

# MOUSE ARTERIAL WALL IMAGING AND ANALYSIS FROM SYNCHROTRON X-RAY MICROTOMOGRAPHY

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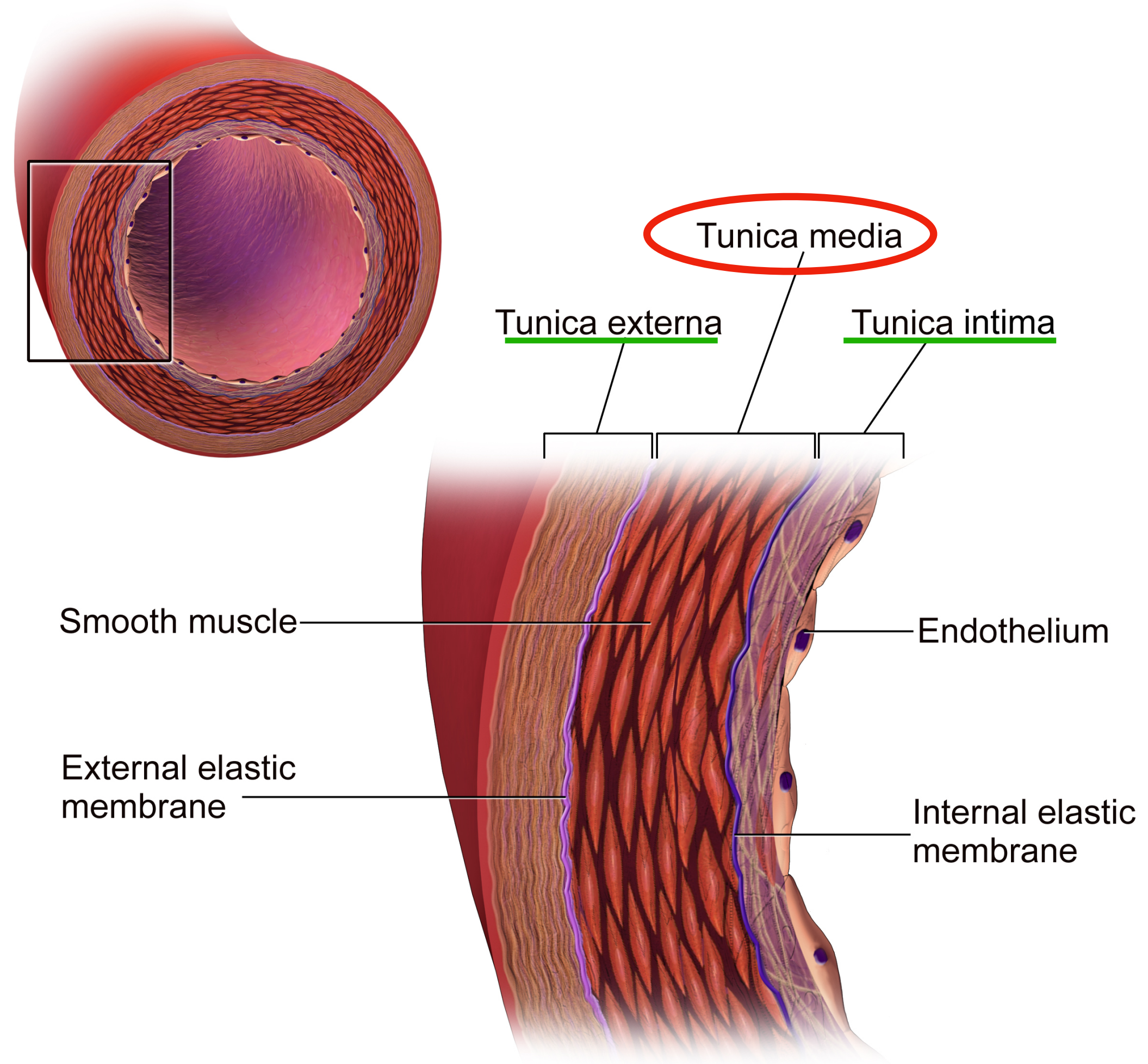
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02/02/2023

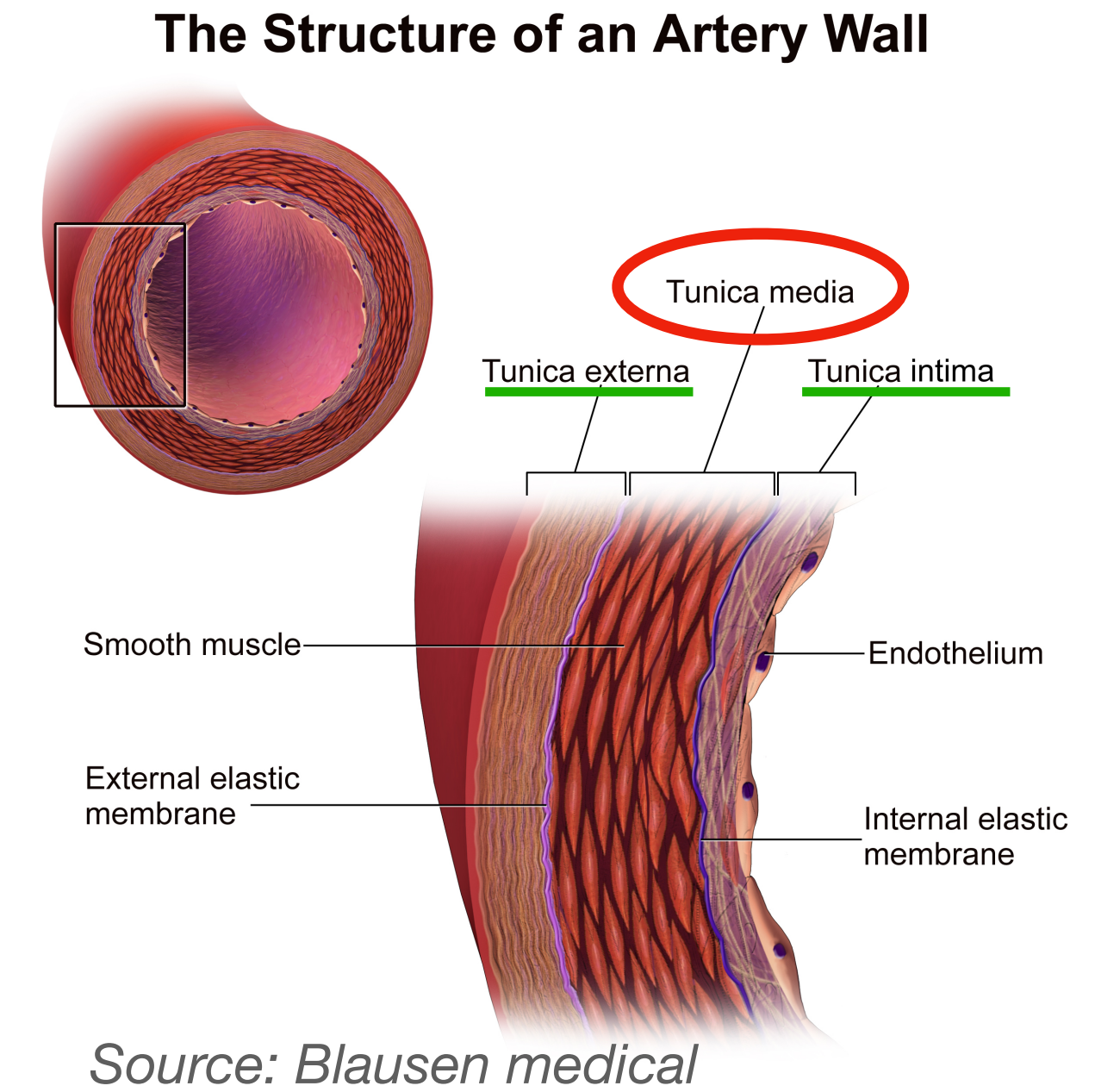
# Introduction

## The Structure of an Artery Wall



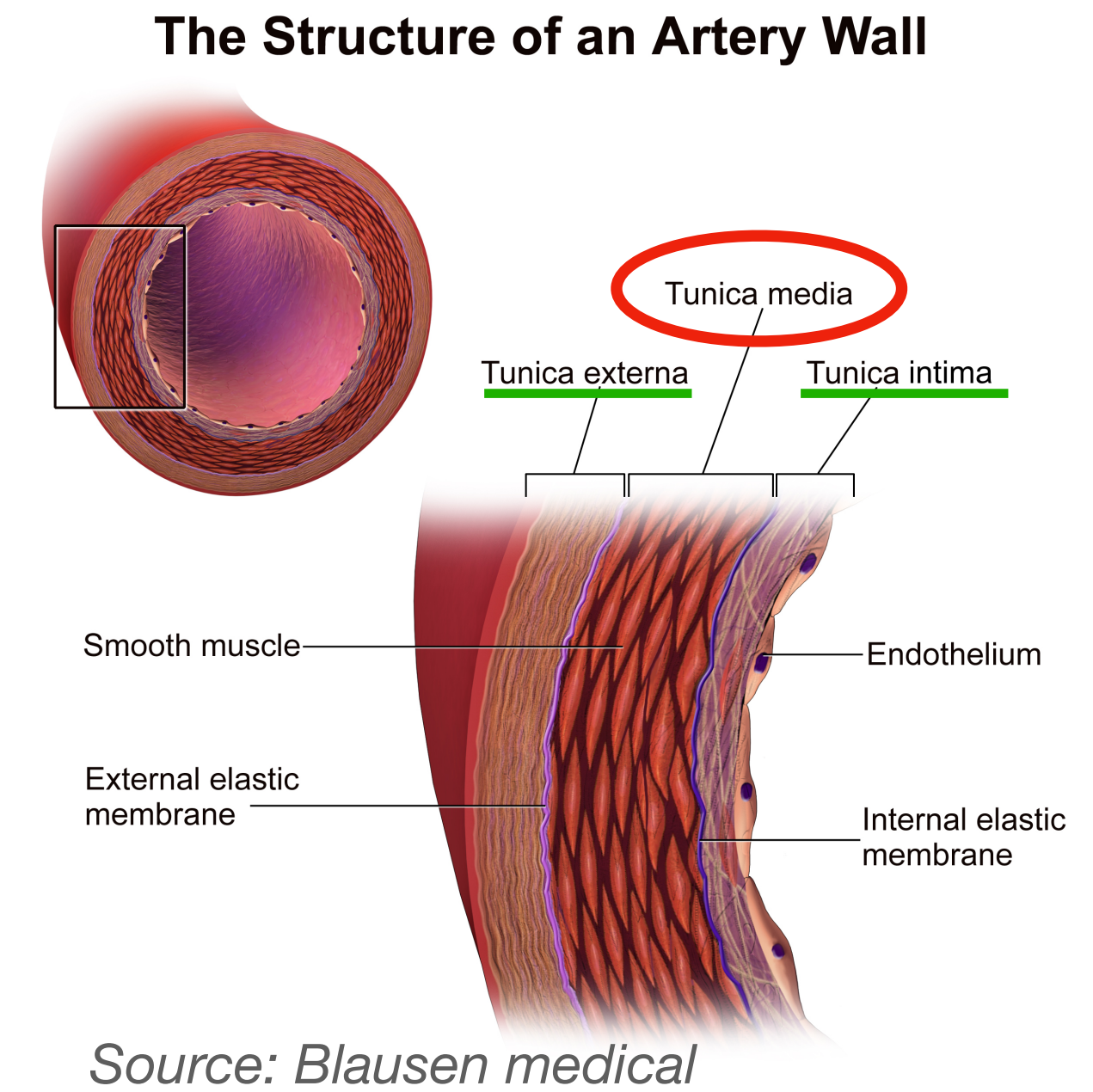
# Introduction

- **Elastic lamellae remodelling** are related to vascular diseases which can be precipitated by metabolic disorders, e.g. diabetes



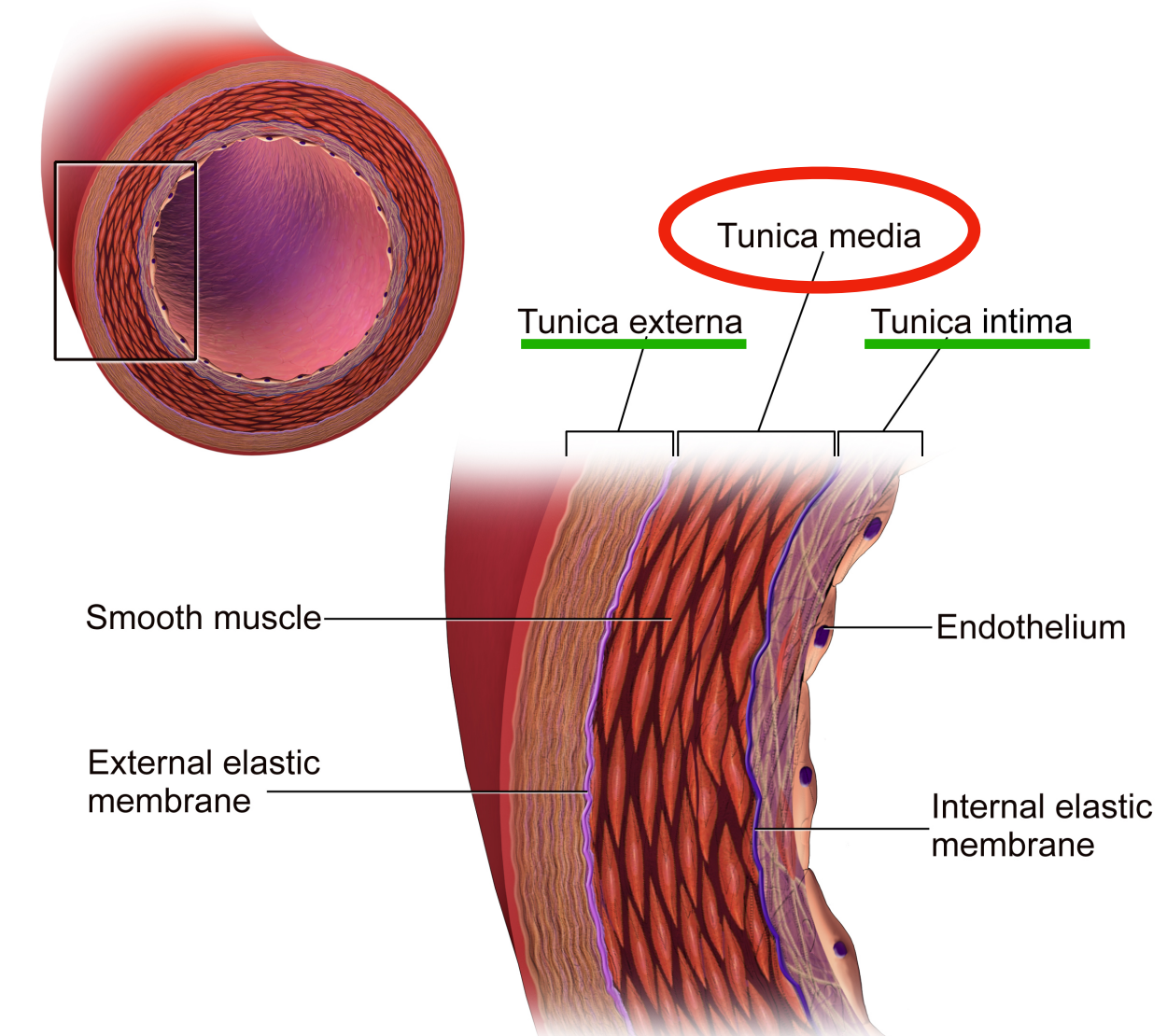
# Introduction

- **Elastic lamellae remodelling** are related to vascular diseases which can be precipitated by metabolic disorders, e.g. diabetes
- Early identification of the very first stages of these diseases is extremely important to avoid irreversible damages on vessels



# Introduction

The Structure of an Artery Wall



Source: Blausen medical

- **Elastic lamellae remodelling** are related to vascular diseases which can be precipitated by metabolic disorders, e.g. diabetes
  - Early identification of the very first stages of these diseases is extremely important to avoid irreversible damages on vessels
- **High-resolution synchrotron X-ray microtomography images** of mice aortae are used

# Acquisition of images

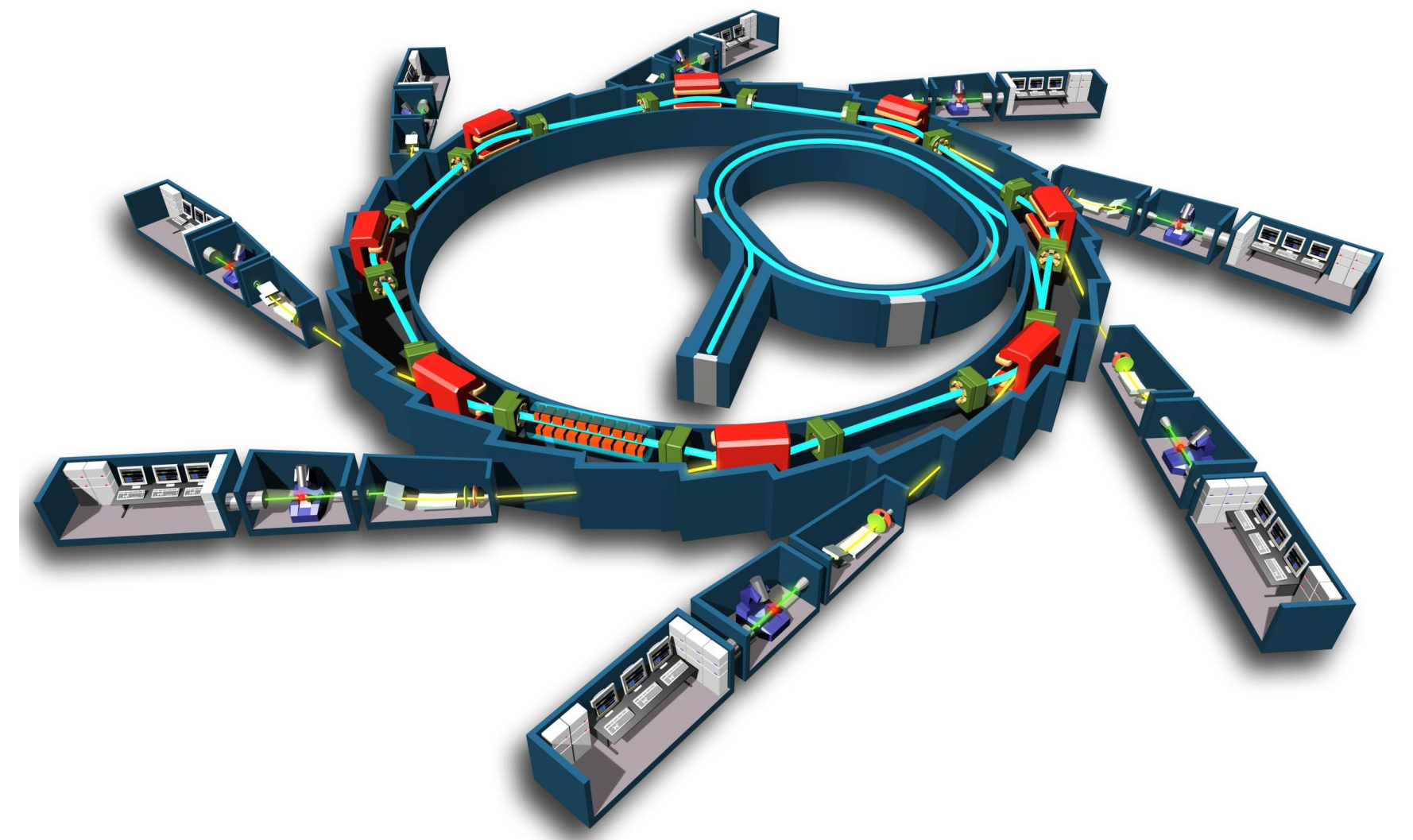
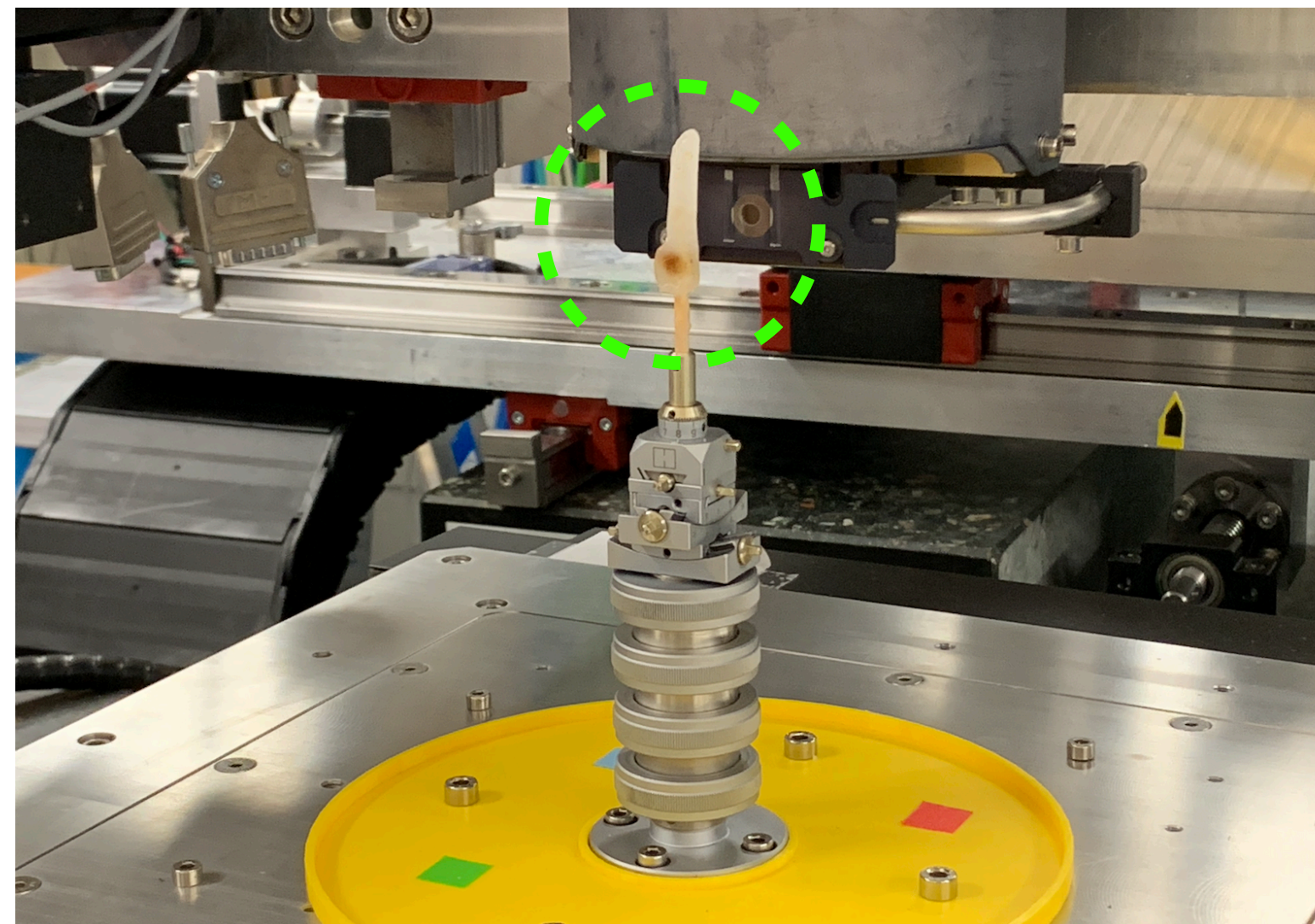
- Tomographic image data acquired on the ANATOMIX beamline of the SOLEIL synchrotron



Source: <https://fr.wikipedia.org/wiki/SOLEIL>

# Acquisition of images

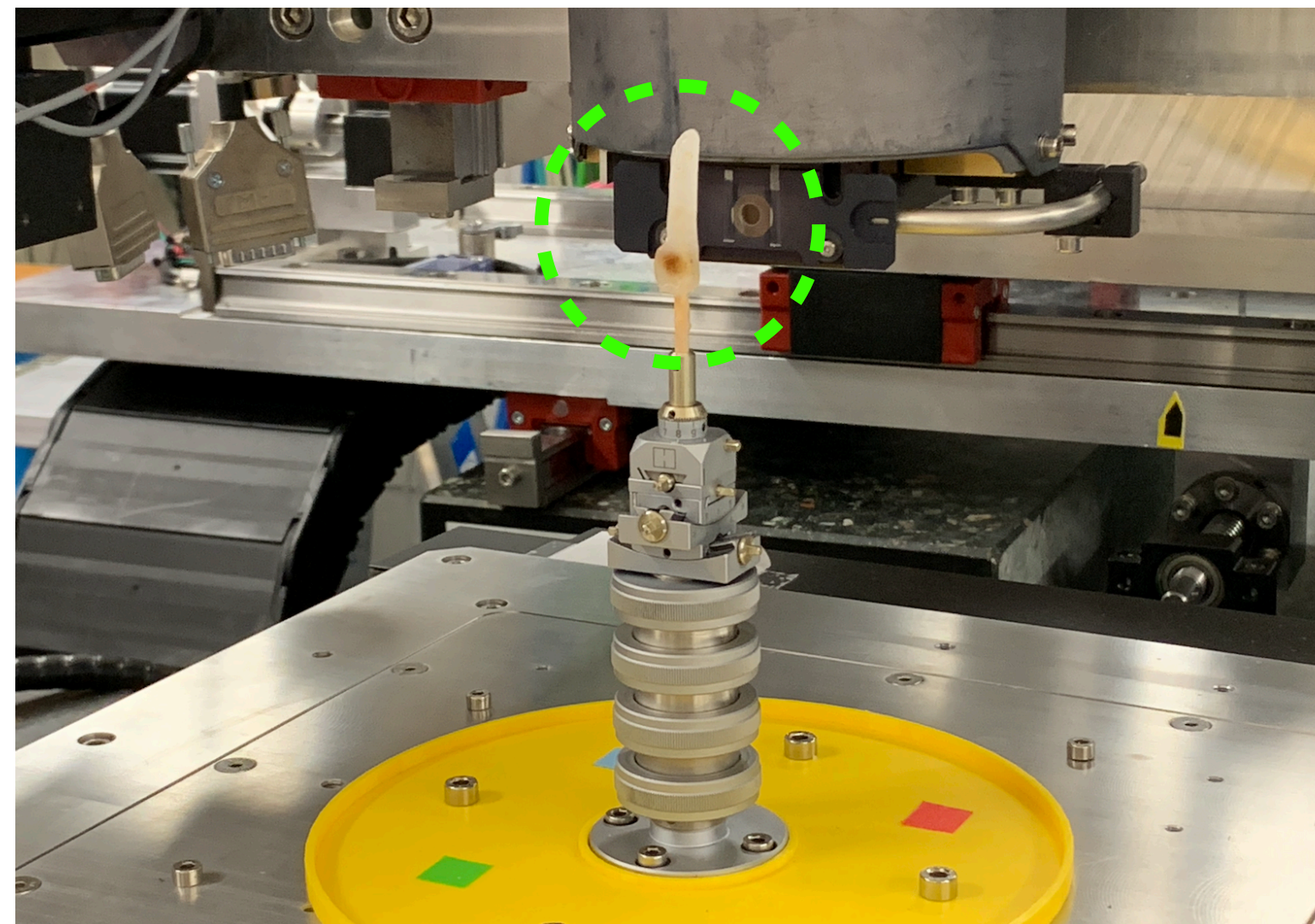
- Tomographic image data acquired on the ANATOMIX beamline of the SOLEIL synchrotron
- Mice aortae divided into 2 groups: **normal** (healthy) and **ill (diabetic)**



Source: <https://fr.wikipedia.org/wiki/SOLEIL>

# Acquisition of images

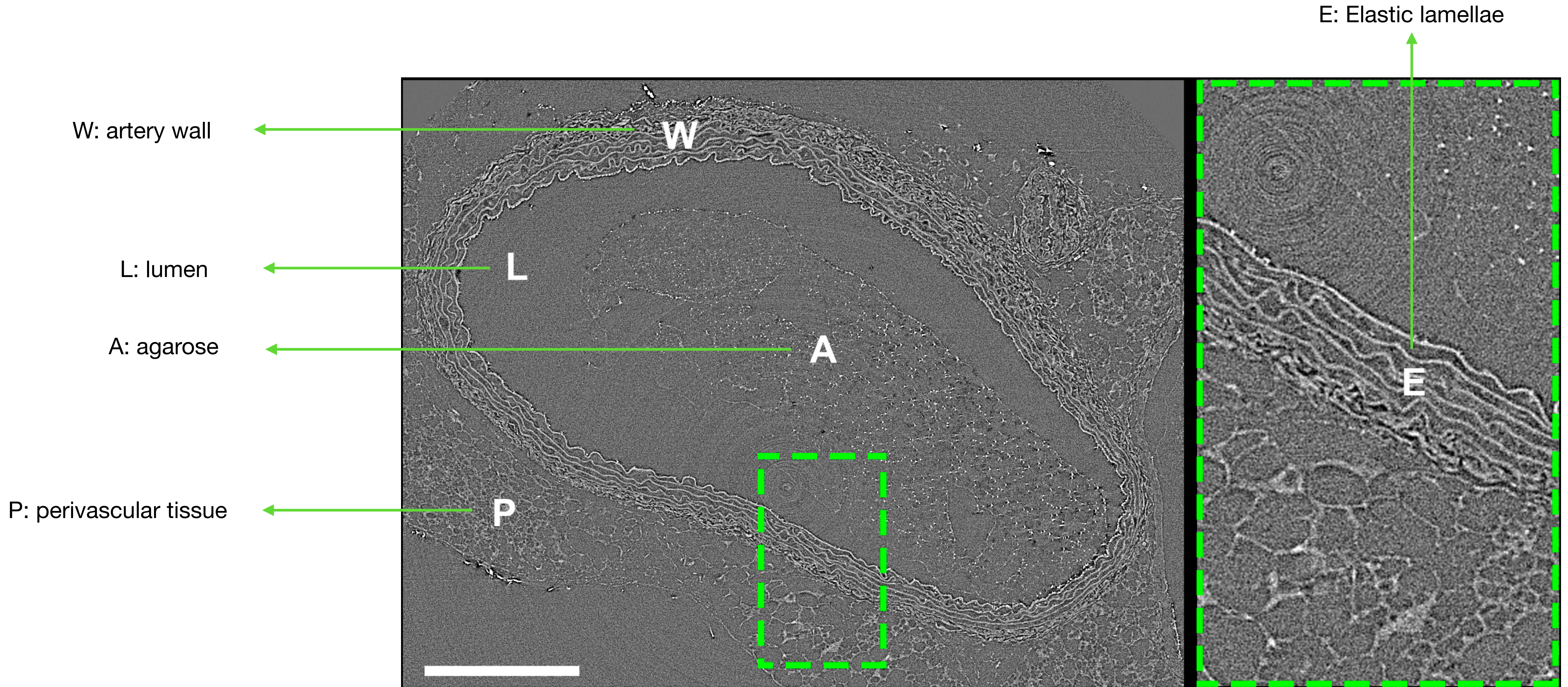
- Tomographic image data acquired on the ANATOMIX beamline of the SOLEIL synchrotron
- Mice aortae divided into 2 groups: **normal** (healthy) and **ill (diabetic)**
- Volume:  $2048^3$  voxels of size  $(0.65\mu m)^3$ 
  - 32 GB per stack



Source: <https://fr.wikipedia.org/wiki/SOLEIL>

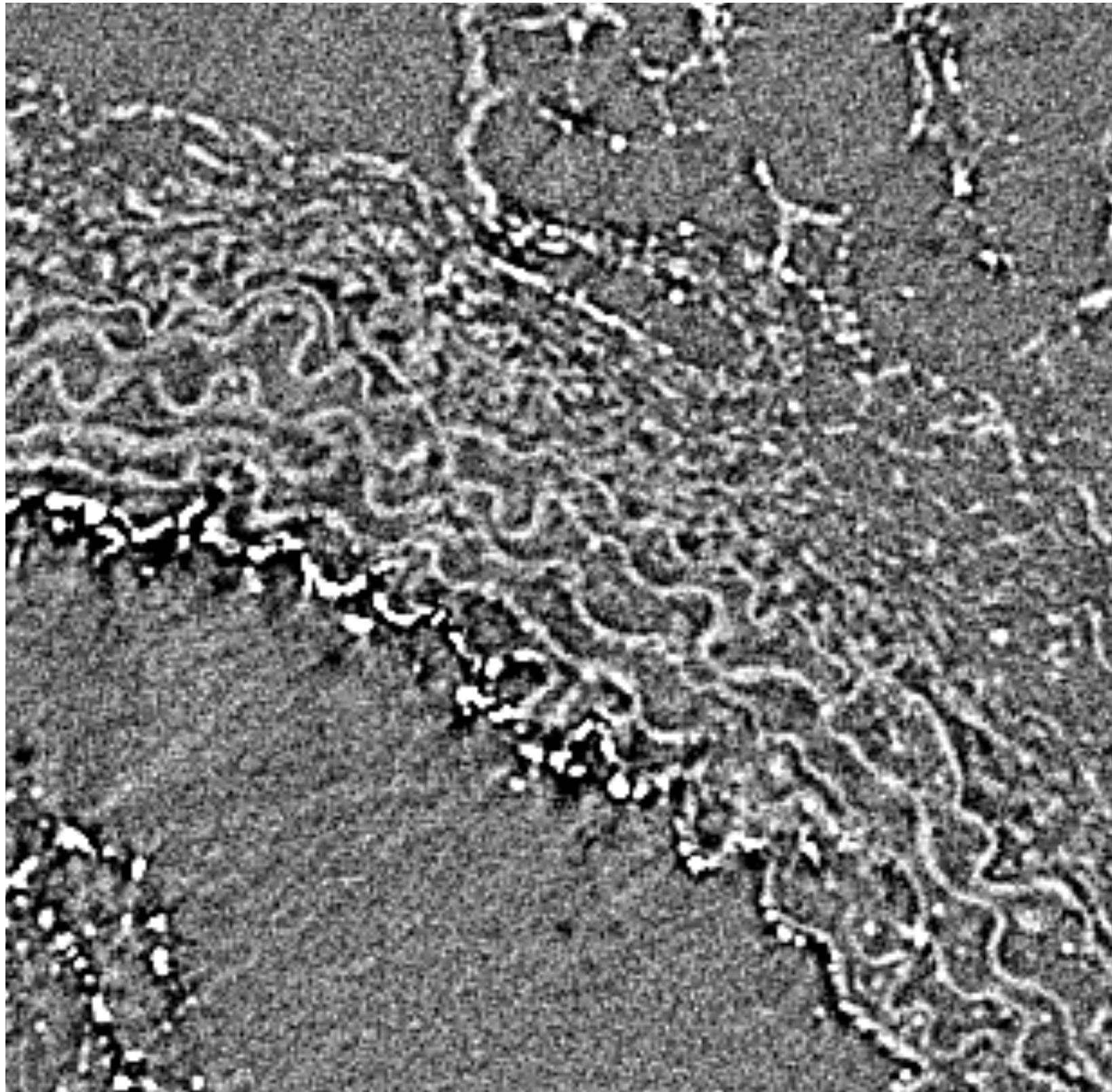


# Image of an aorta

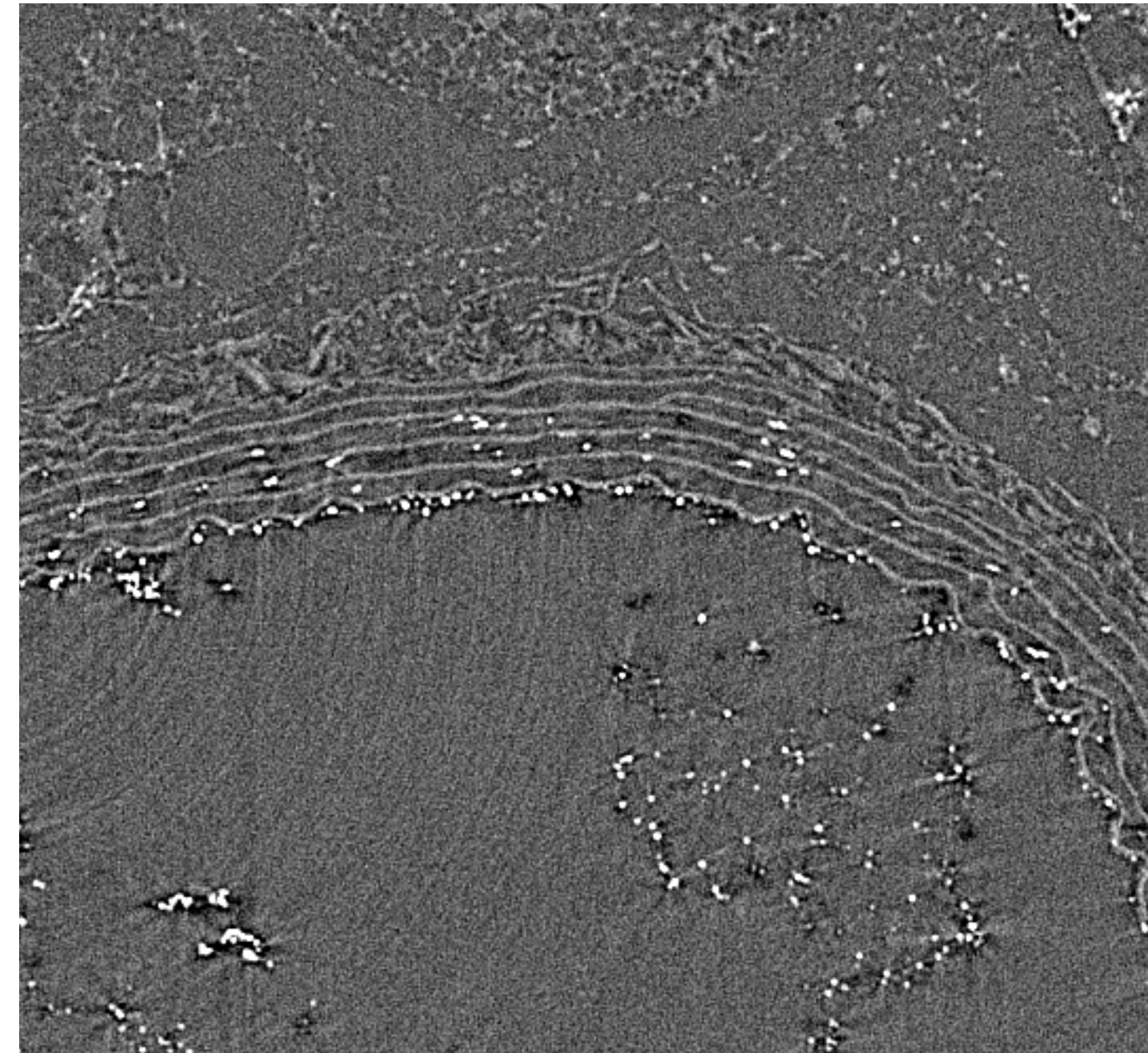


# Comparison of 2 groups

## Observation



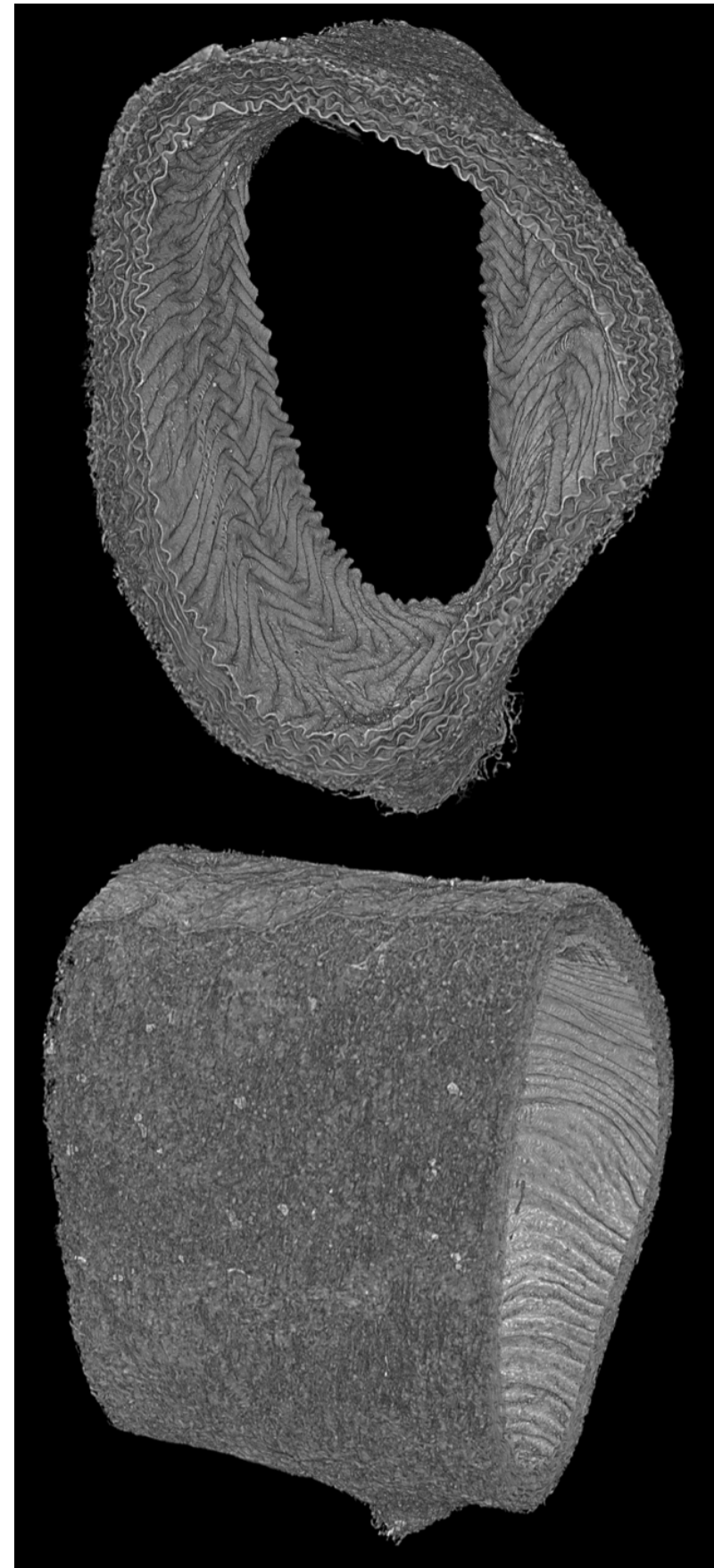
Normal



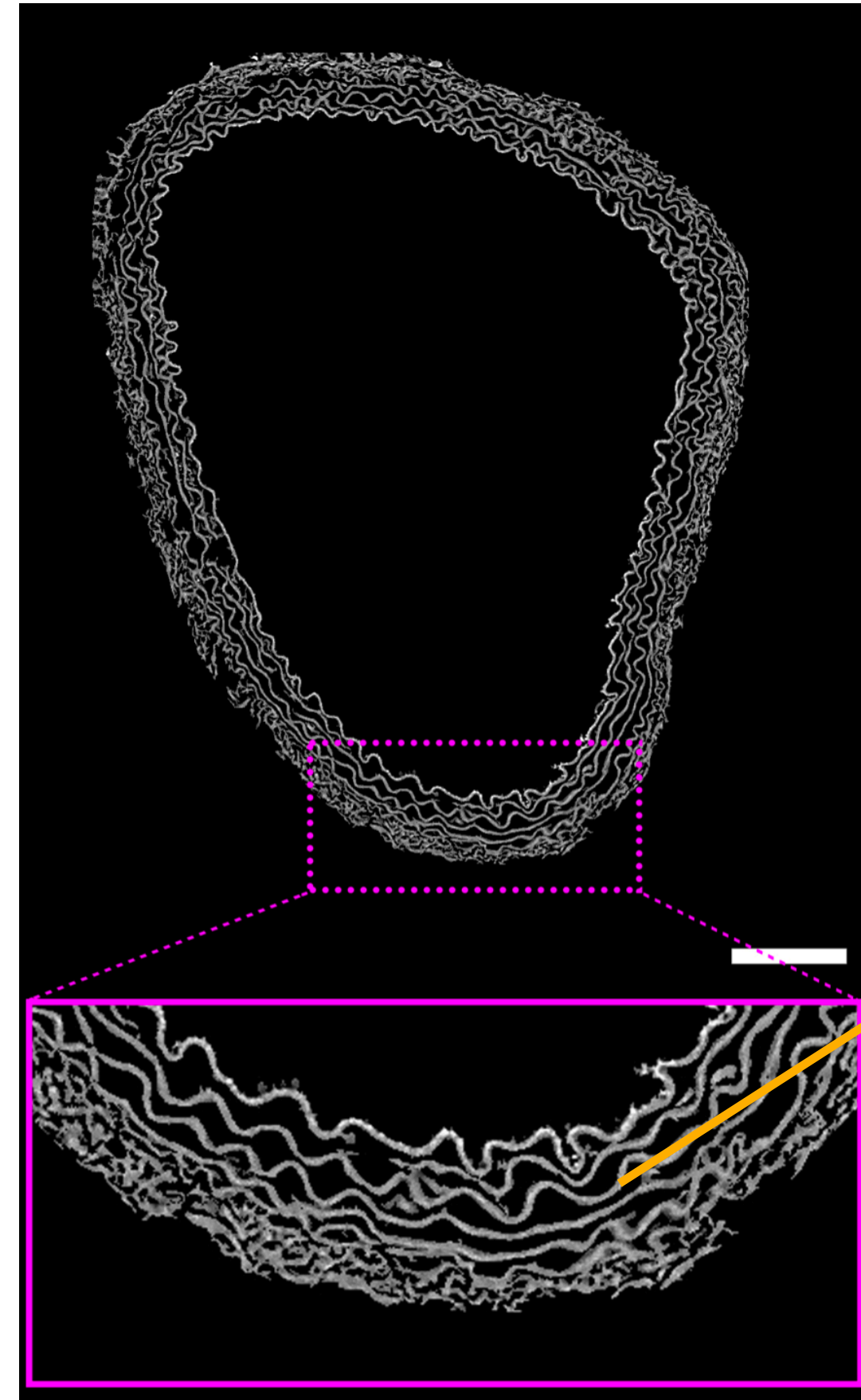
Diabetic

# Analysis of the waviness

## Material

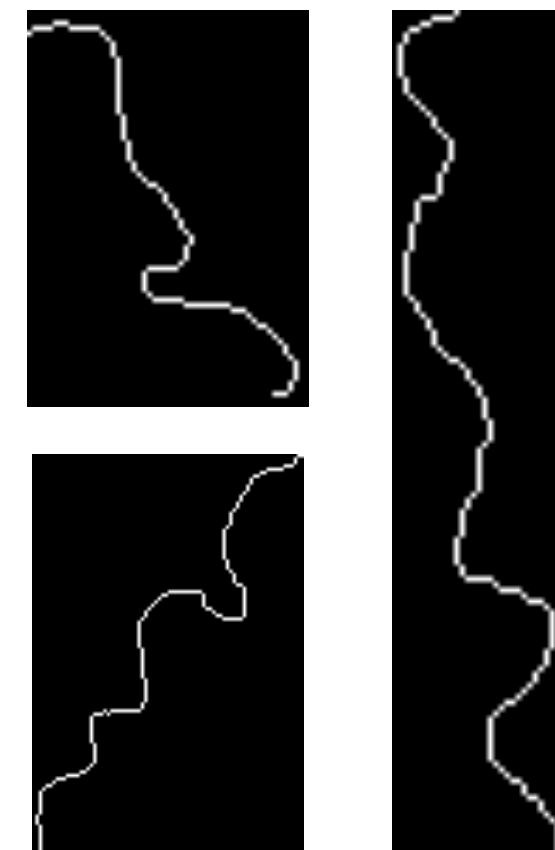


3D view



Segmented image

Segmented (based on Otsu method) and skeletonized fragments of elastic lamellae



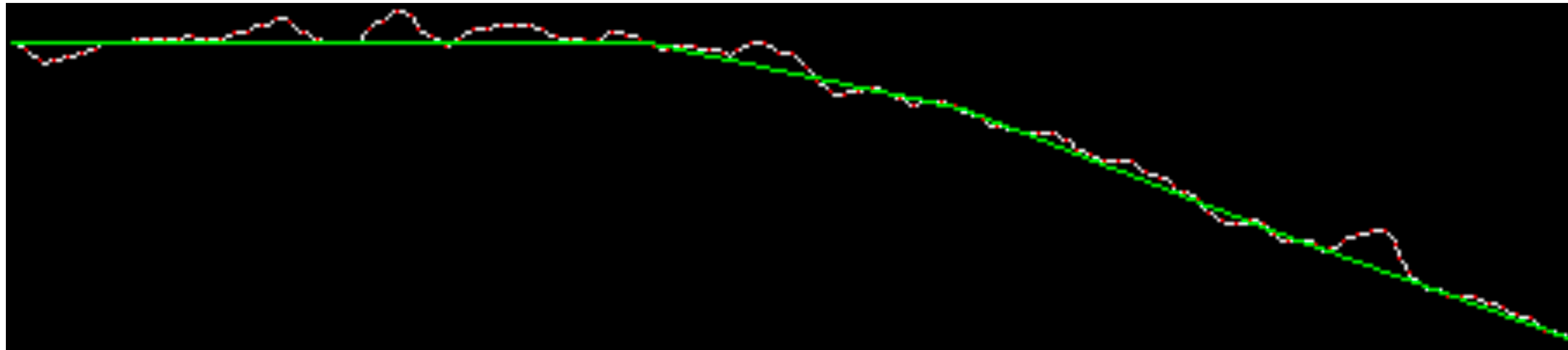
Normal mice



Diabetic mice

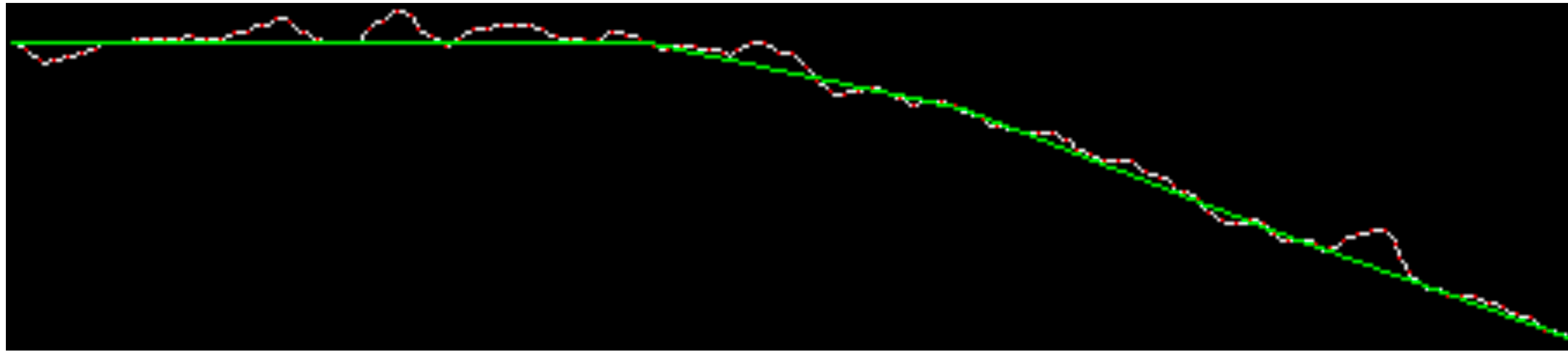
# Analysis of the waviness

## Measurement



# Analysis of the waviness

## Measurement



Ratio:  $\rho = \frac{L_{Euc}}{L_{geo}}$

Euclidean distance:  $L_{Euc} = \sum_{0 \leq j < L_{geo}/\sigma, (j+1)\sigma \leq L_{geo}} \|V_{e_{(j+1)\sigma}} - V_{e_{j\sigma}}\|_2$

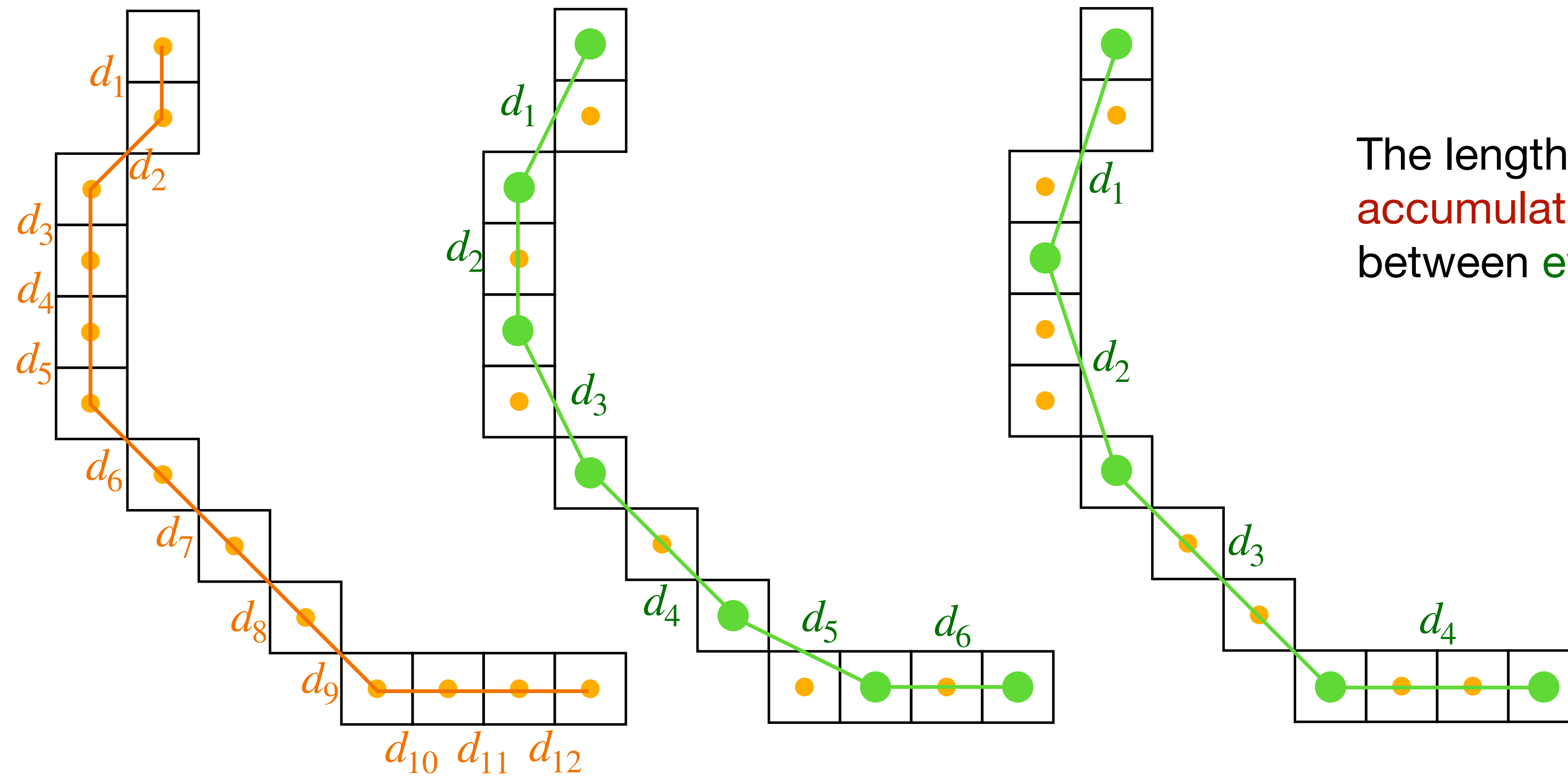
where  $\sigma$  is the sampling rate of **geodesic distance**,  $j$  are subsampled indices

Geodesic distance:  $L_{geo} = \sum_{0 \leq i < k} \|V_{g_{i+1}} - V_{g_i}\|_2$

where  $k$  is the number of pixels and  $V_i$  are vertices of the curve

# Analysis of the waviness

## Geodesic distance



The length of a curve is calculated by **accumulating** the **Euclidean distances** between **every 2 adjacent selected pixels**

All the pixels

Selected pixels with  $s = 2$

Selected pixels with  $s = 3$

# Analysis of the waviness

## Geodesic distance

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$s$	1	2	3	4	5	6	7	8	9
$\alpha$	1.0551	1.0128	1.0046	0.9999	0.9955	0.9939	0.9907	0.9890	0.9842

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We chose  $s = 4$  as the ratio of subsampling

We also tested  $s$  with straight lines and  $s = 4$  makes  $L_{geo}$  close enough to the real length

# Analysis of the waviness

## Euclidean distance

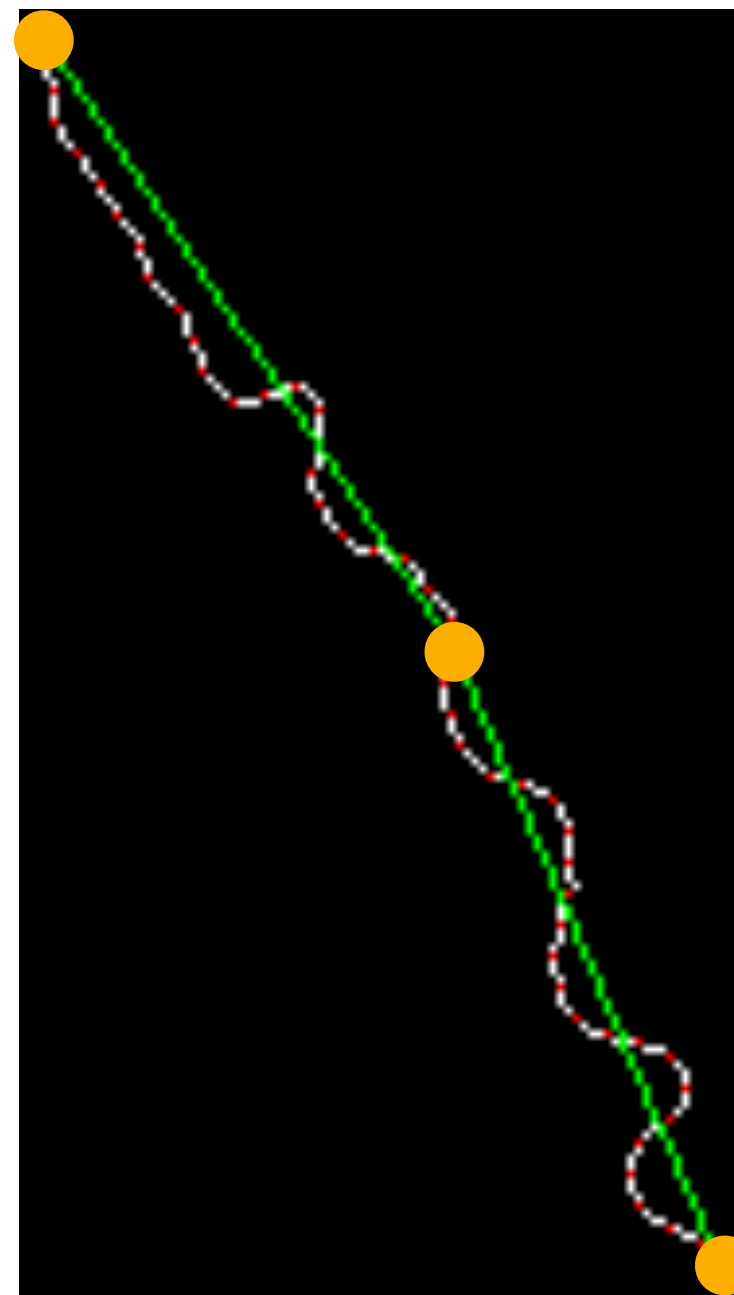
3 different cases depending on their geodesic lengths

$$L_{geo} \leq 100$$



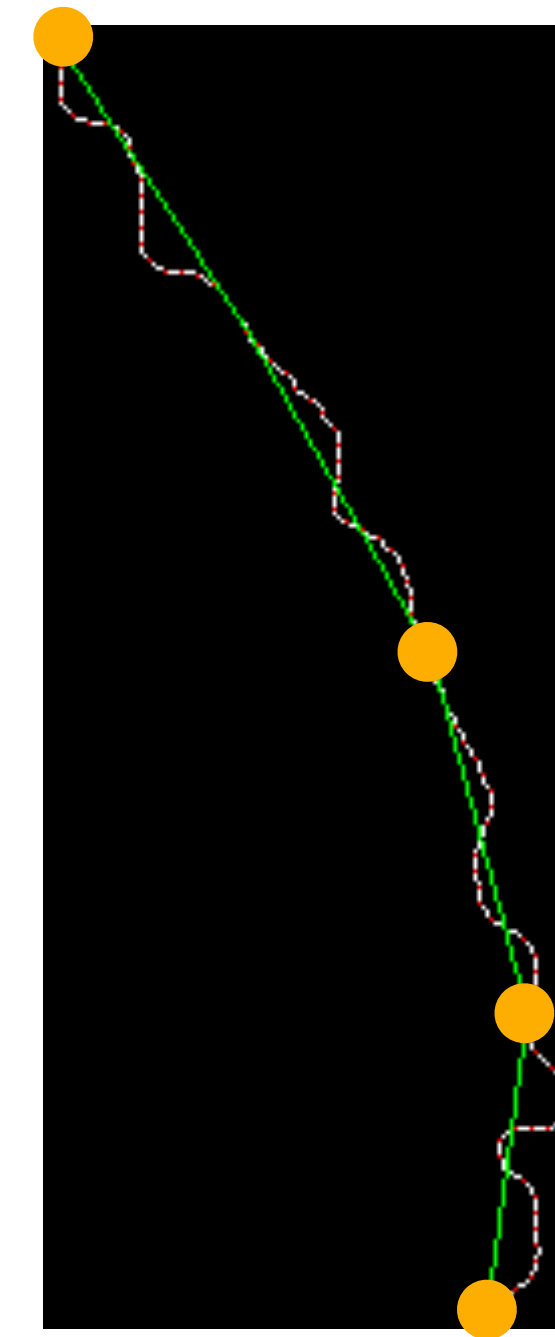
$L \approx 30 \text{ pixels}$

$$100 < L_{geo} \leq 300$$



$L \approx 30 \text{ pixels}$

$$300 < L_{geo}$$



$L \approx 30 \text{ pixels}$



# Analysis of the waviness

## Result

Mann-Whitney U  
test

Normal	Thoracic (6 samples)						Abdominal (4 samples)				
$\bar{\rho}$	0.8929	0.8993	0.7578	0.8324	0.8557	0.7968	0.7701	0.8379	0.8380	0.8303	
Diabetic	Thoracic (6 samples)						Abdominal (5 samples)				
$\bar{\rho}$	0.8815	0.8769	0.8864	0.9310	0.9268	0.9236	0.8965	0.9303	0.8621	0.8804	0.8749
p-value	Thoracic (normal vs. diabetic) : 0.06555						Abdominal (normal vs. diabetic) : 0.01996				
p-value	Thoracic & Abdominal (normal vs. diabetic) : 0.003474										

2000 ~ 3000 fragments for each sample (= a 3D image of a mouse from 6 to 6.5 months)

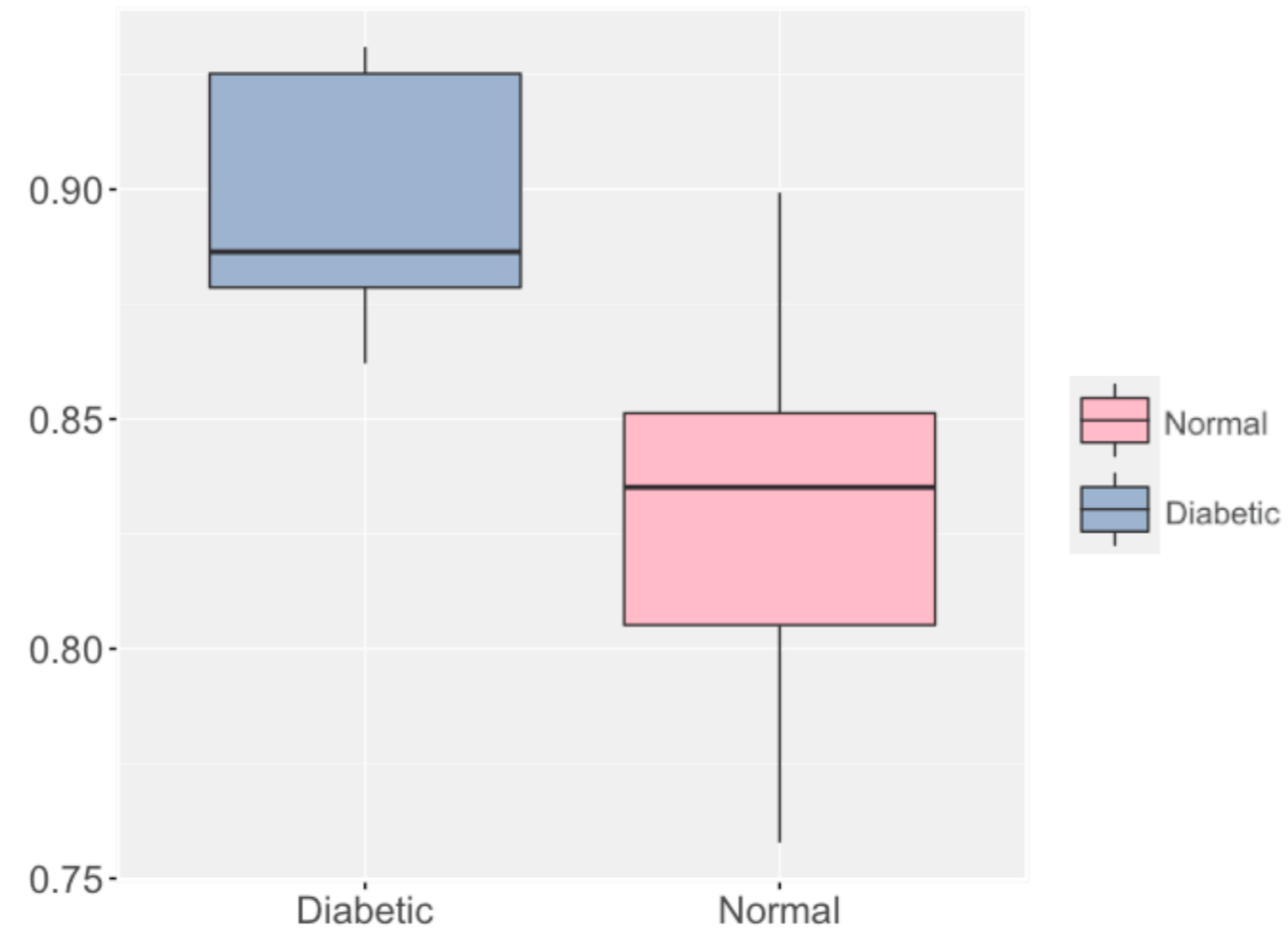
The measurement  $\rho$  is calculated for each fragment and is averaged in each group

# Analysis of the waviness

## Result

Mann-Whitney U test :  $p - value = 0.0035 \ll 0.05$

**A significant difference between healthy and diabetic mice in terms of elastic lamellae waviness**

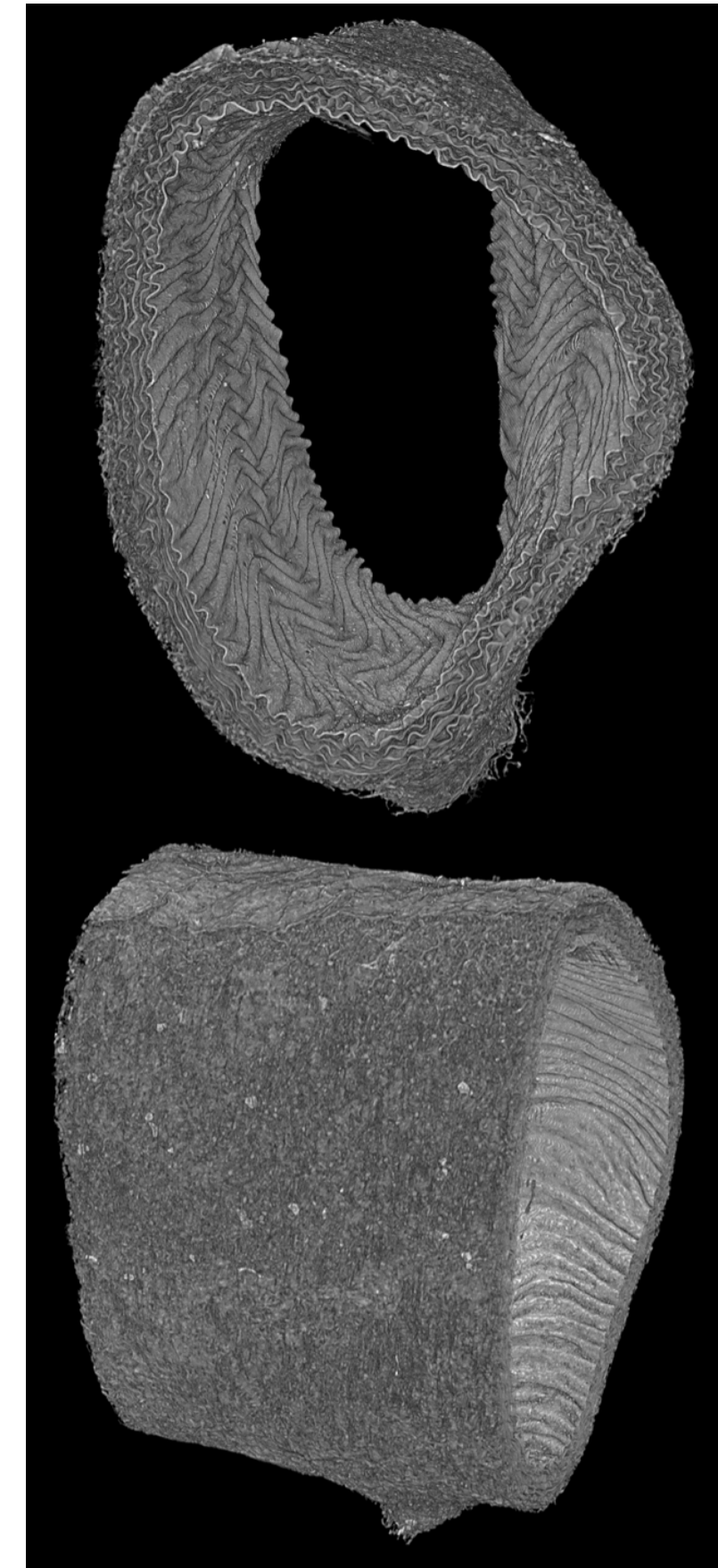


# Segmentation

In order to perform a more comprehensive analysis



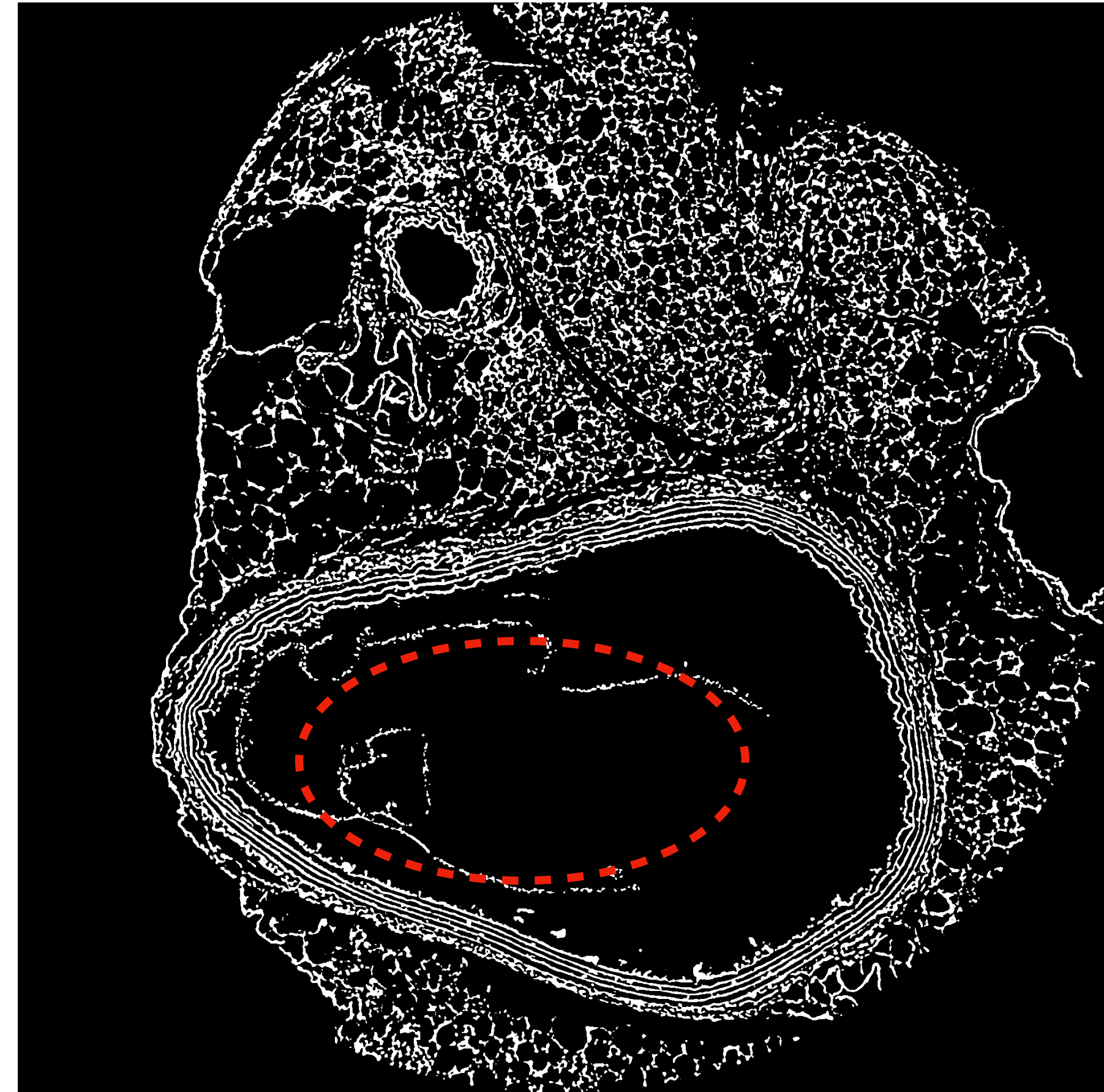
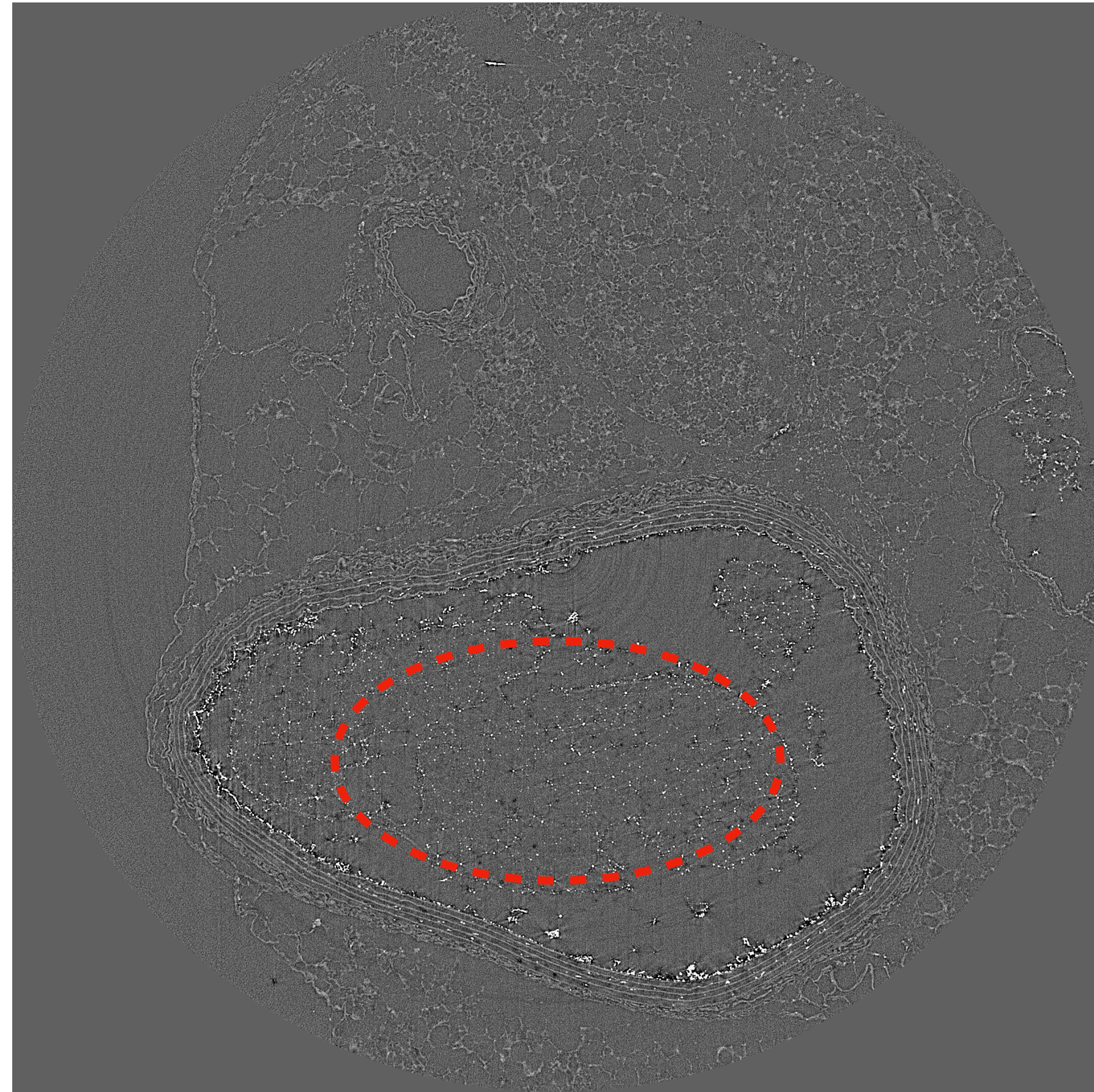
2D fragments



3D arterial wall

# Segmentation

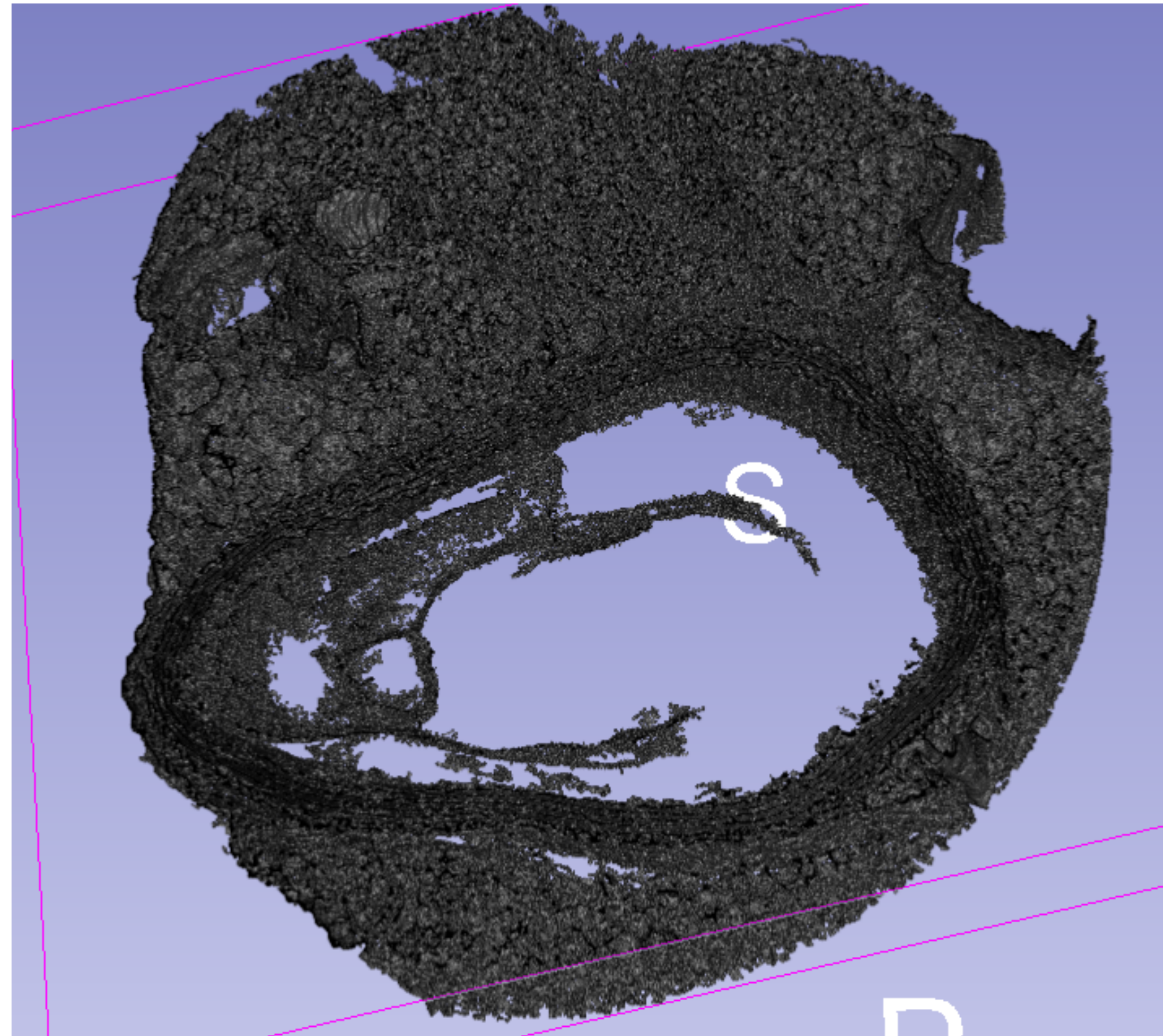
## Extraction of high density regions



Agarose mixed during the process of acquiring images

# Segmentation

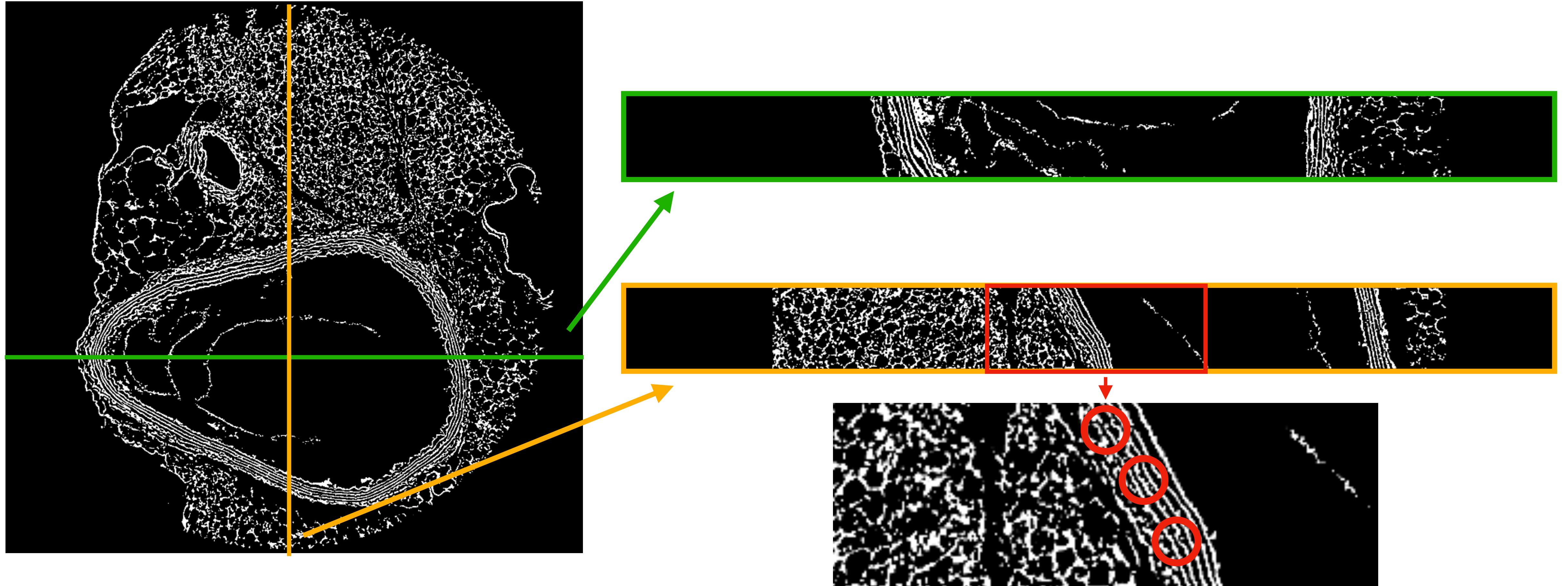
Extraction of high density regions



Agarose mixed during the process of acquiring images

# Segmentation

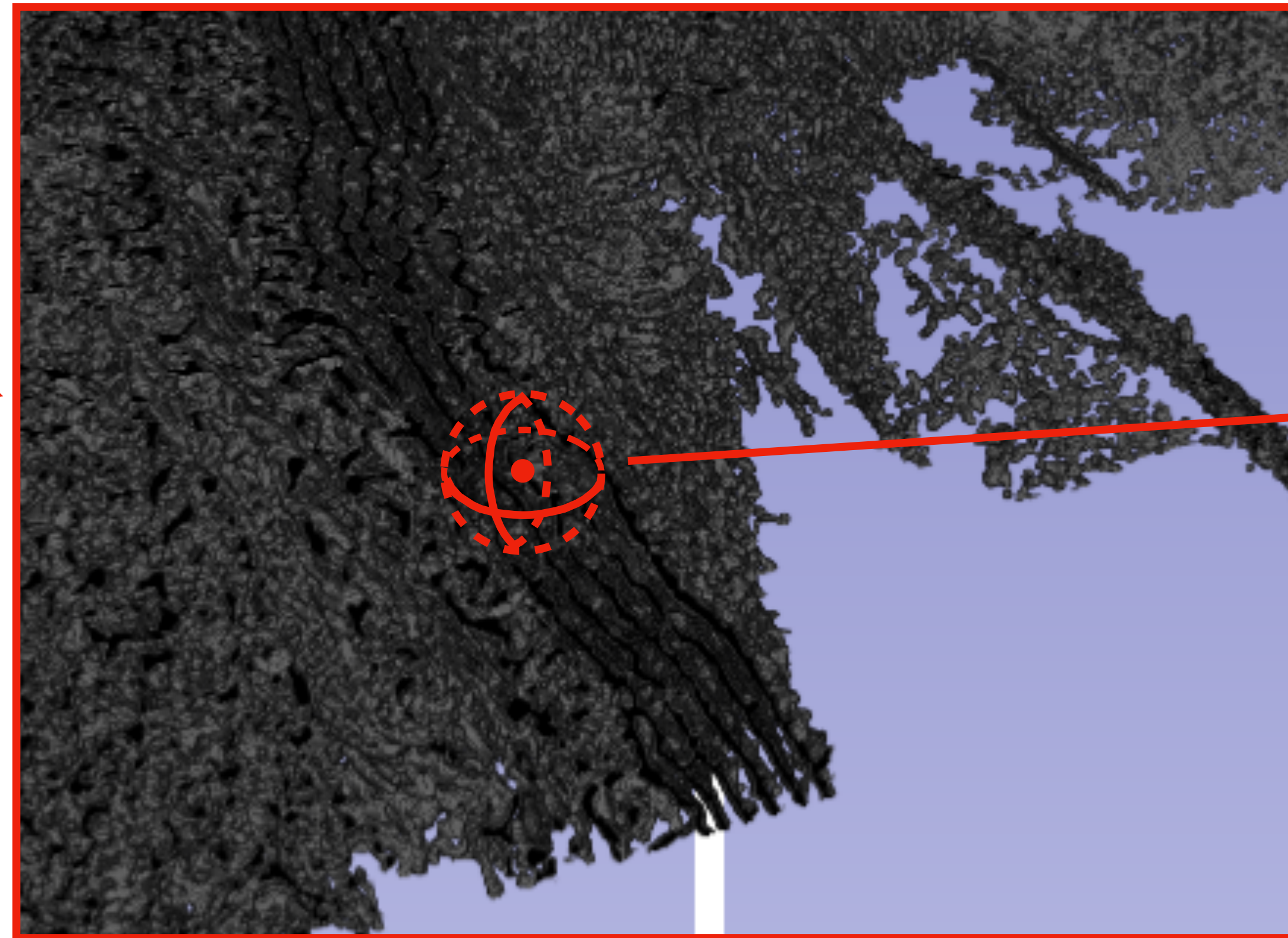
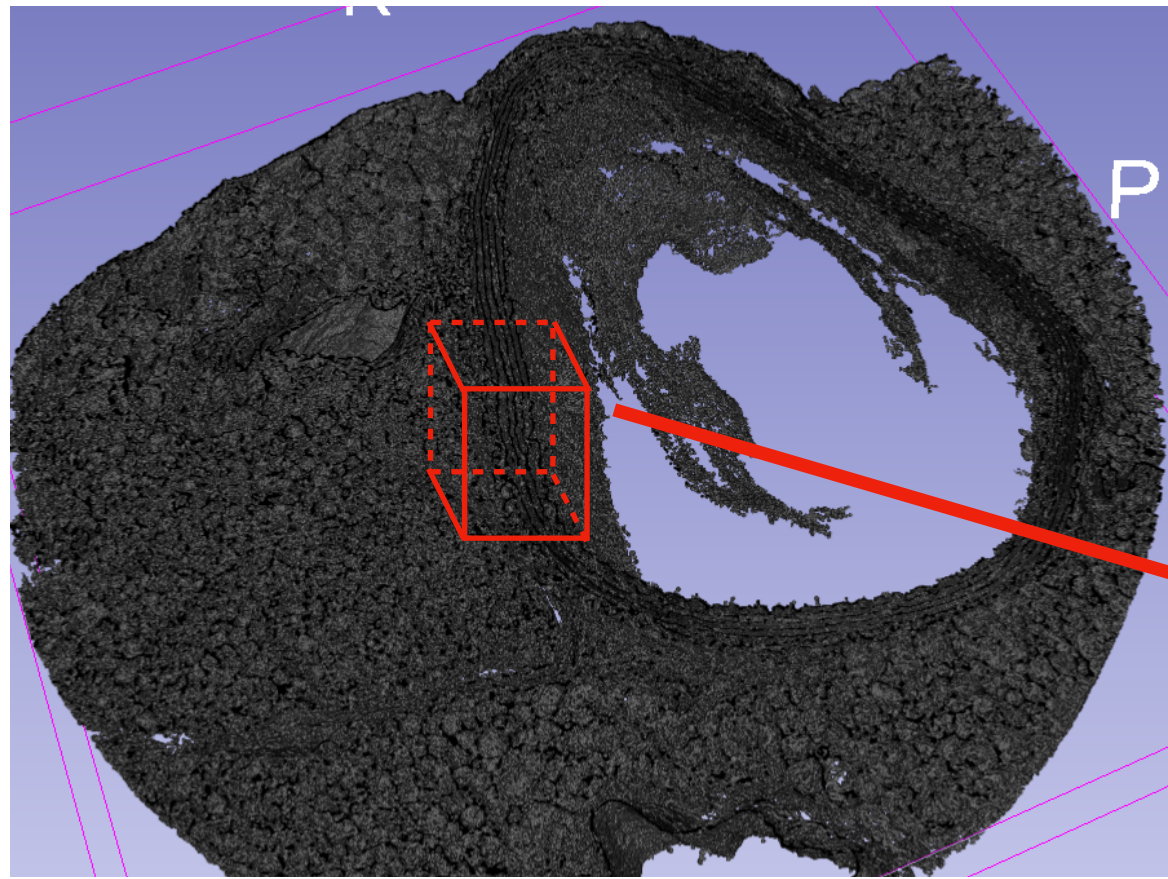
## Extraction of high density regions



Using spheres to extract non-agarose regions

# Segmentation

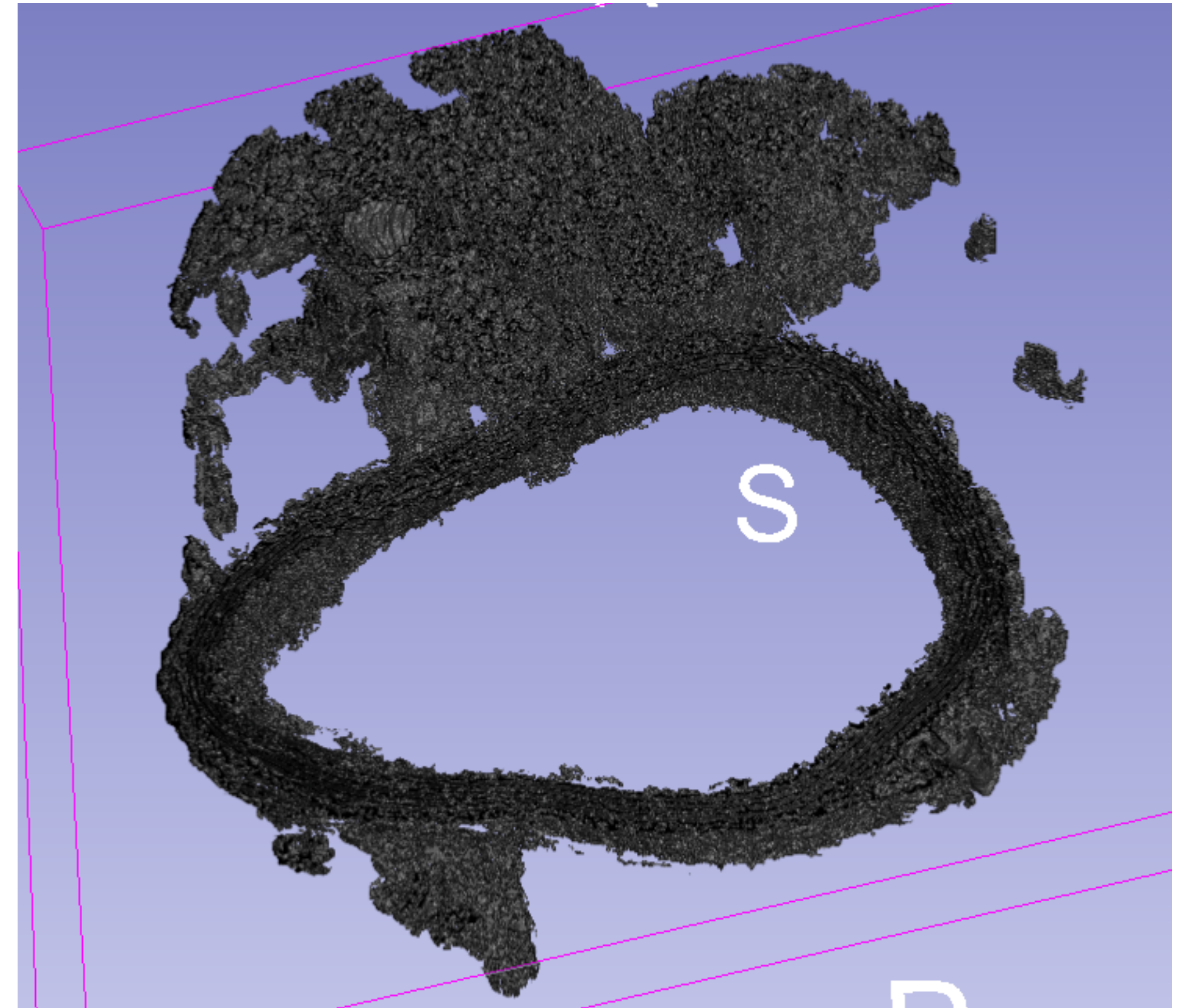
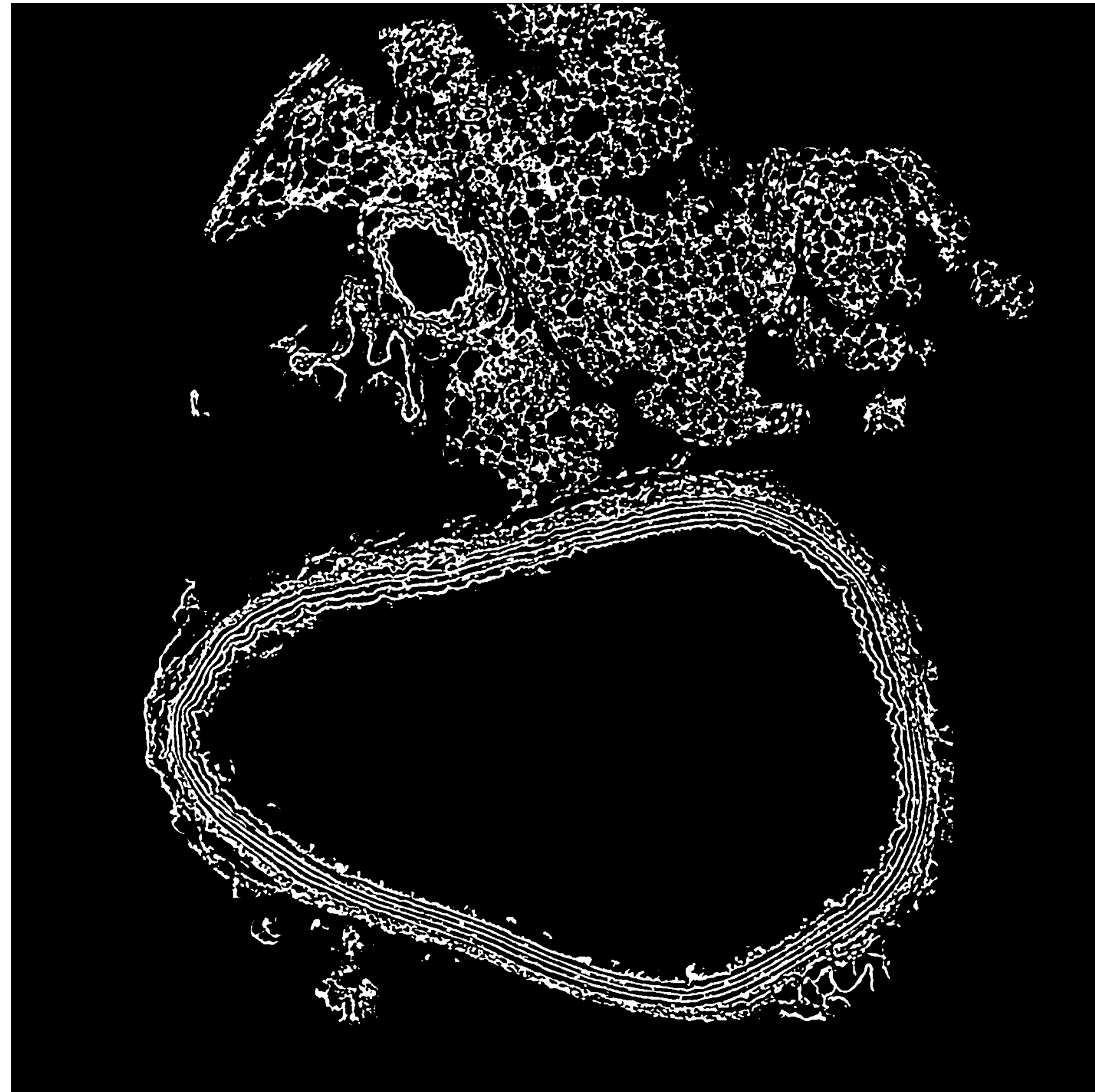
## Extraction of high density regions



$$\sum_{\substack{p \in \mathcal{N}(p(x_0, y_0, z_0), R) \\ I(p) > 0}} p(x, y, z) > \frac{1}{4}V(R)$$

# Segmentation

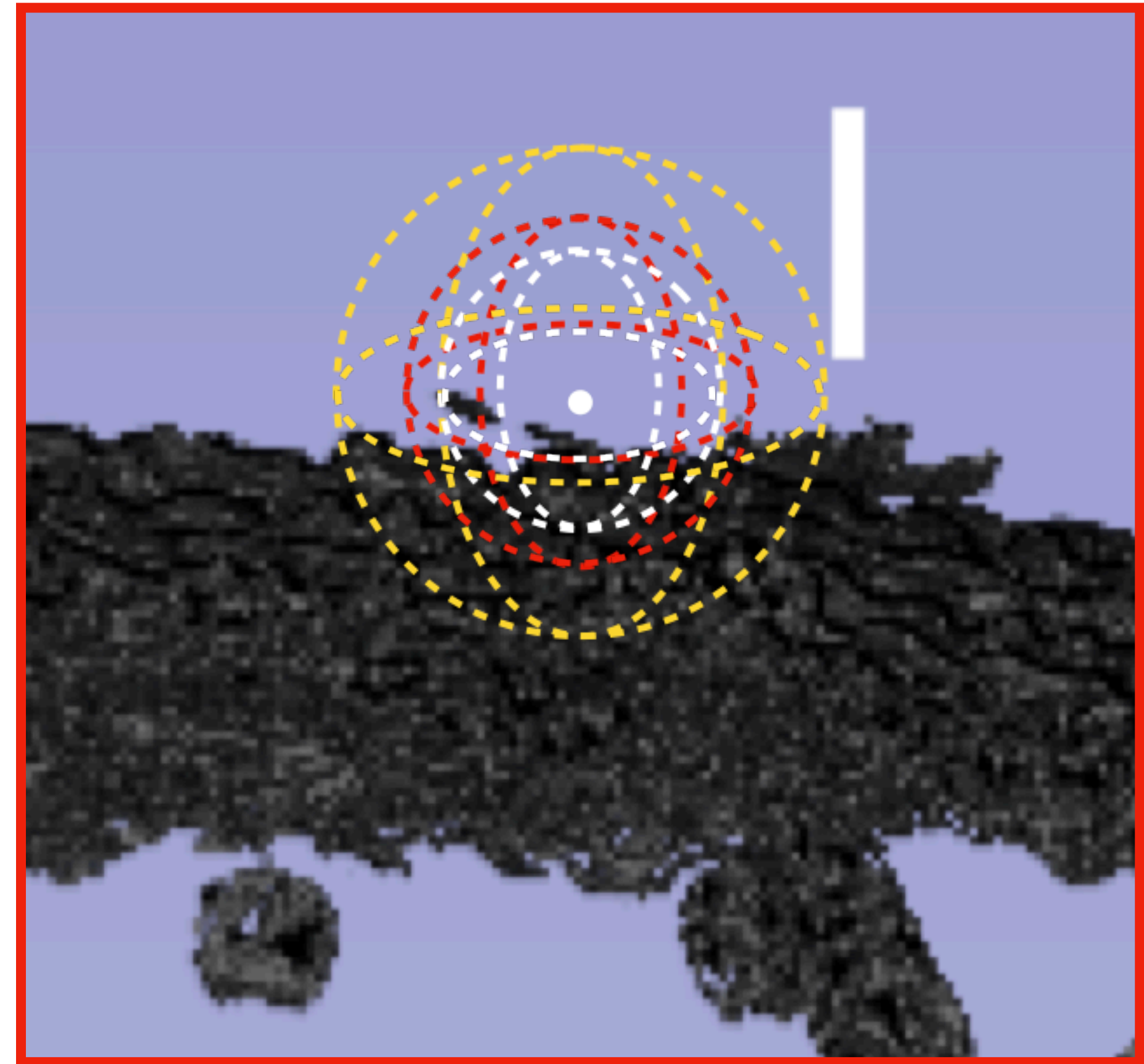
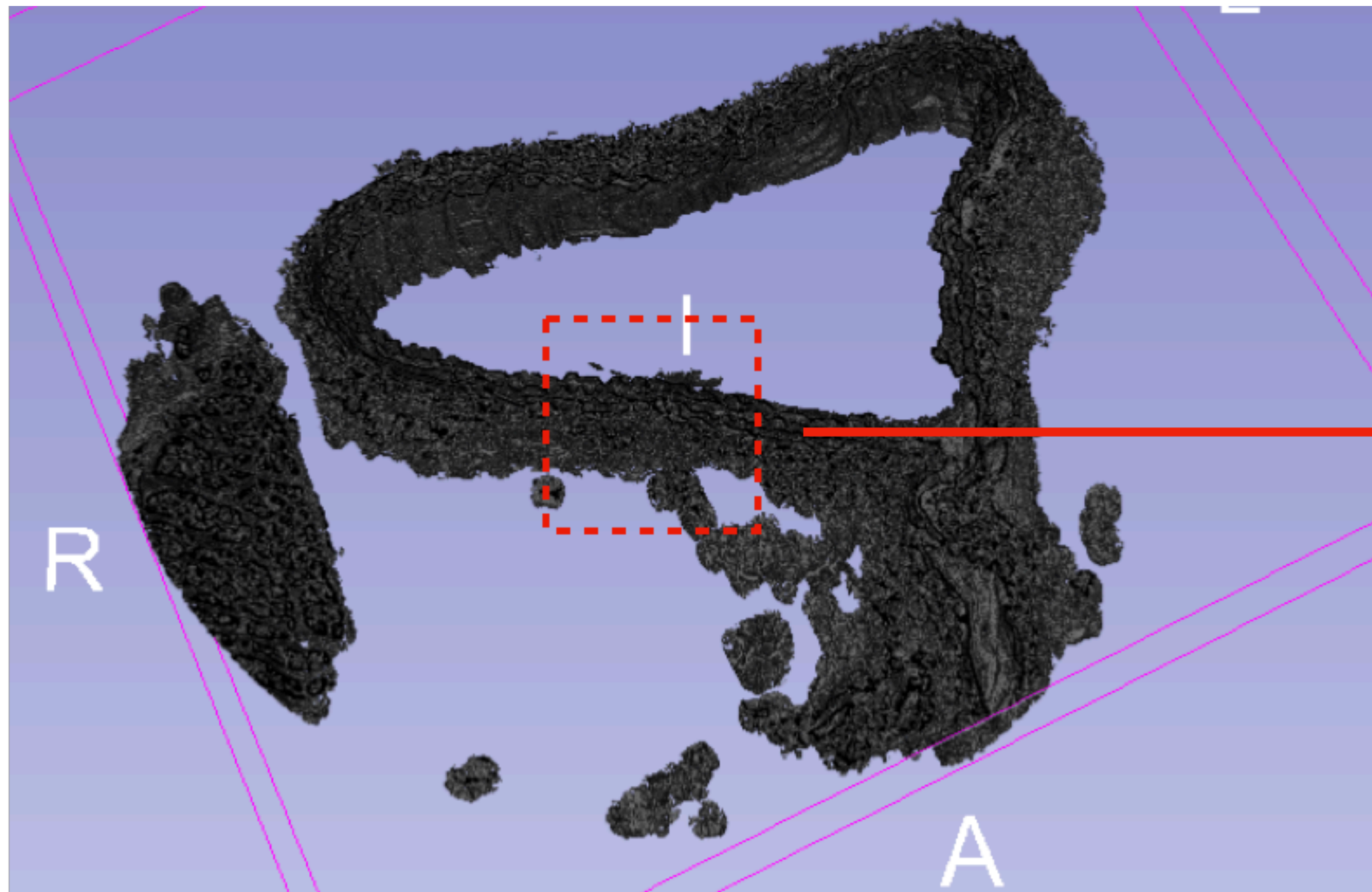
Extraction of high density regions





# Segmentation

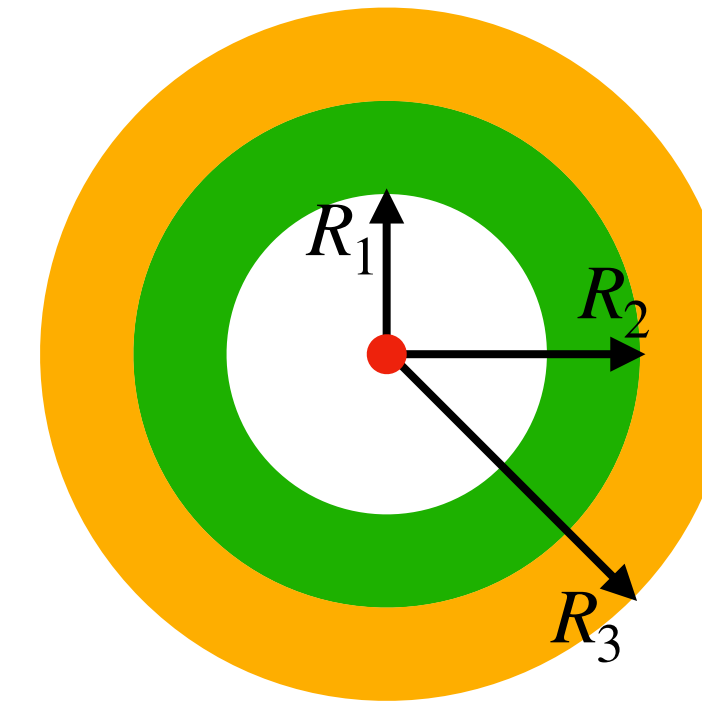
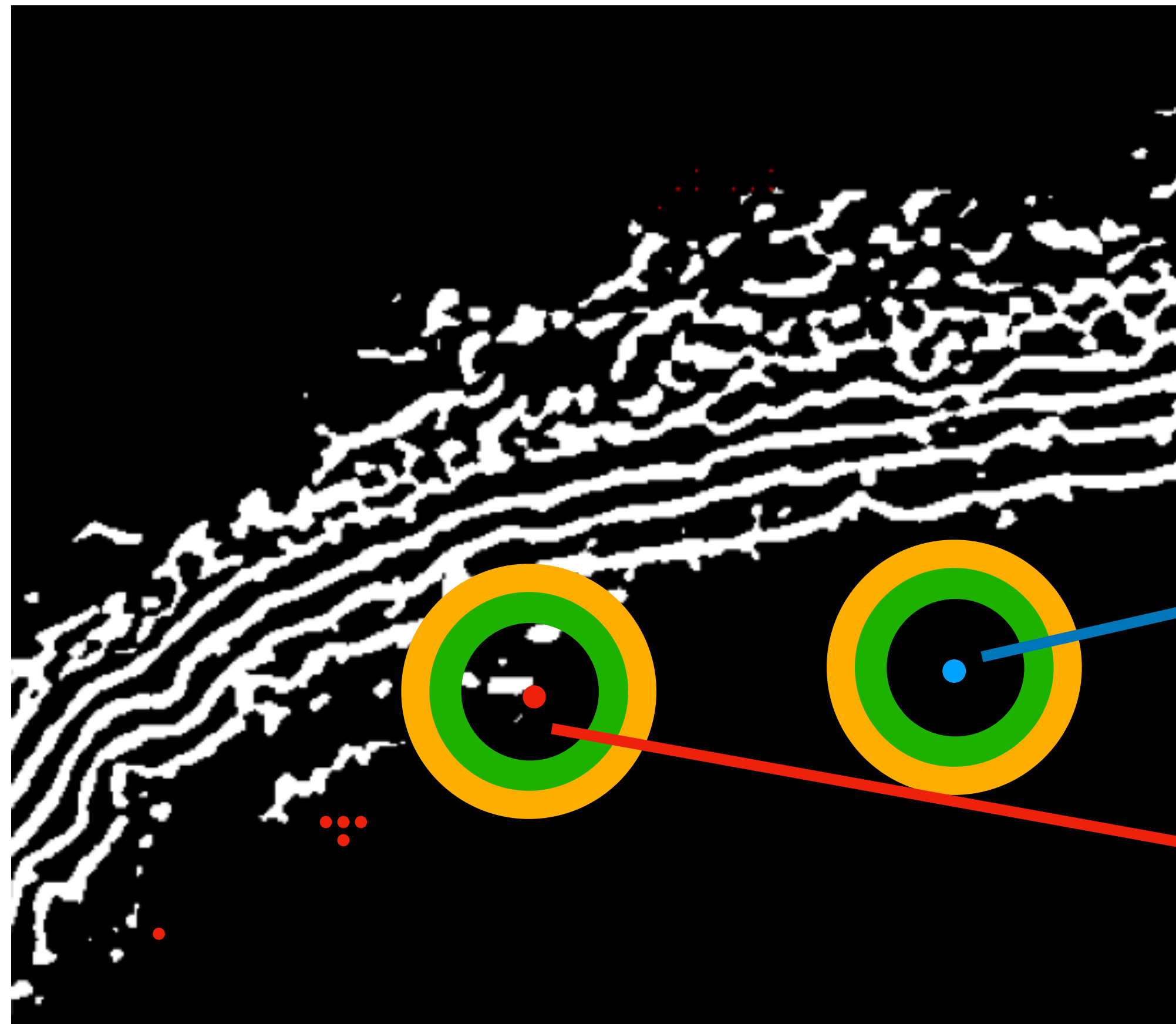
## Extraction of lumen



Using concentric spheres to improve the robustness

# Segmentation

## Extraction of lumen



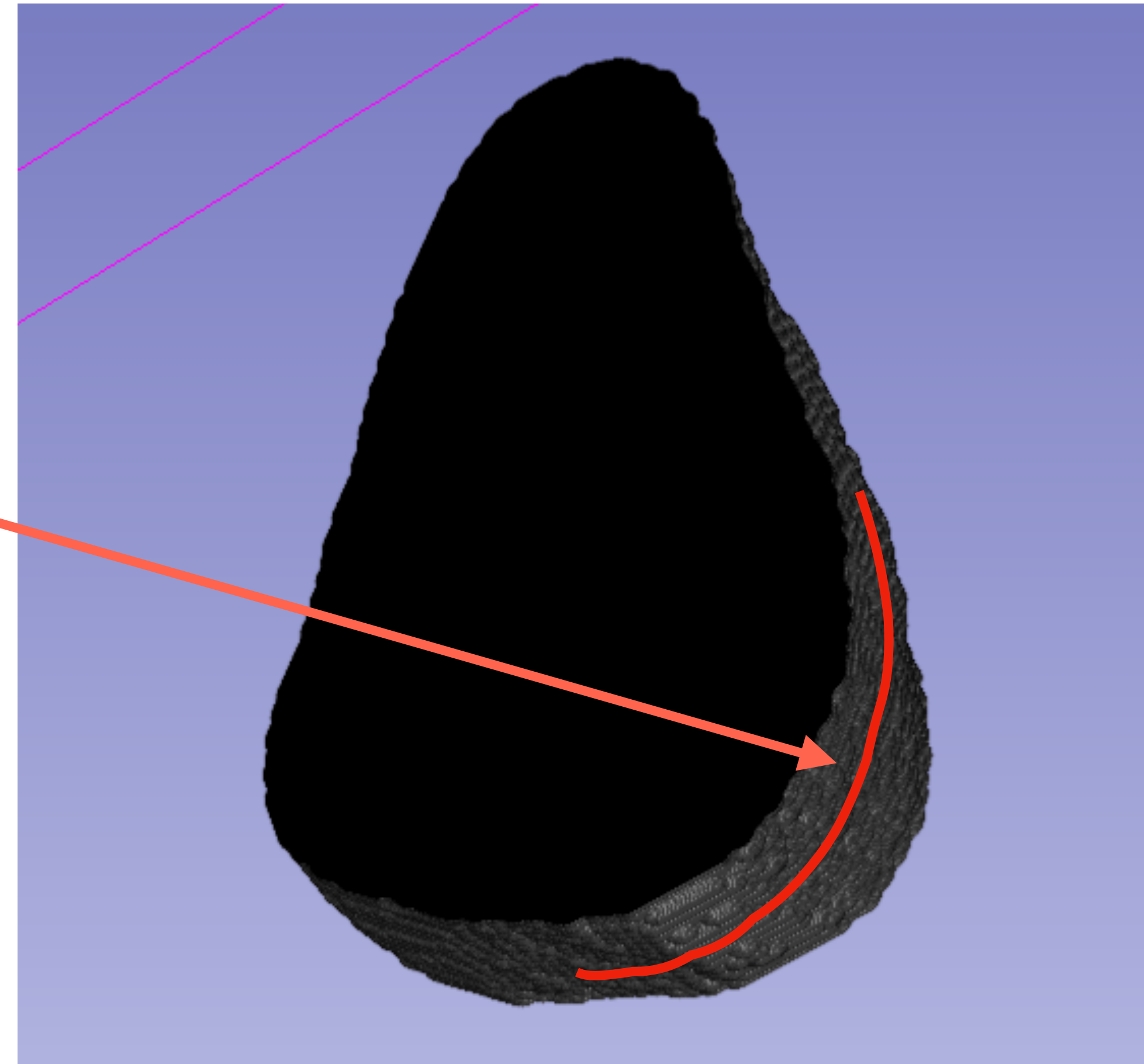
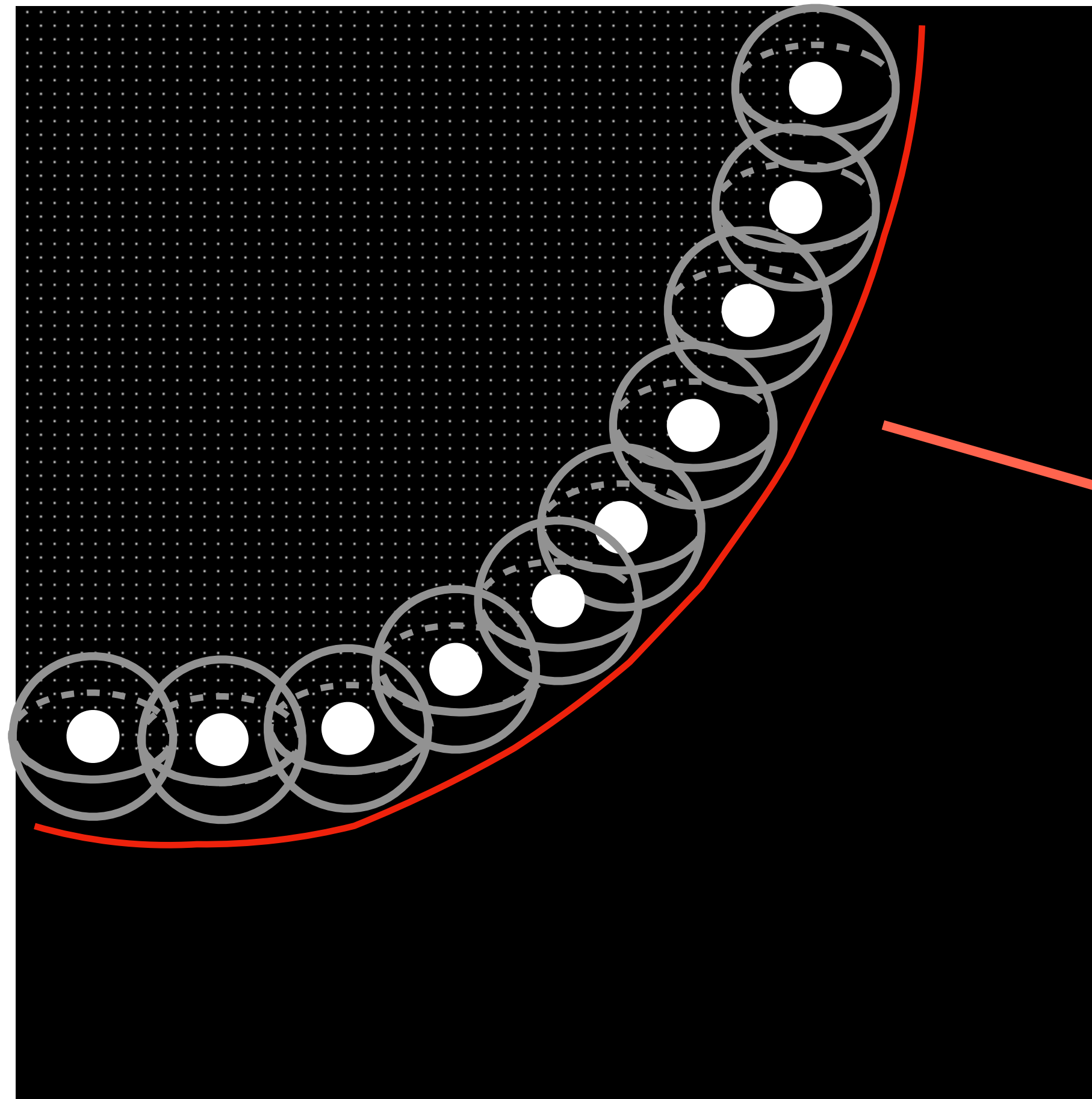
$$\left\{ \begin{array}{l} \sum_{\substack{p \in \mathcal{N}(p(x_0, y_0, z_0), R_2) \\ p \notin \mathcal{N}(p(x_0, y_0, z_0), R_1) \\ I(p) > 0}} I(p) < \frac{1}{16}(V(R_2) - V(R_1)) \end{array} \right.$$

$$\left\{ \begin{array}{l} \sum_{\substack{p \in \mathcal{N}(p(x_0, y_0, z_0), R_2) \\ p \notin \mathcal{N}(p(x_0, y_0, z_0), R_1) \\ I(p) > 0}} I(p) \geq \frac{1}{16}(V(R_2) - V(R_1)) \end{array} \right.$$

$$\left\{ \begin{array}{l} \text{and} \sum_{\substack{p \in \mathcal{N}(p(x_0, y_0, z_0), R_3) \\ p \notin \mathcal{N}(p(x_0, y_0, z_0), R_2) \\ I(p) > 0}} I(p) < \frac{1}{16}(V(R_3) - V(R_2)) \end{array} \right.$$

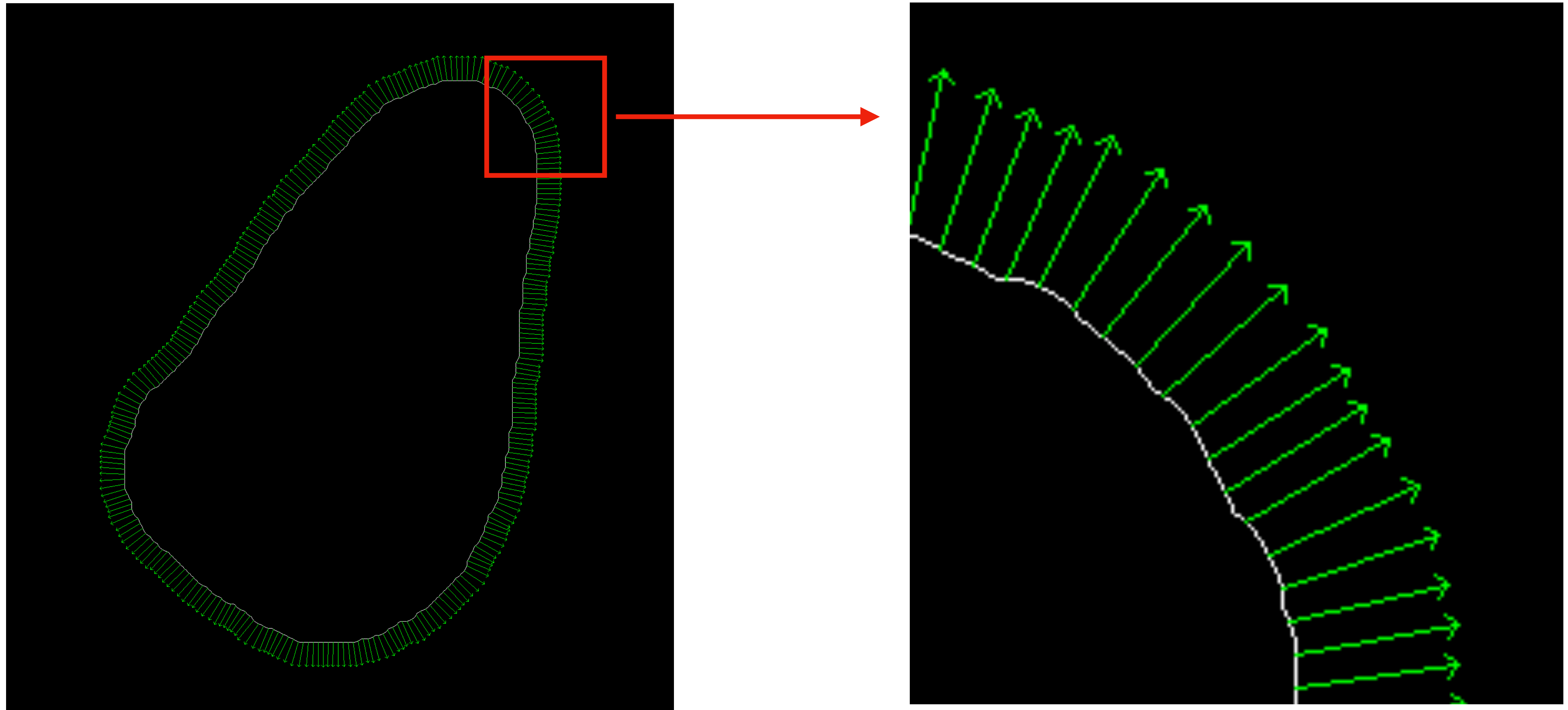
# Segmentation

## Extraction of lumen



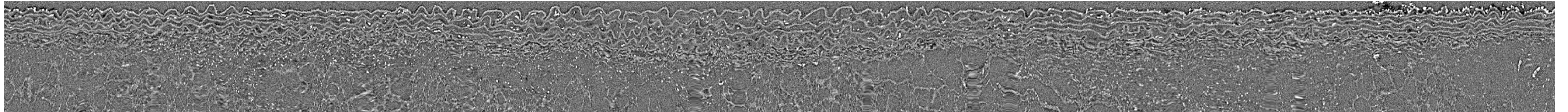
# Segmentation

## Normal field



# Segmentation

## Straightening elastic lamellae

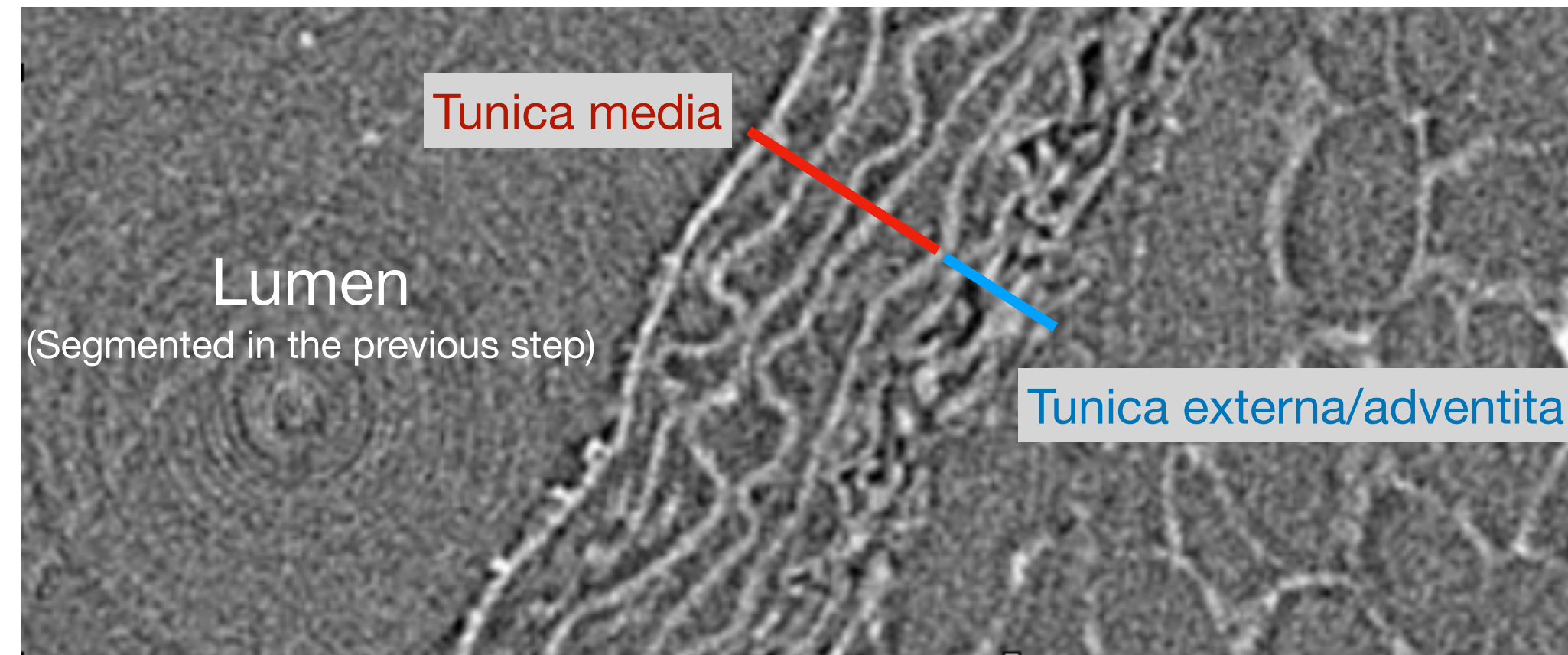


Initial image



Binary image

# Segmentation Problem

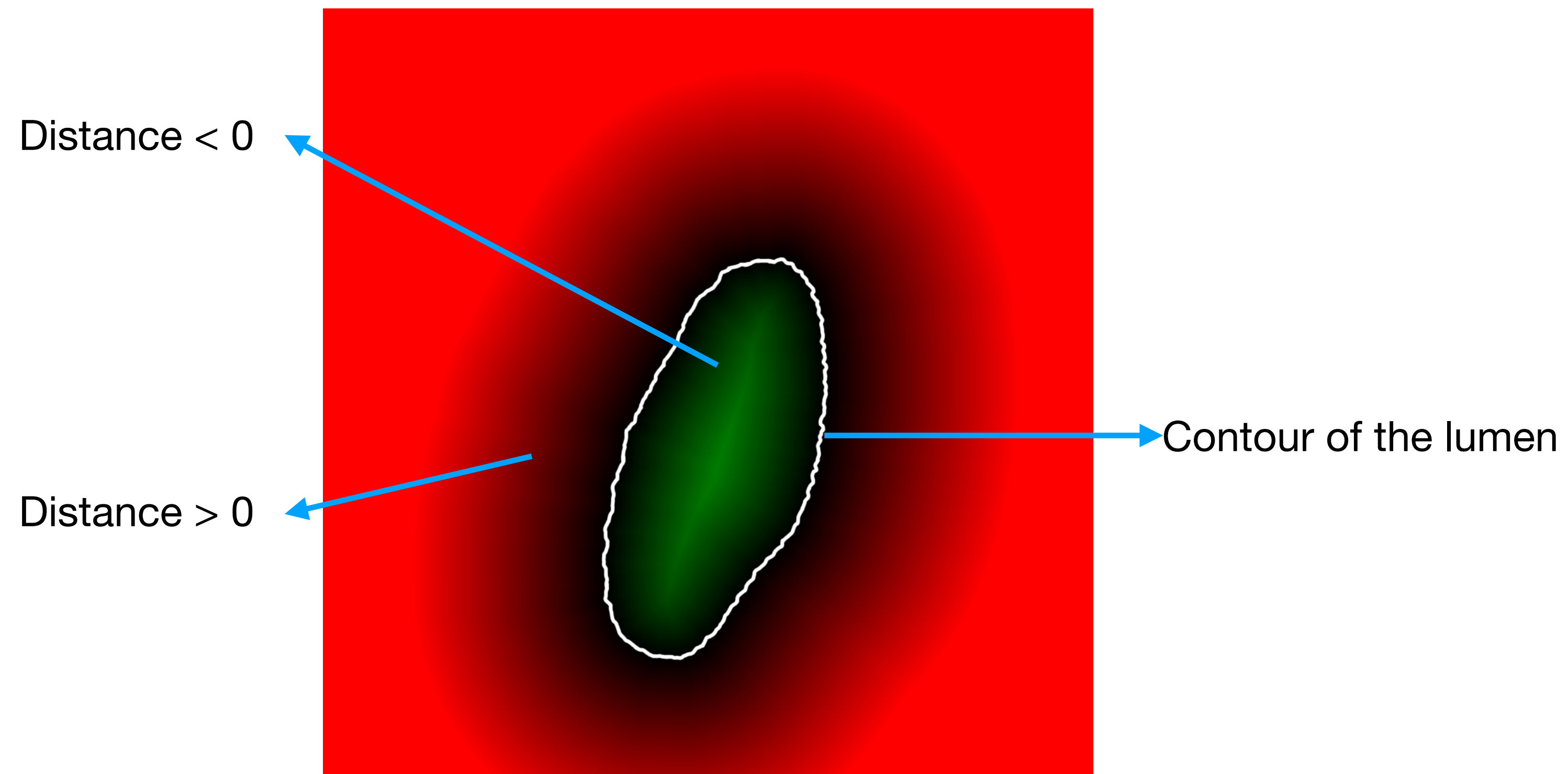


The border between 2 textures : elastic lamellae and adventitia

# Segmentation

## A 2D implementation

- Distance map: the distance between any pixel and the contour of the lumen

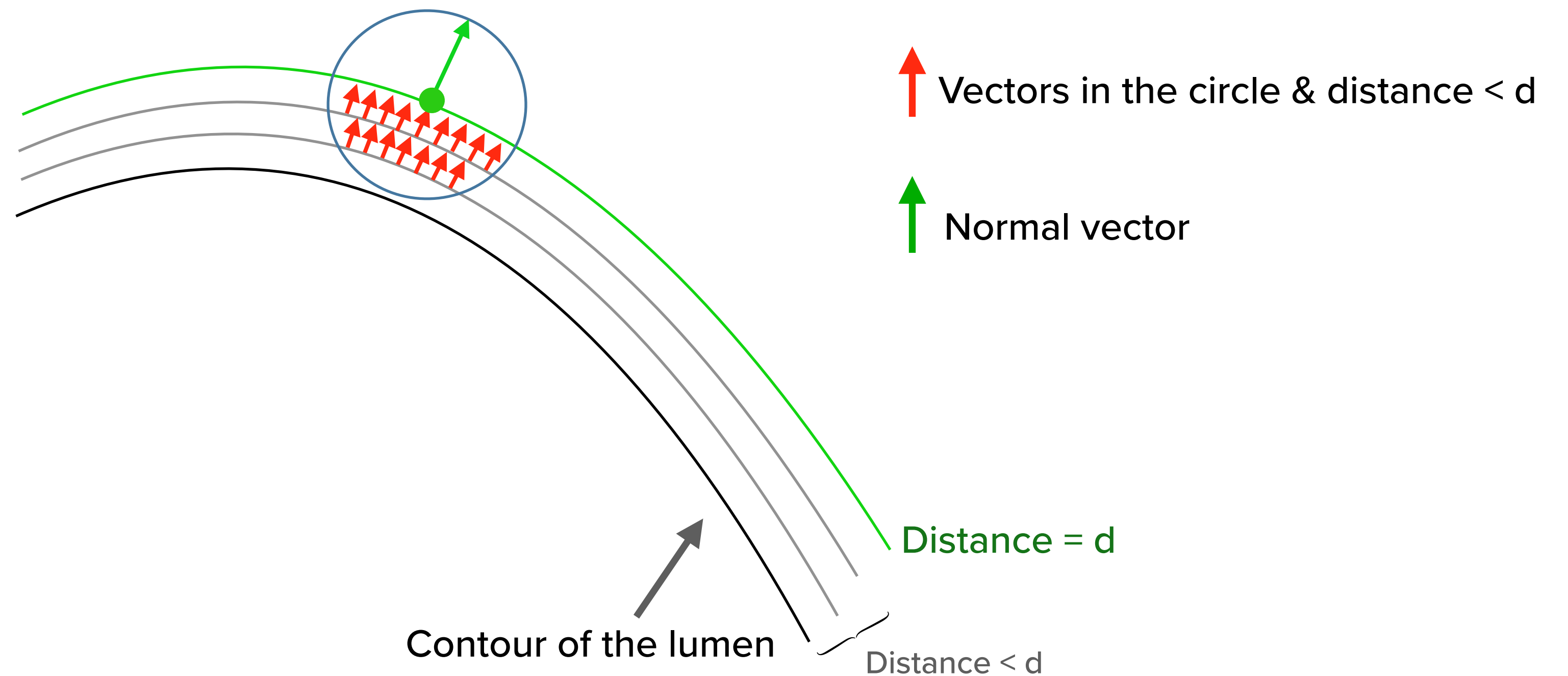


# Segmentation

## A 2D implementation

- Normal vector field

$$\vec{n}(x) = \frac{\sum_{y \in R \cap B(x, \rho_1)} \vec{n}(y)}{|\sum_{y \in R \cap B(x, \rho_1)} \vec{n}(y)|}$$

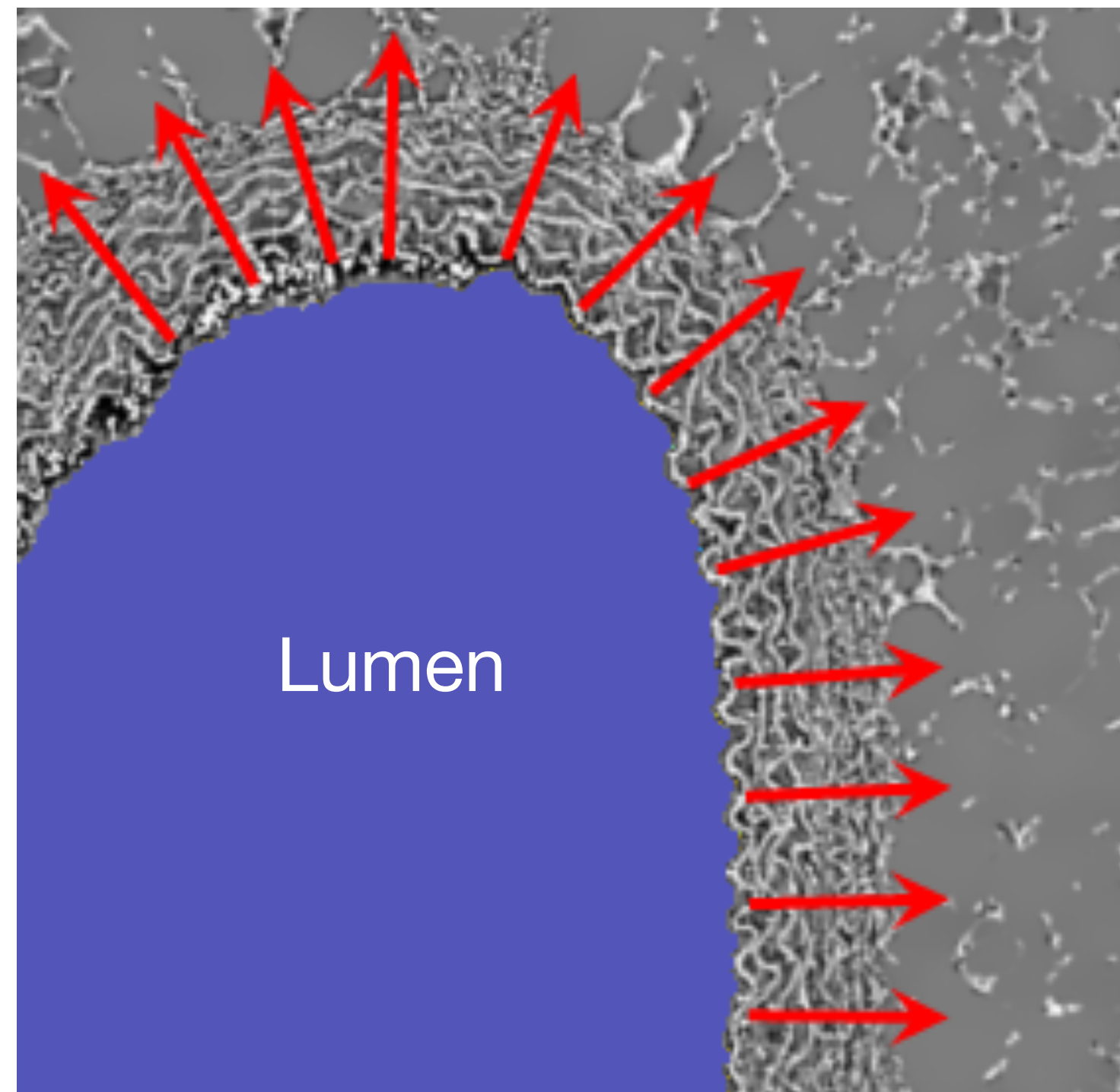




# Segmentation

## A 2D implementation

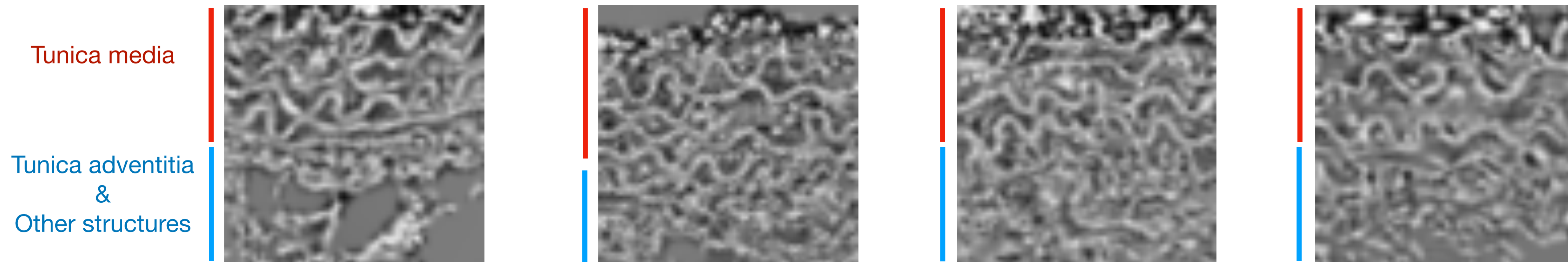
- It enables us to get normal vectors of any pixel at any distance



# Segmentation

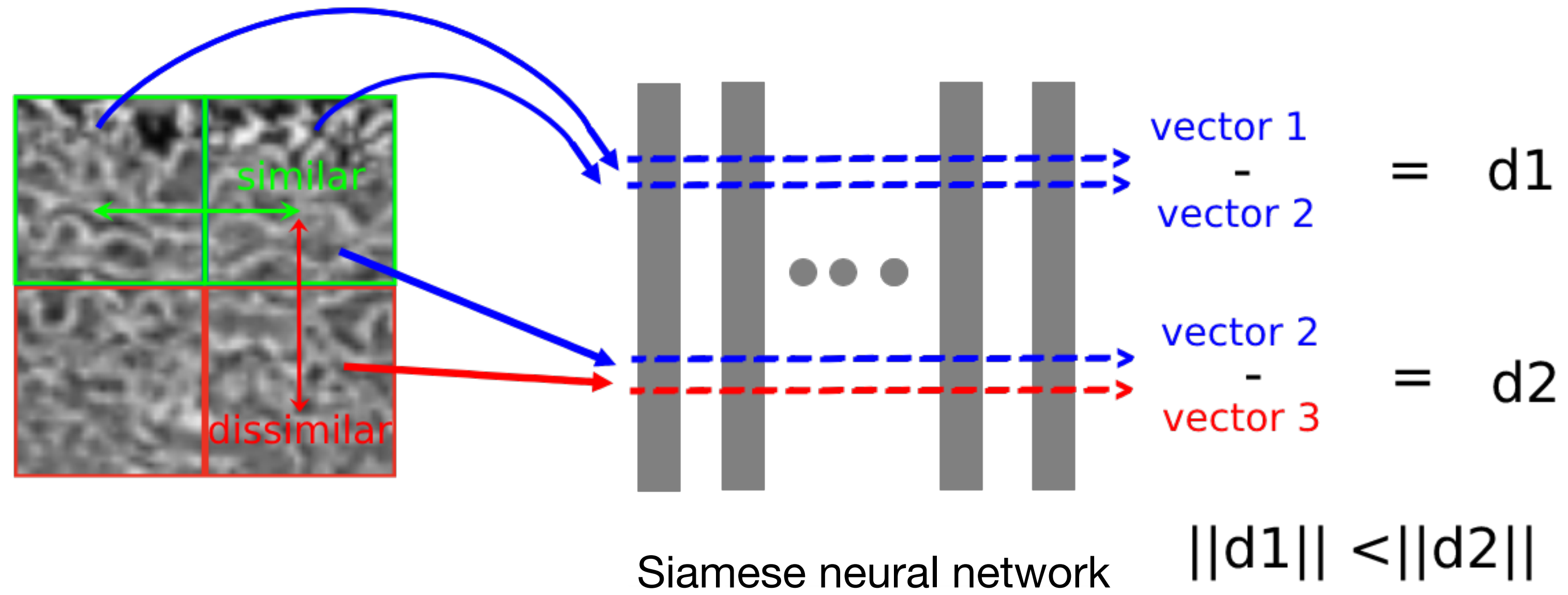
## A 2D implementation

- Rotating and cutting patches with the help of the normal vector field



# Segmentation

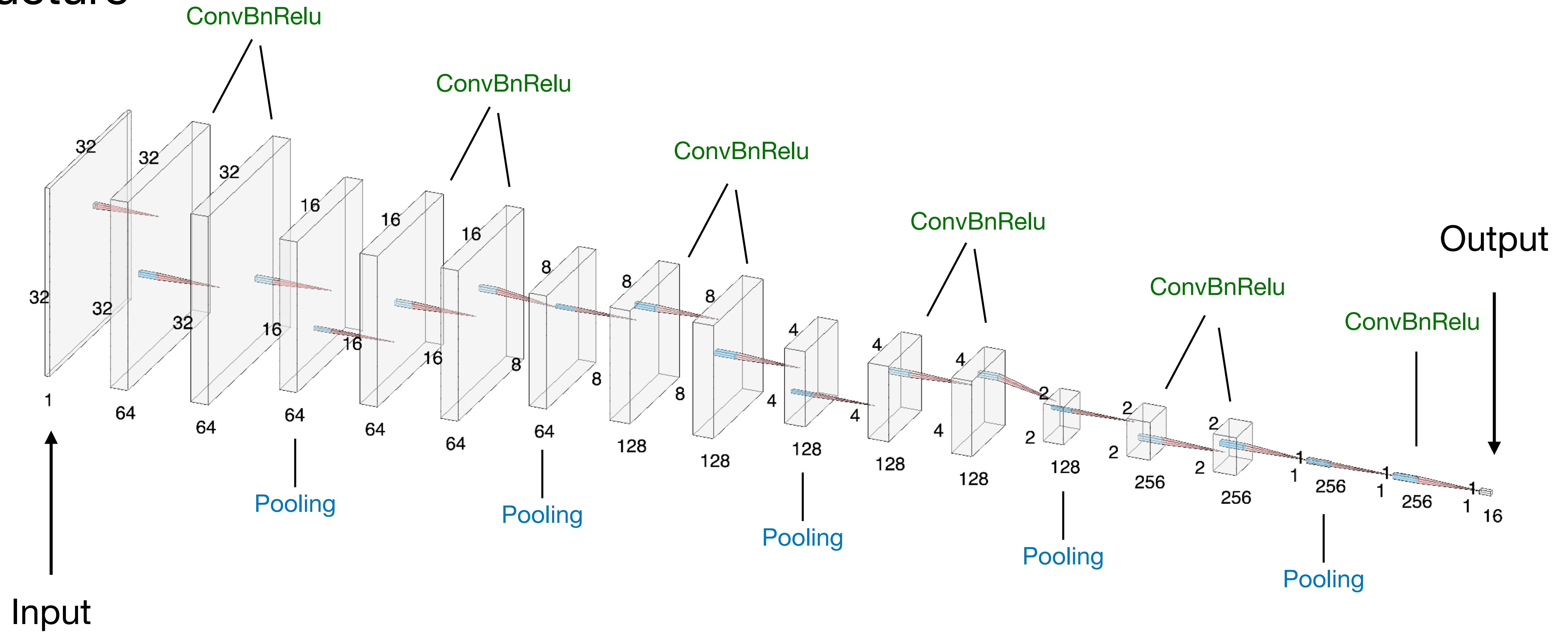
## A 2D implementation



# Segmentation

## A 2D implementation

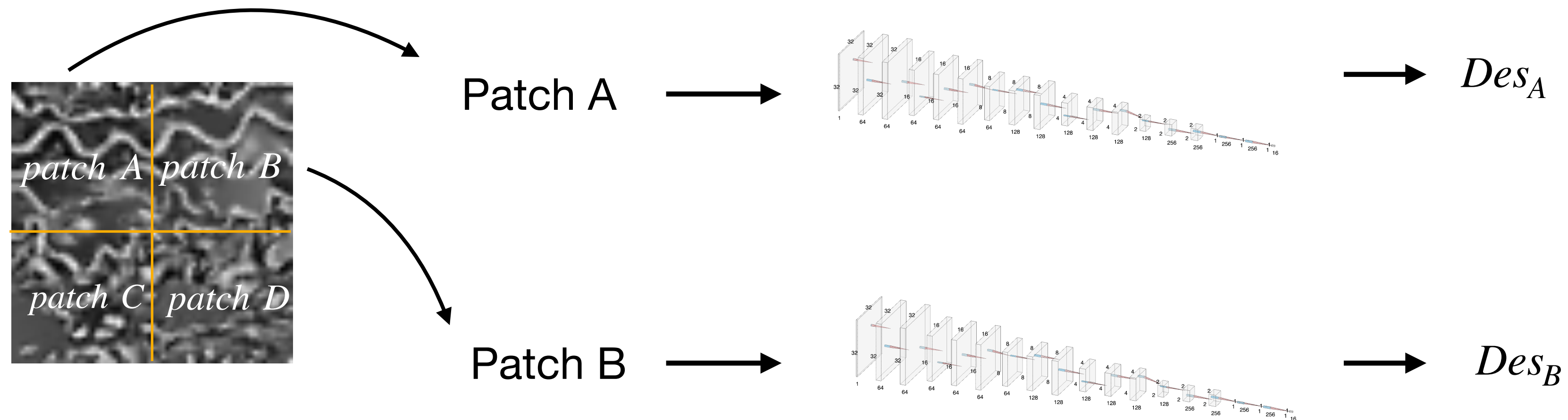
- Structure



# Segmentation

## A 2D implementation

- Loss function



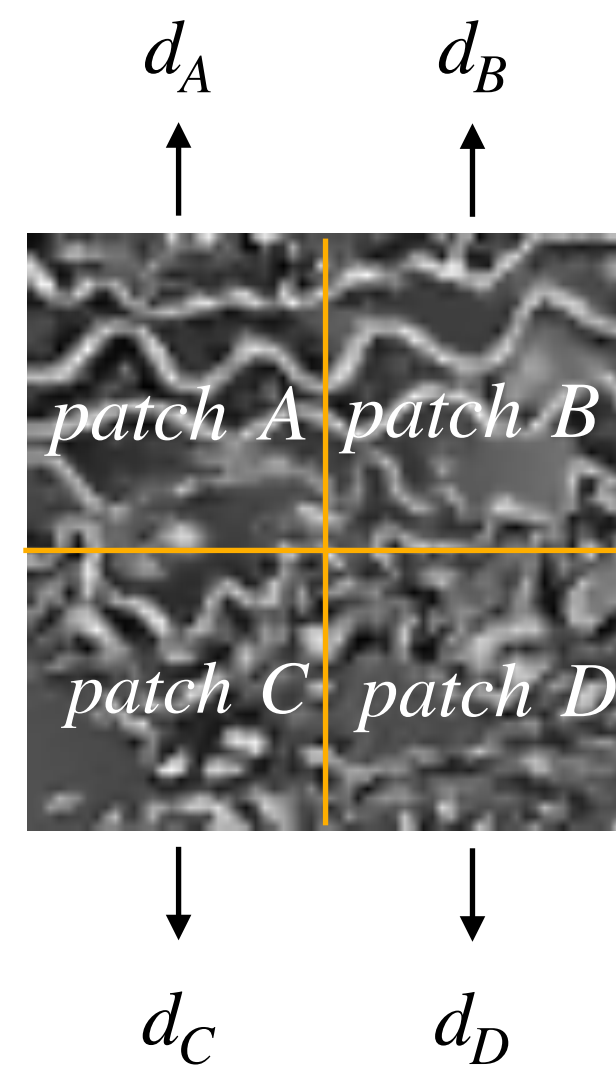
- $$\mathcal{L}(d_{ij}, d_{kl}) = \alpha \cdot \delta_{ik} \cdot \Delta^T \cdot \Delta + \beta \cdot (1 - \delta_{ik}) \cdot [\max\{0, m_p - (\Delta^T \cdot \Delta)^{1/2}\}]^2$$

where  $\Delta = d_{ij} - d_{kl}$ ,  $\delta$  is the Kronecker symbol,  $\alpha = 2$ ,  $\beta = 1$ ,  $m_p = 2$

# Segmentation

## A 2D implementation

- Training
  - 1457  $2D$  slices generate 47118 image patches of size  $64^2$
  - 80 % for training, 20 % for validation



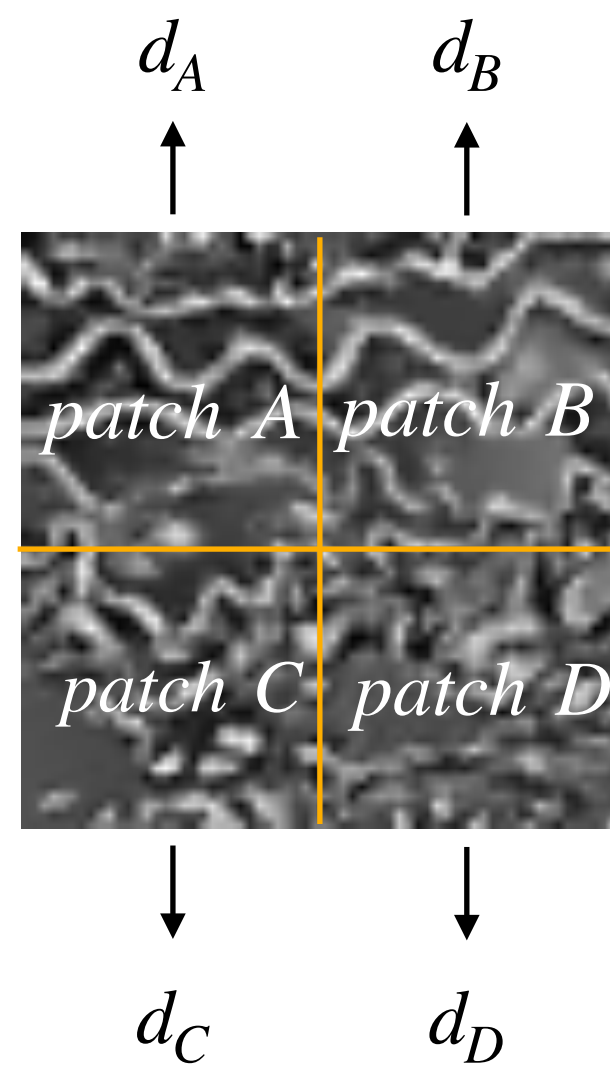
A prediction is considered correct if:

$$\|d_A - d_B\|_2 < \min\{\|d_A - d_C\|_2, \|d_A - d_D\|_2\}$$

# Segmentation

## A 2D implementation

- Training: 5 epochs, 164s
- Validation:



A prediction is considered correct if:

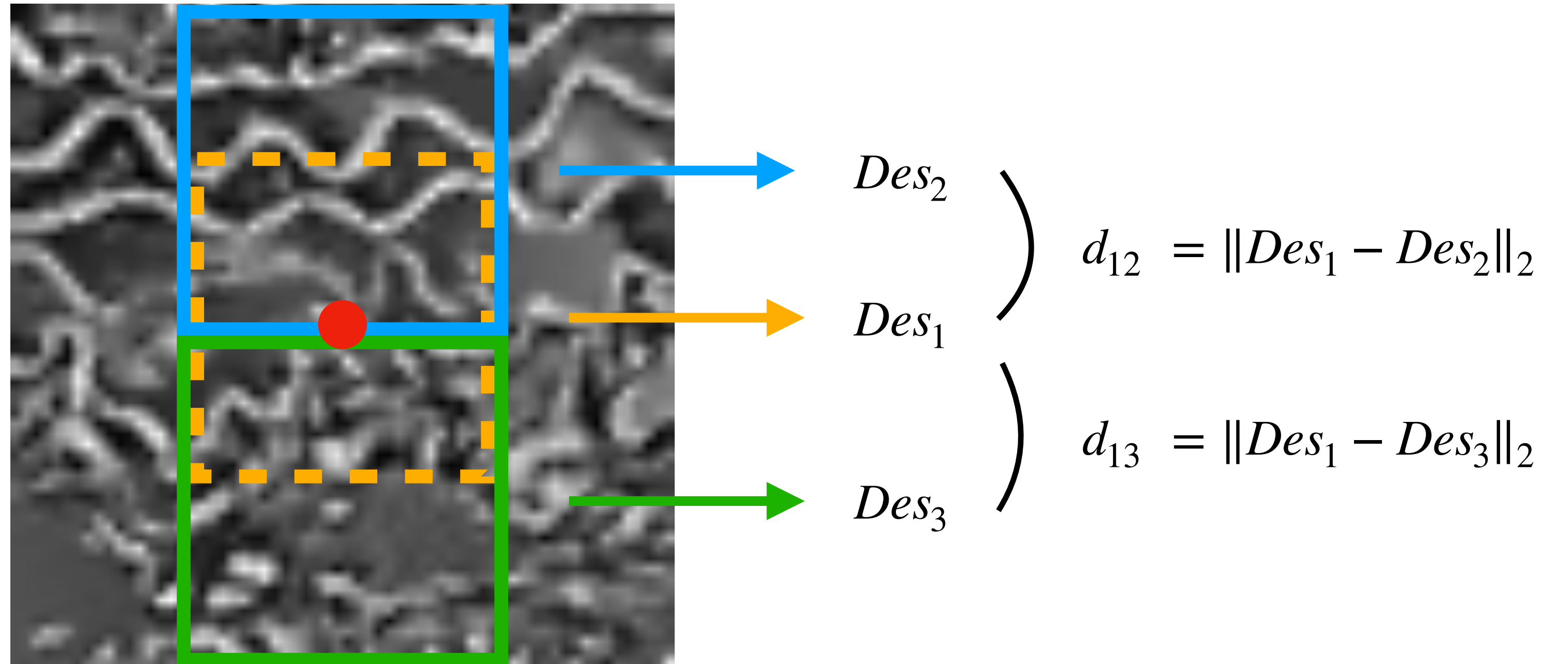
$$\|d_A - d_B\|_2 < \min\{\|d_A - d_C\|_2, \|d_A - d_D\|_2\}$$

Accuracy: 99.14 %

# Segmentation

## A 2D implementation

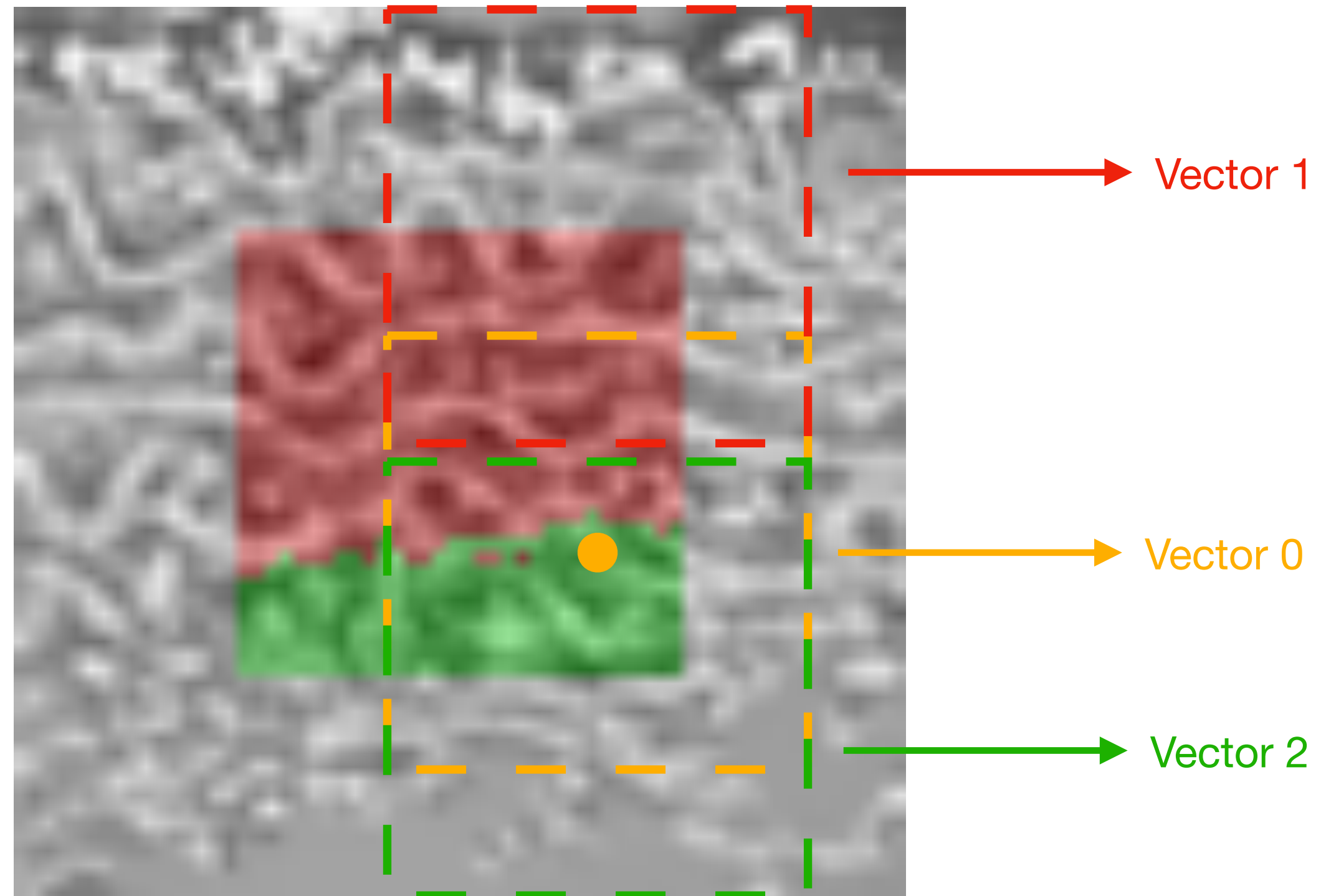
- Compare  $d_{12}$  and  $d_{13}$





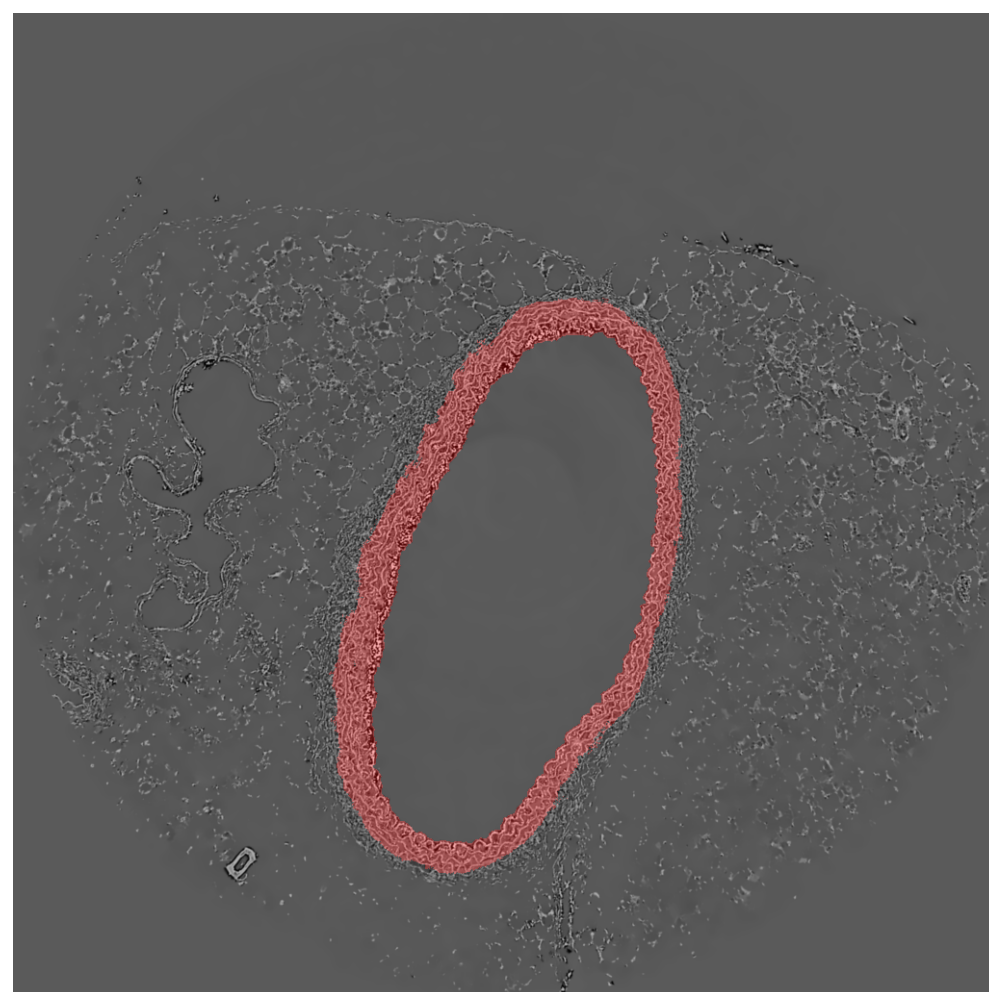
# Segmentation

## A 2D implementation

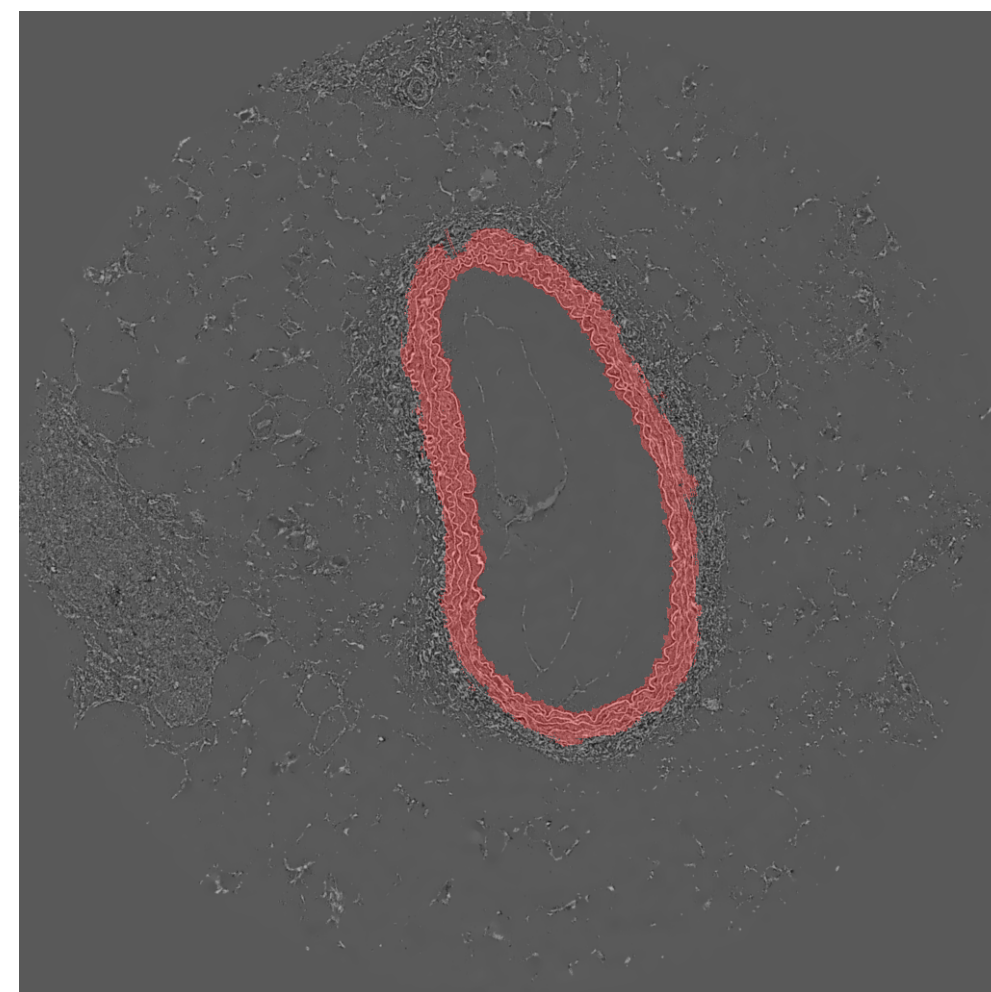


# Segmentation

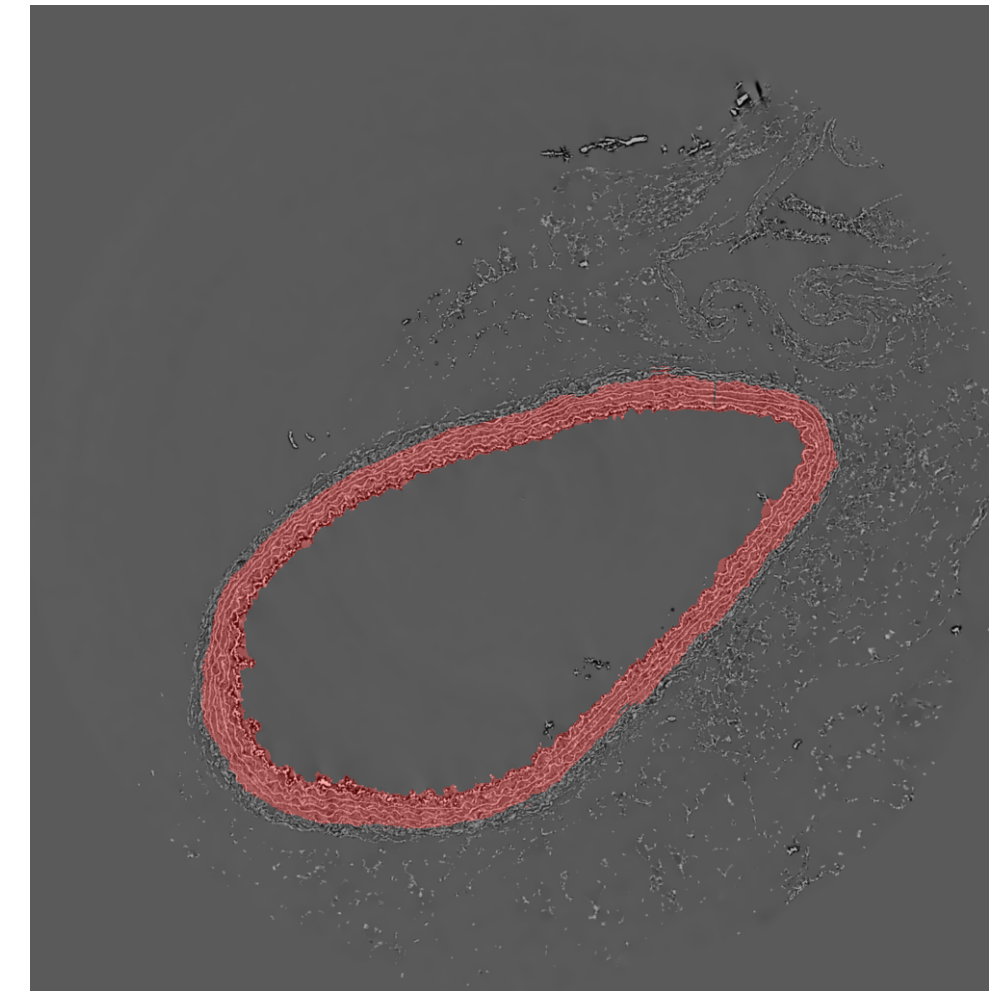
## A 2D implementation



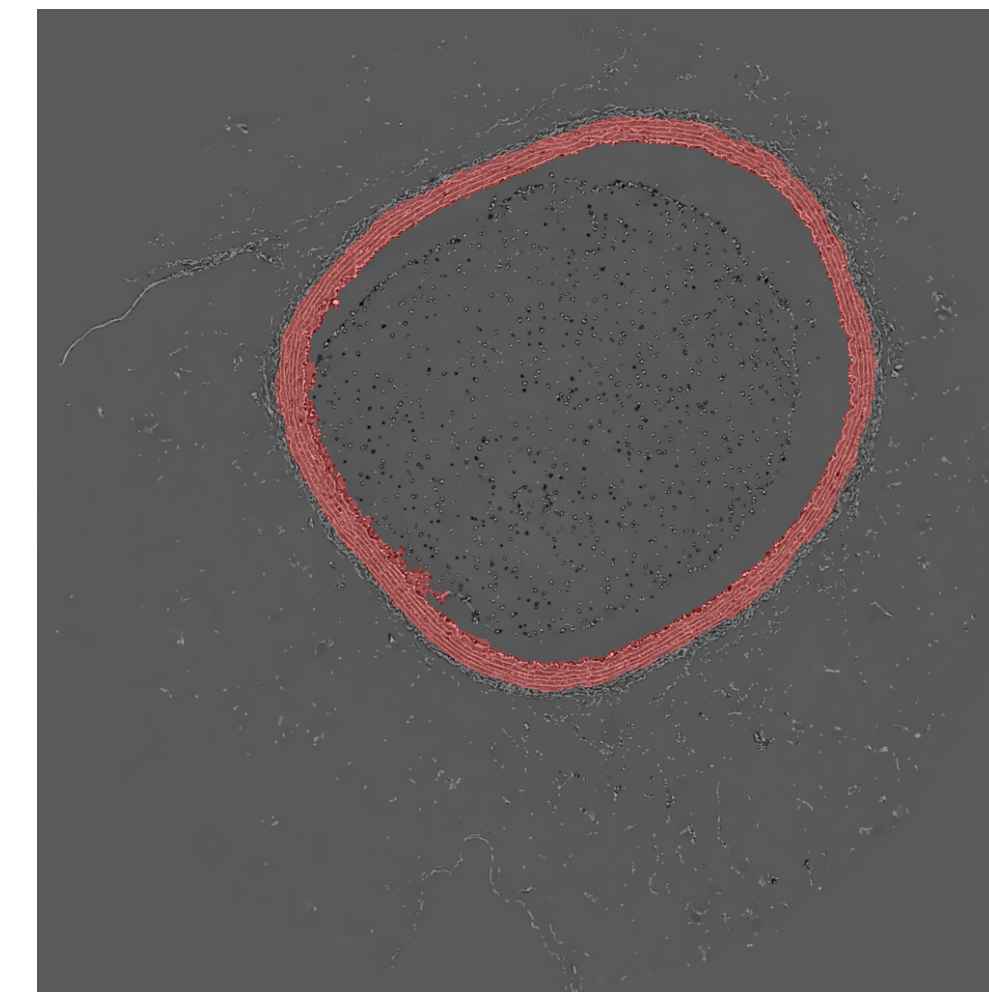
0.926



0.921



0.933

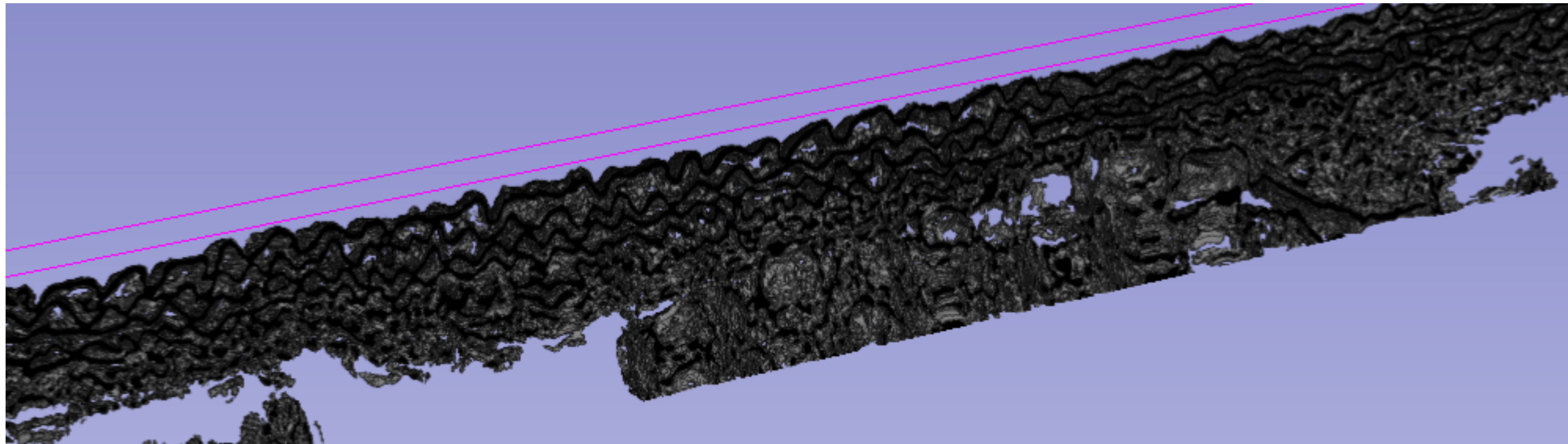


0.917

Dice score:

# Current work

- Classifying elastic lamellae by their orders (from 1 to 5)
- Implementing the 2D texture classification method in 3D



A stack of straightened 2D images (50 frames)

**Thank you!**