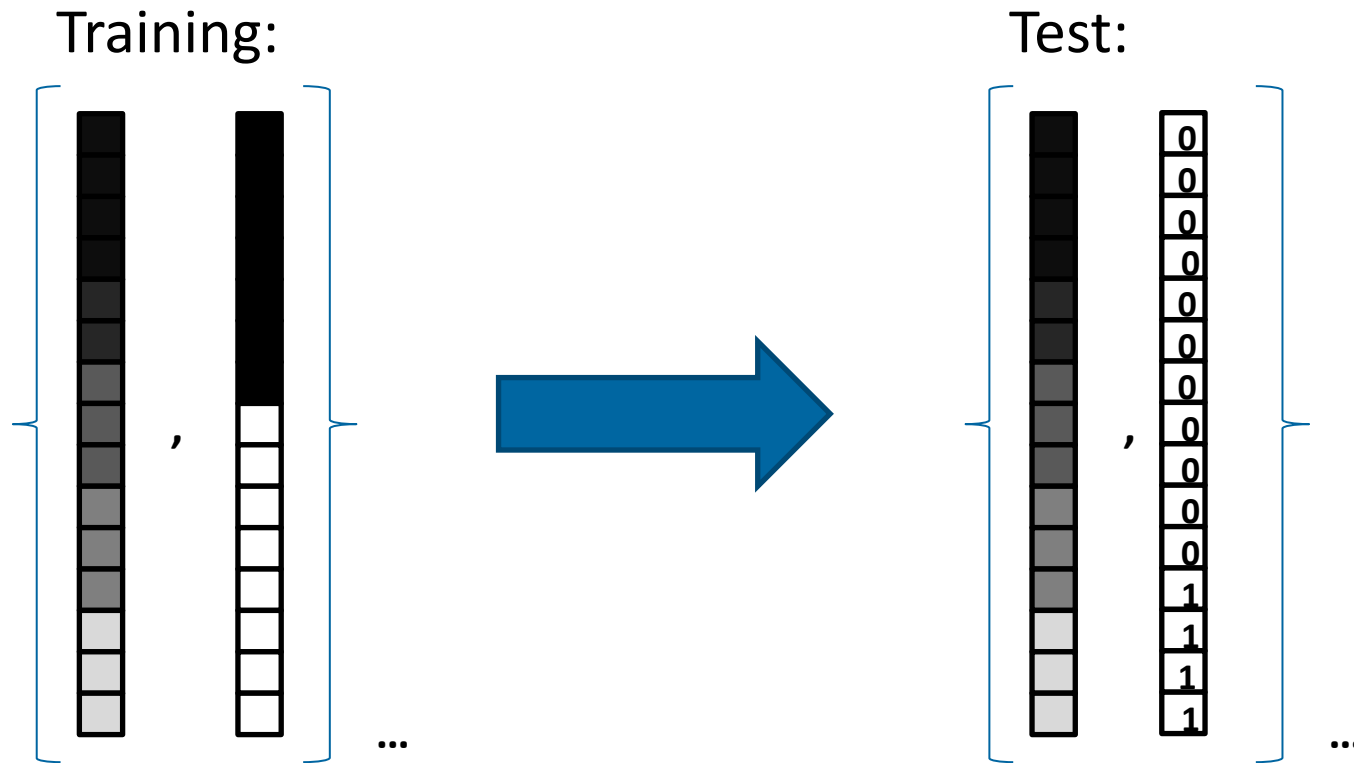
$$r(c) = 0.5 \left(\alpha \left(1 - \frac{I(c)}{I_p(c)} \right) + \beta \right)$$

Output: Adjusted coronary radius at each centerline point after correction for PV



$$\Pr_{pv}(x_p \in \text{Lumen}) = \begin{cases} 0, & r^{x_p} \geq r' \\ 1, & r^{x_p} \leq r' \end{cases}$$

Applying PV radius correction on the likelihood map



$$\Pr(x_p \in \text{Lumen}) = \begin{cases} \Pr_d(x_p), & \mathbb{1}_{pv}(c(x_p)) = 0 \\ \Pr_{pv}(x_p), & \mathbb{1}_{pv}(c(x_p)) = 1 \end{cases}$$

Graph min-cut segmentation (Boykov et al, 2001)

- Binary separation of coronaries from the rest (background) formulated as a graph min-cut problem

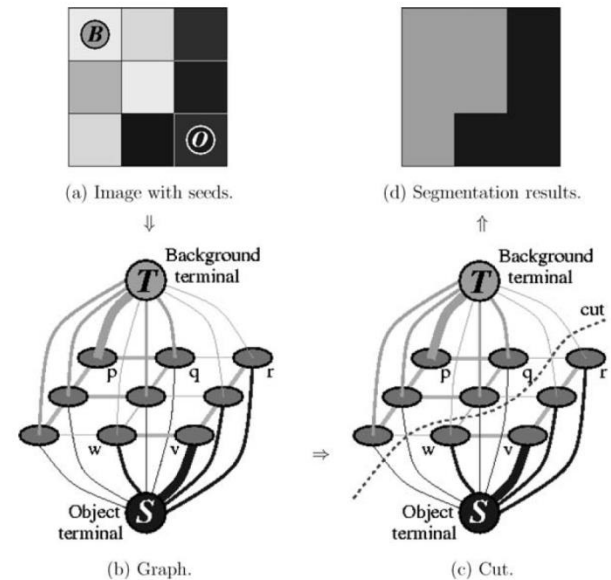
- Minimization of the following energy:

$$E(X) = \sum_{p \in P} \Psi_p(x_p) + \lambda \sum_{p, q \in E} \Psi_{p, q}(x_p, x_q)$$

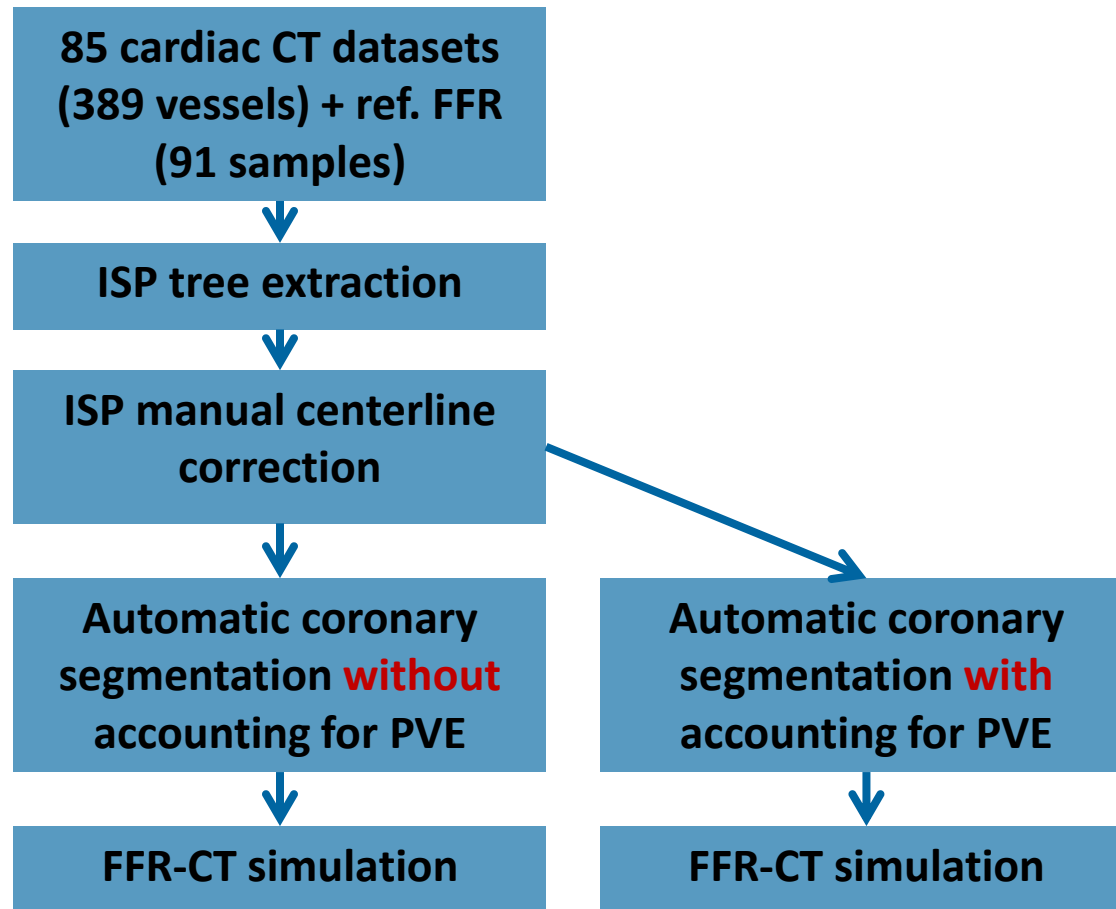
$$\Psi_p(x_p) = -\log \Pr(x_p \in \text{Lumen})$$

$$\Psi_{p, q}(x_p, x_q) = \exp \left(-\frac{(I(x_p) - I(x_q))^2}{\sigma_c(x_p)} \right) \cdot \exp(-d(x_p, x_q)^2)$$

- Globally optimal minimization for submodular functions (edge weights ≥ 0)



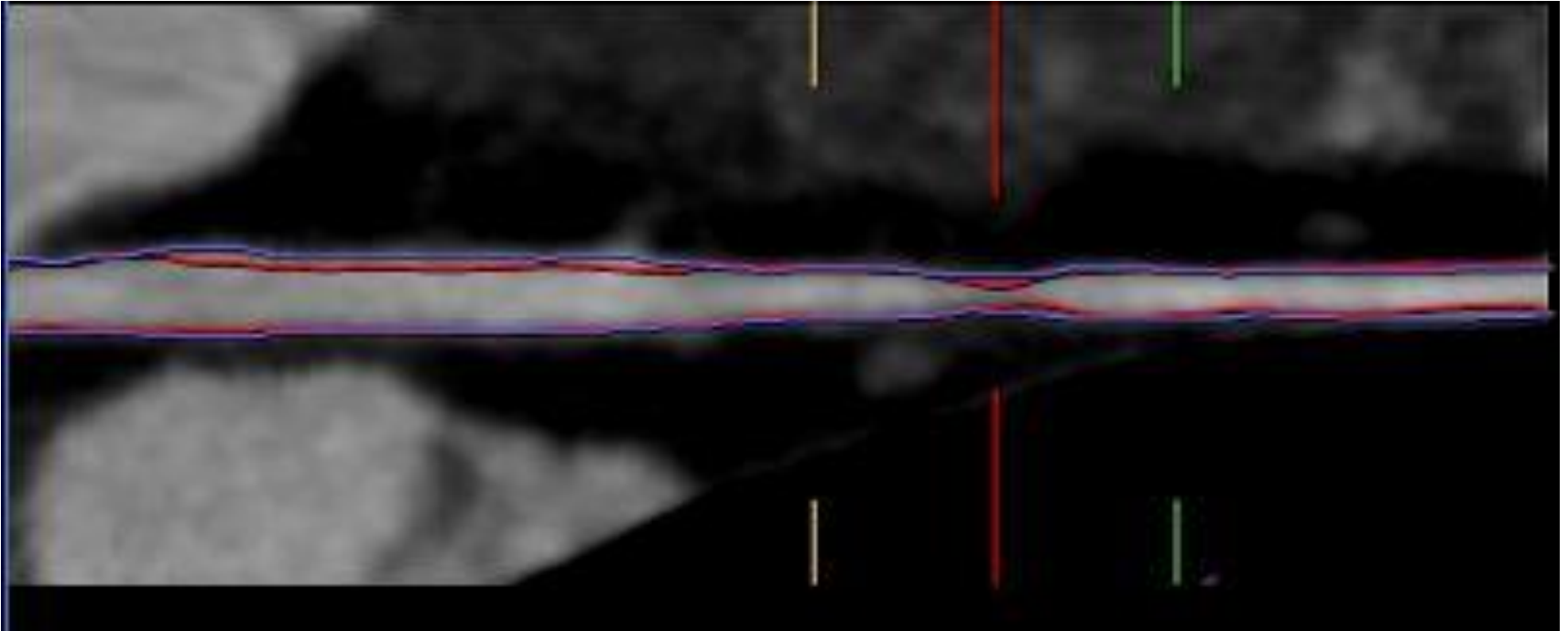
Experimental setup



Comparison: Flow simulation agreement with invasive FFR

Segmentation result: qualitative comparison

Without accounting for PVE

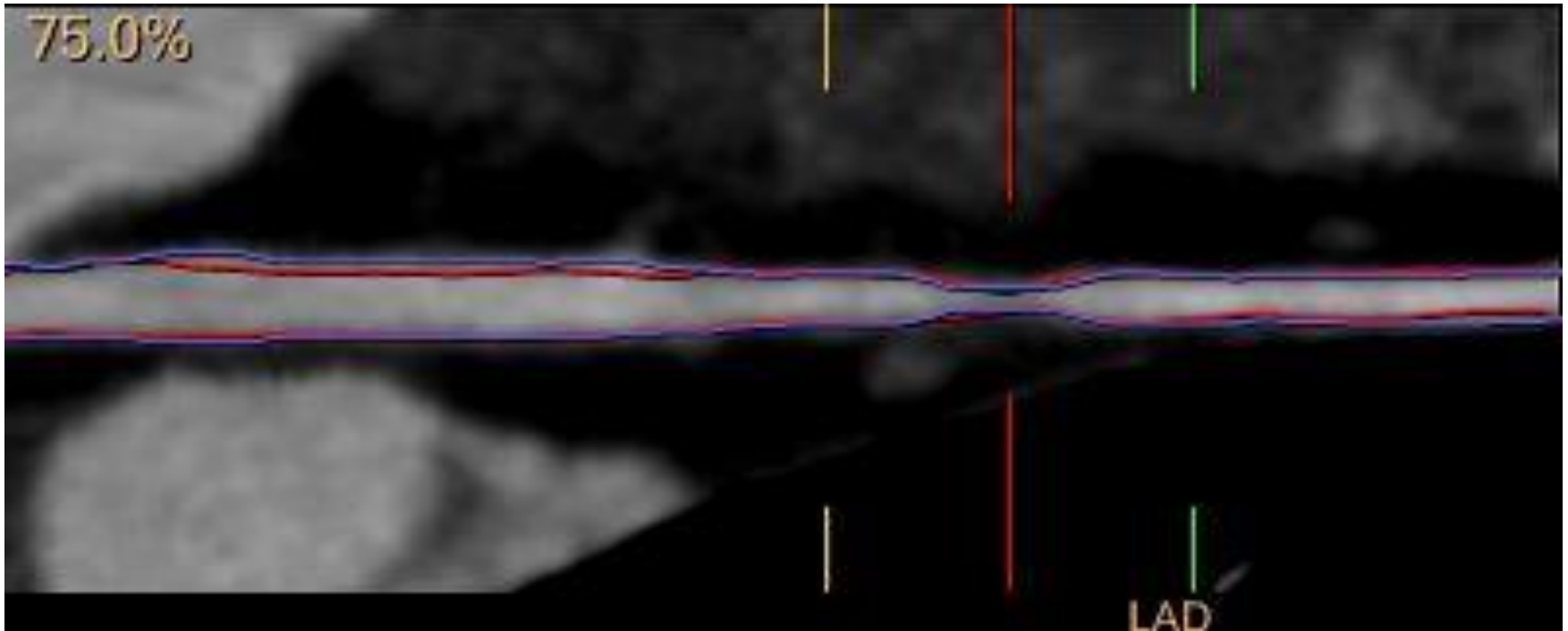


Blue – Automatic segmentation results **without** accounting for PVE

Red – manual expert segmentation that accounts for PVE

Segmentation result: qualitative comparison

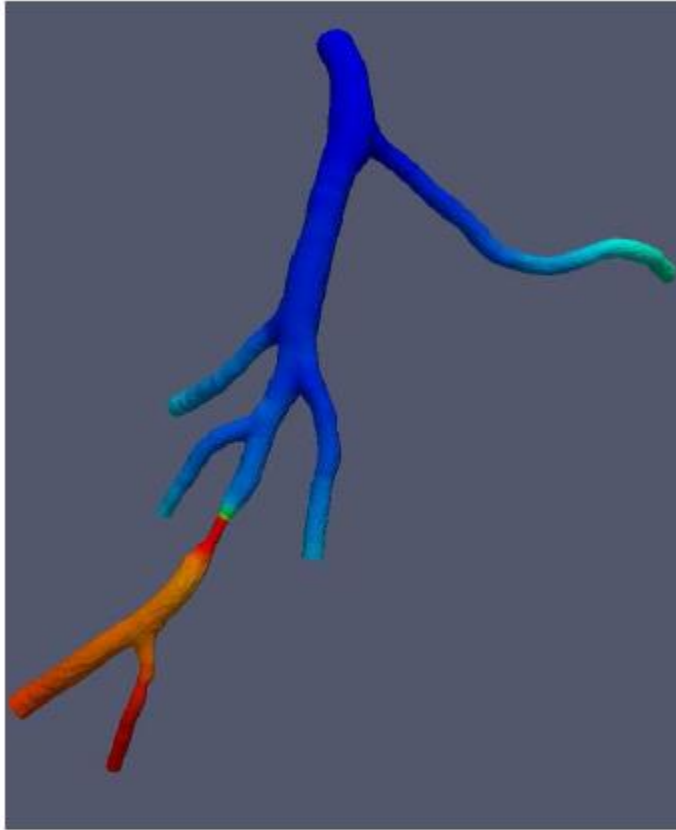
With accounting for PVE



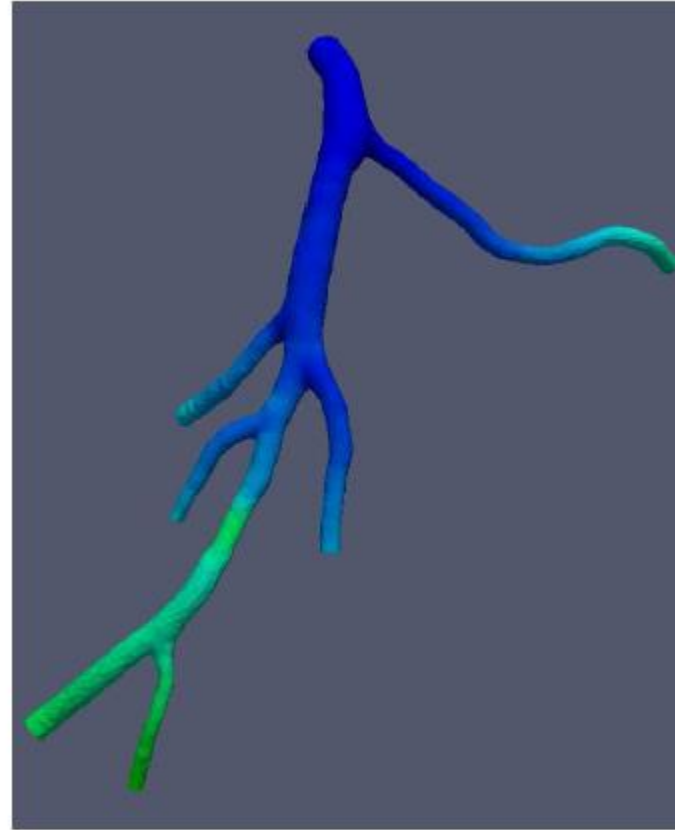
Blue – Automatic segmentation results **with** accounting for PVE

Red – manual expert segmentation that accounts for PVE

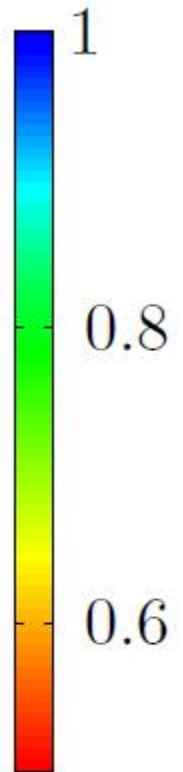
Experimental results: representative case



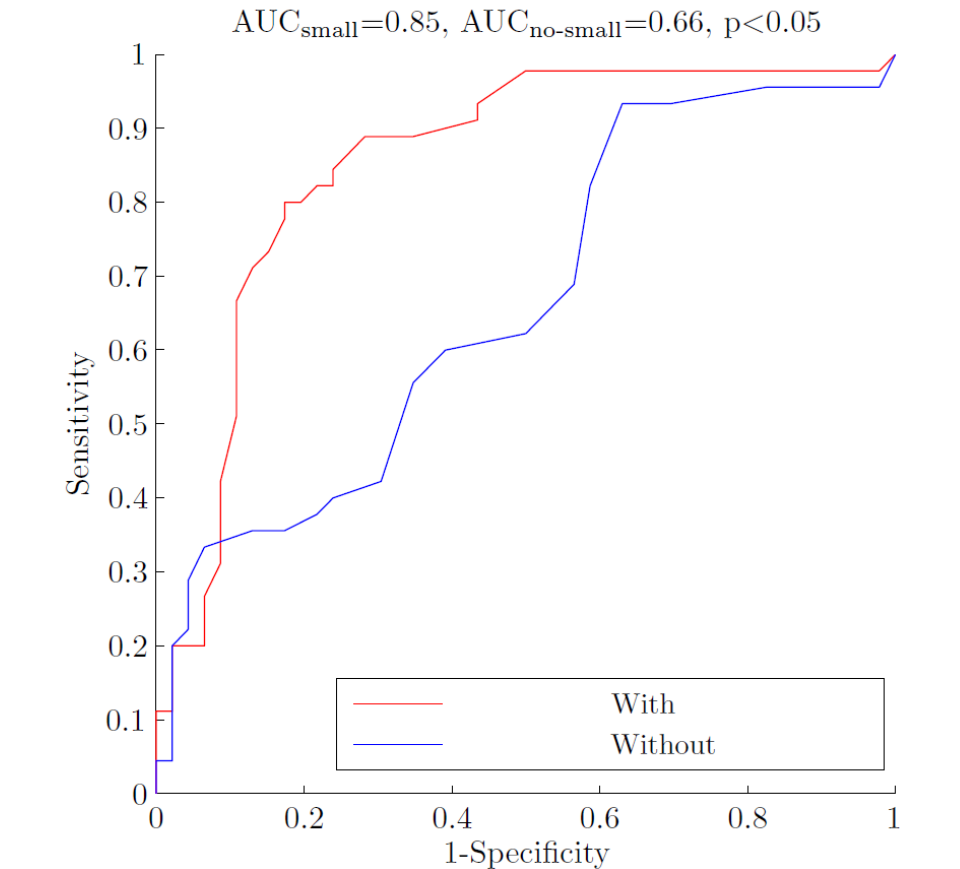
(a) With accounting for the PVE



(b) Without accounting for the PVE



Experimental results: ROC analysis



Accounting for PVE significantly improved the detection performance by means of area under the ROC curve (AUC) by 29% (N=91, 0.85 vs. 0.66, $p<0.05$).

Summary

- Functional assessment of coronary lesions based on CCTA and flow simulation requires accurate automatic lumen segmentation
- Partial volume effect may cause overestimation of small vessel diameter and reduce flow simulation accuracy
- Partial volume effect can be detected by analyzing the intensity profile along the vessel centerline
- New graph min-cut based algorithm for accurate coronary lumen segmentation that accounts for potential partial volume effects
- Accounting for partial volume in the automatic segmentation yield a substantial improvement in correlation between automatic estimation of FFR from CCTA and invasive FFR measurements

