Vascular Network Analysis with Manual and Automatic Segmentation Using Fuzzy Mathematical Morphology

Pedro Bibiloni, Manuel González-Hidalgo, Arnau Mir, Nuria Prats-Domínguez

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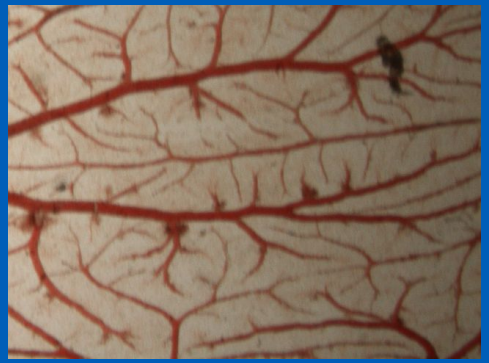
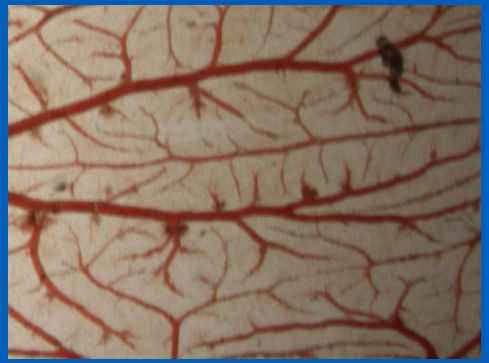
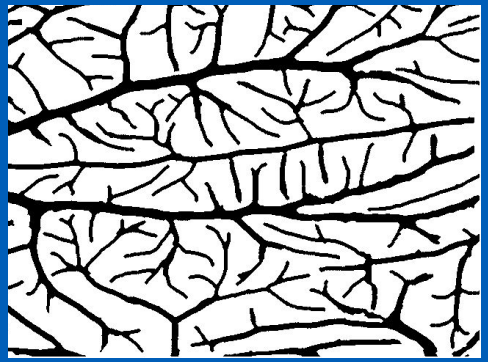
UIB Universitat de les Illes Balears
Departament de Ciències Matemàtiques i Informàtica

SCOPIA

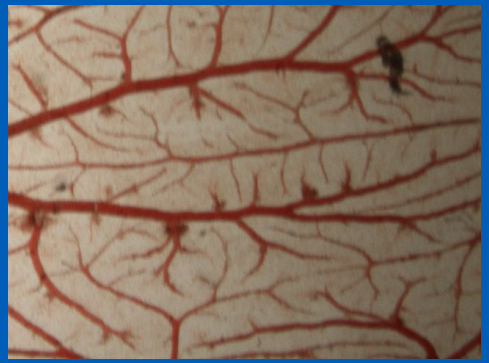
Institut d'Investigació Sanitària Illes Balears
IdISBa

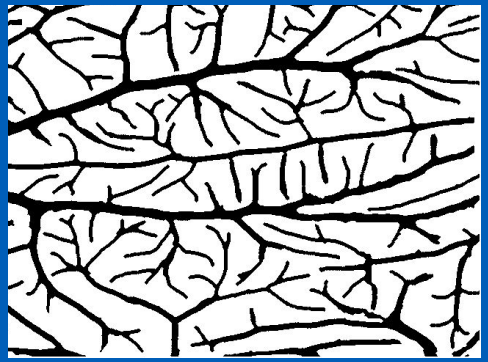






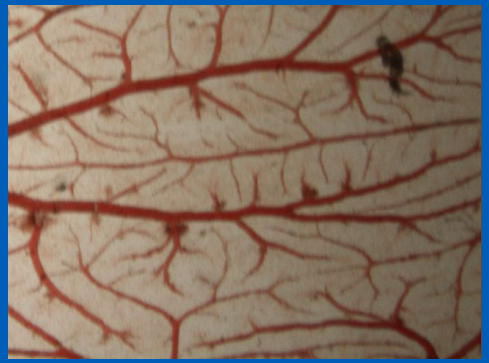
Manual features	

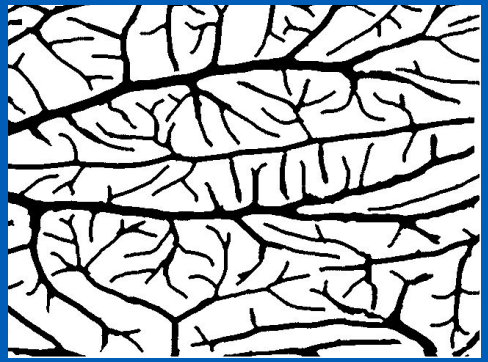




Manual features	

Automatic features	





Manual features	

Automatic features	

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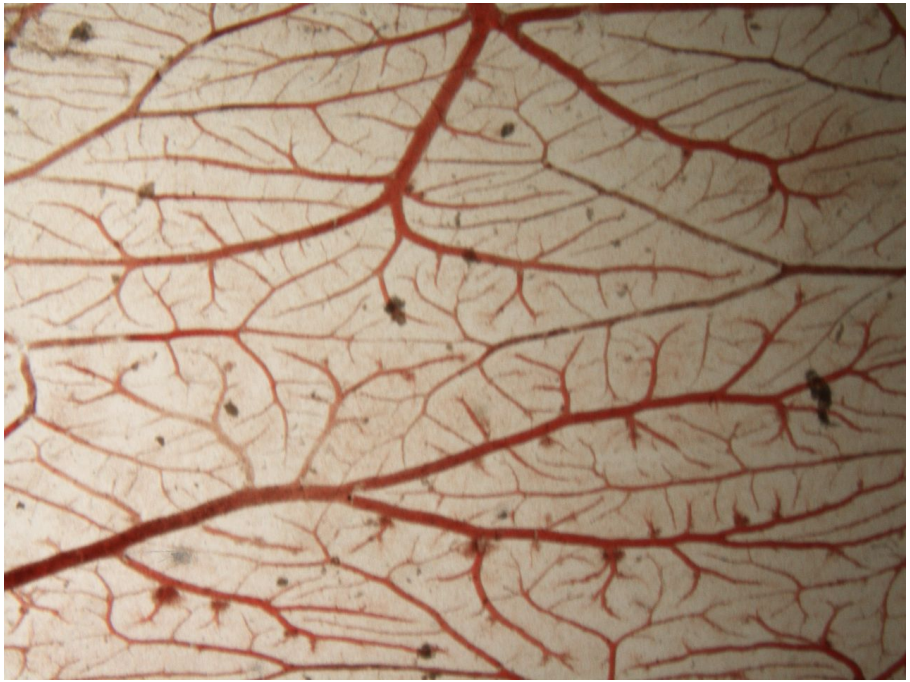
Dataset

- Chorioallantoic Membrane of chicken embryos
- Quantify angiogenesis (methyl jasmonate)



Dataset

- 30 samples
  - 1280 × 960 pixels
  - Manual segmentation

	0 µL	25 µL	50 µL	100 µL	Total
CONTROL	4				4
W-MJ		5	4	2	11
L-CONTROL				5	5
L-MJ		3	5	2	10

Vascular Features – Description

Global features

- Terminal points (TP)
- Bifurcation points (BP)
- Density of vascular area (DVA)
- Density of vascular network (DVN)

Local features

- Bifurcation angle (BA)
- Bifurcation index (BI)
- Diameter relation (DR)
- Area ratio (AR)

Fuzzy Mathematical Morphology

Preliminaries

Image A, Structuring element B

$$\mathbb{Z}^2 \mapsto [0, 1]$$

Reflection [of the structuring element]:

$$\overline{B}(x, y) = B(-x, -y)$$

Conjunction C, Fuzzy Implication function I

$$[0, 1]^2 \mapsto [0, 1]$$

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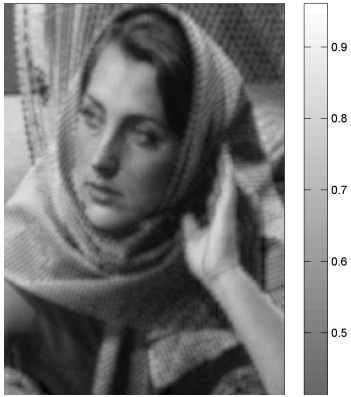
Fuzzy Mathematical Morphology

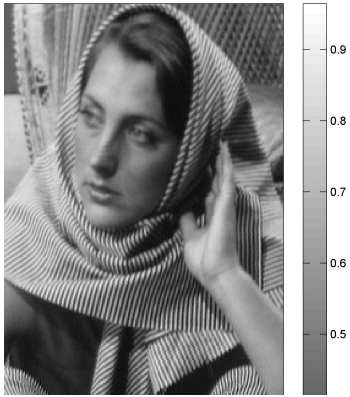
$$\mathcal{E}_I(A,B)(y) = \inf_x I\big(B(x-y), A(x)\big)$$

$$\mathcal{D}_C(A,B)(y) = \sup_x C\big(B(x-y), A(x)\big)$$

Fuzzy Mathematical Morphology



$\mathcal{E}$



$\mathcal{D}$

Fuzzy mathematical morphology

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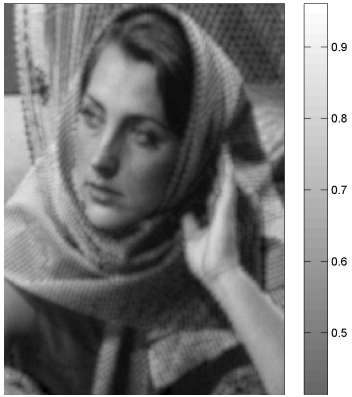
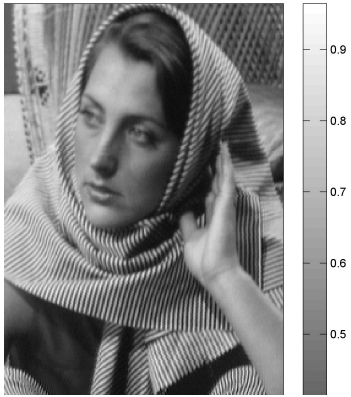
$$\mathcal{BTH}_{C,I}(A,B) = \mathcal{E}_I\left(\mathcal{D}_C(A,B), \overline{B}\right) - A$$

Fuzzy Mathematical Morphology

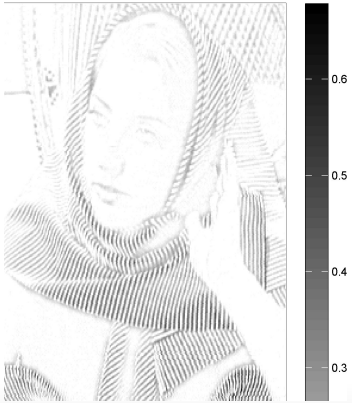


$\mathcal{E}$



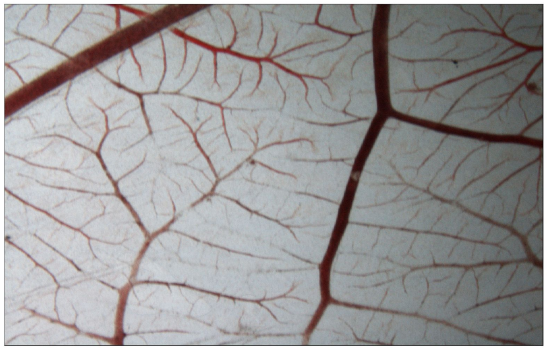
$\mathcal{D}$

$\mathcal{BTH}$



Automatic Vessel Segmentation

Automatic Vessel Segmentation – Method



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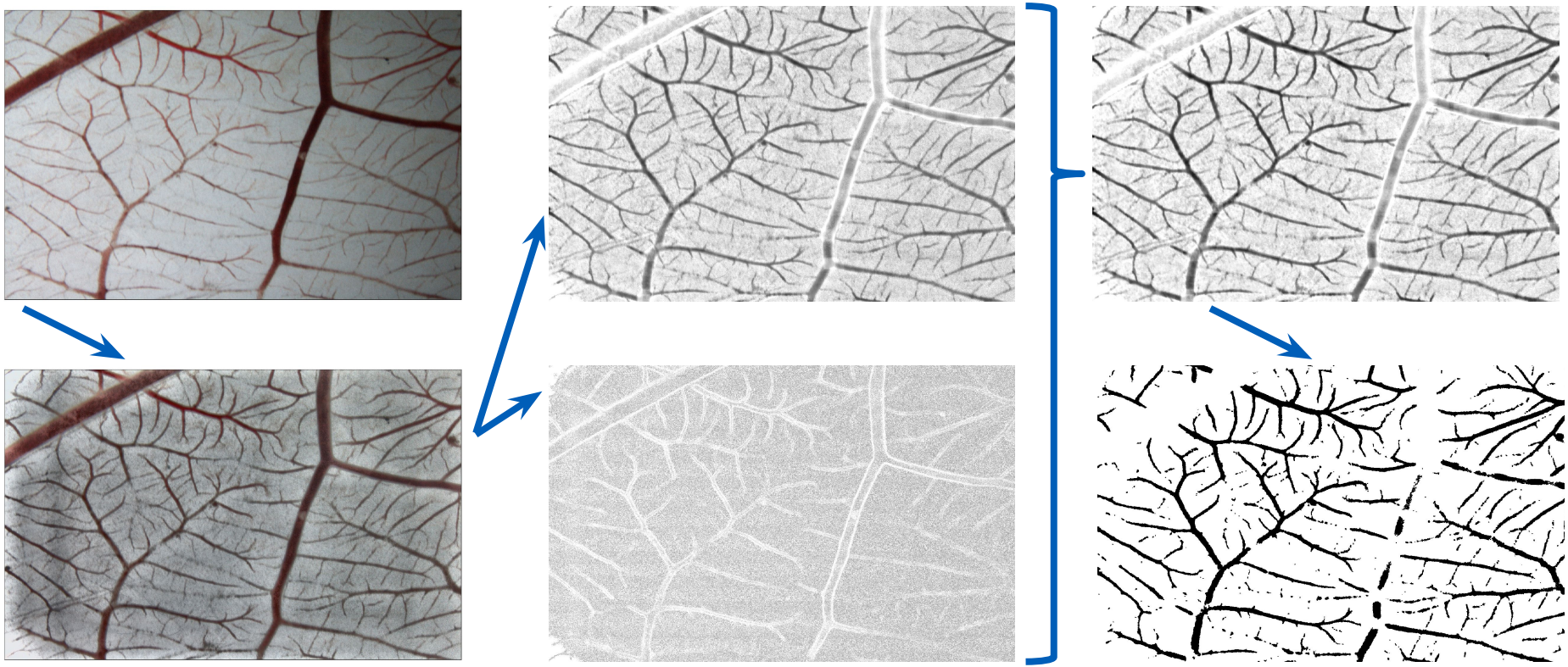

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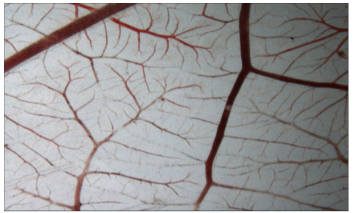
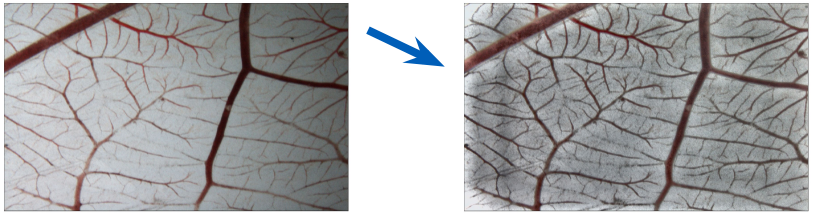


Automatic Vessel Segmentation – Method

1. Preprocessing:
   a. Shade correction
   b. CLAHE



Automatic Vessel Segmentation – Method

1. Preprocessing:
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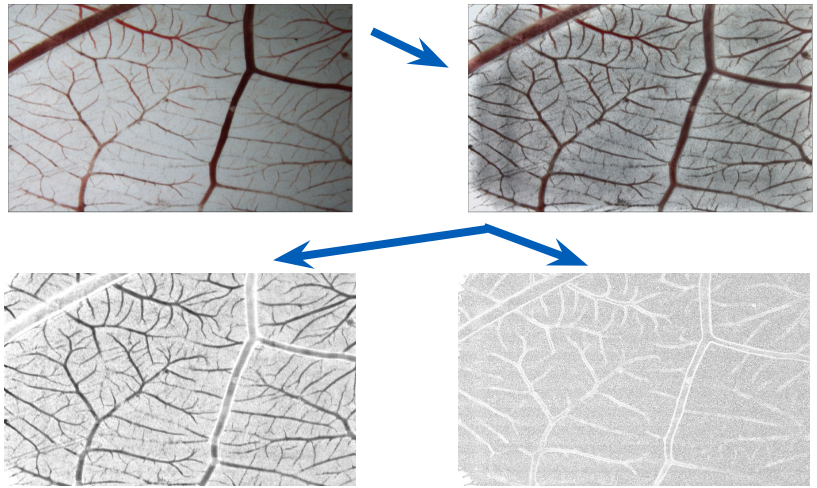
   b. CLAHE
2. Difference of black top-hat transforms



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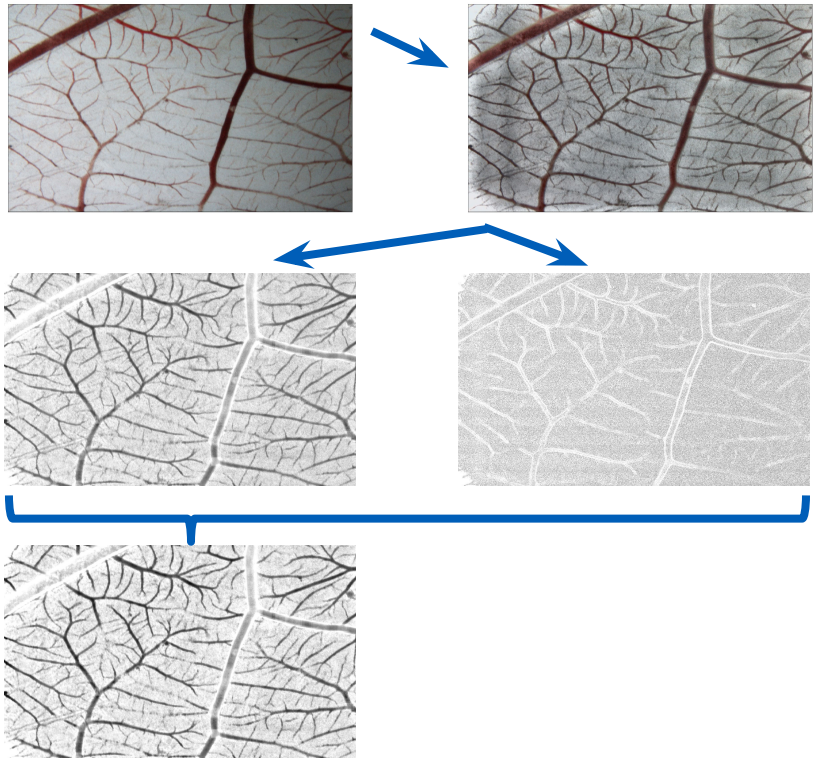
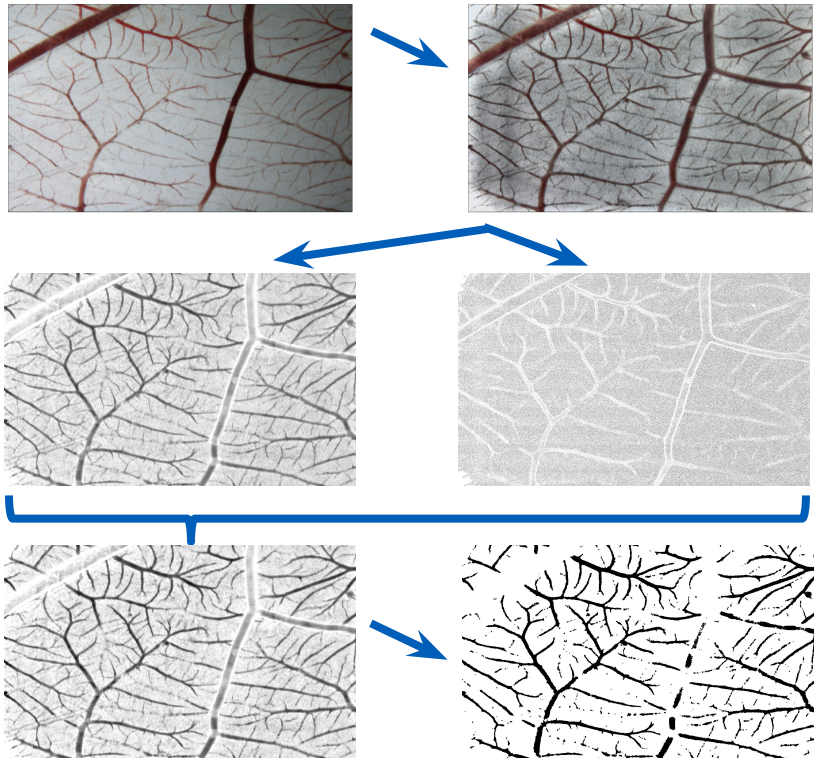
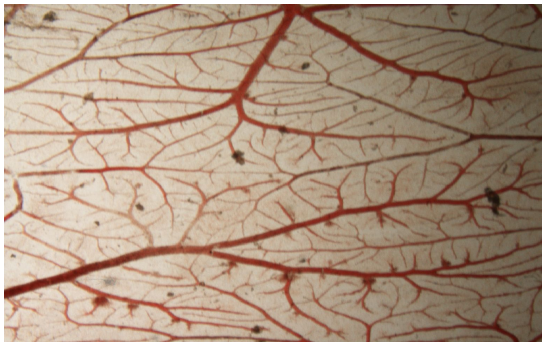
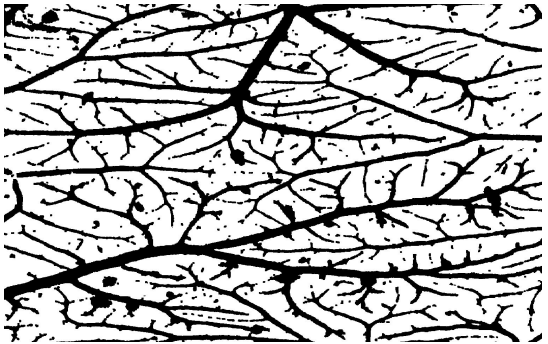
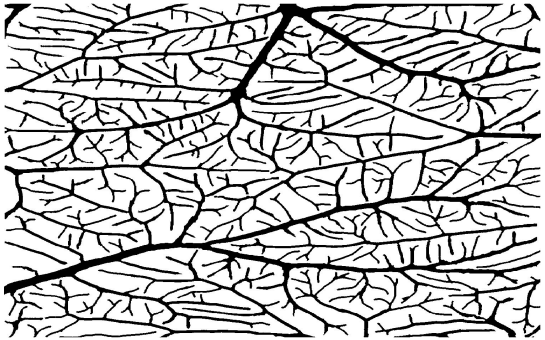
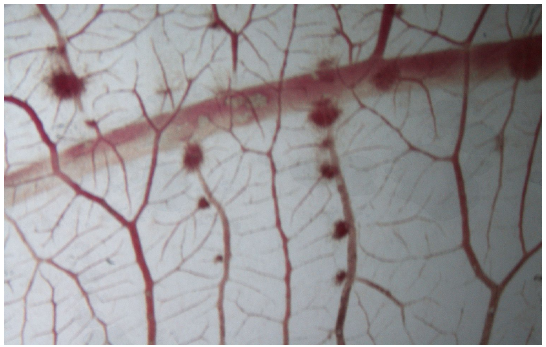


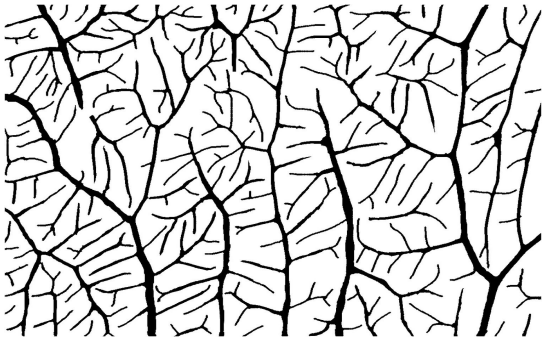
Automatic Vessel Segmentation – Method

1. Preprocessing:
   a. Shade correction
   b. CLAHE
2. Difference of black top-hat transforms
3. Binarization:
   a. Hysteresis
   b. Remove small regions



Automatic Vessel Segmentation – Results



Automatic Vessel Segmentation – Results

Precision	Sensitivity	Specificity	F_1-score
0.7071	0.4554	0.9600	0.5382

Vascular Features

Vascular Features – Description

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Global features

- ⇨ Density of vascular area (DVA)

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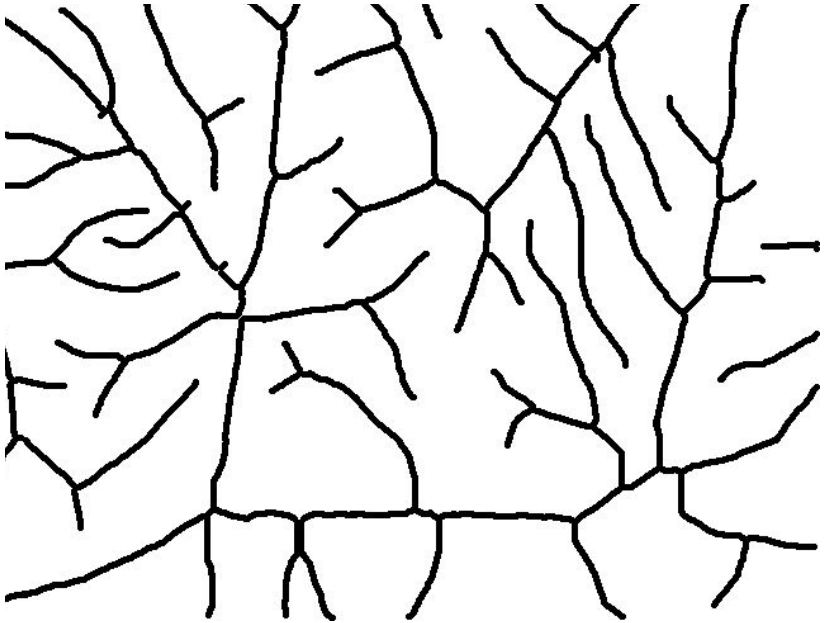

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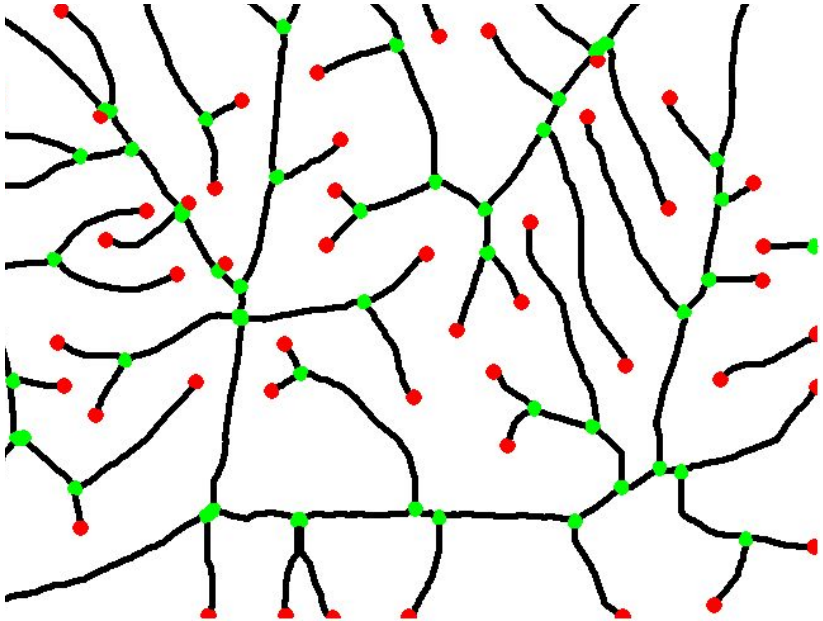

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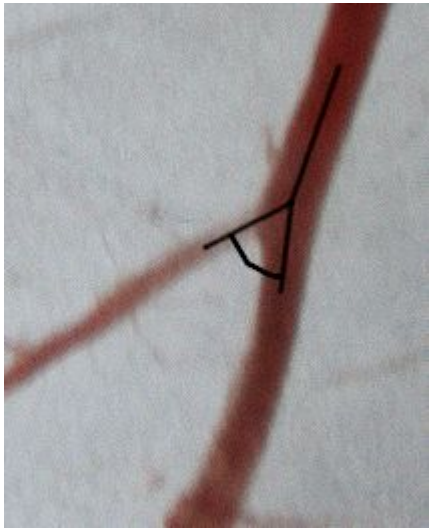
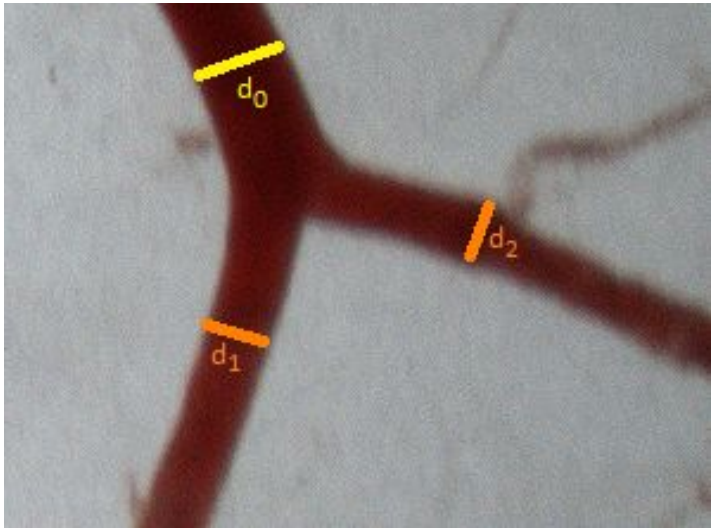


Local features

- ↦ Bifurcation angle (BA)

Vascular Features – Description



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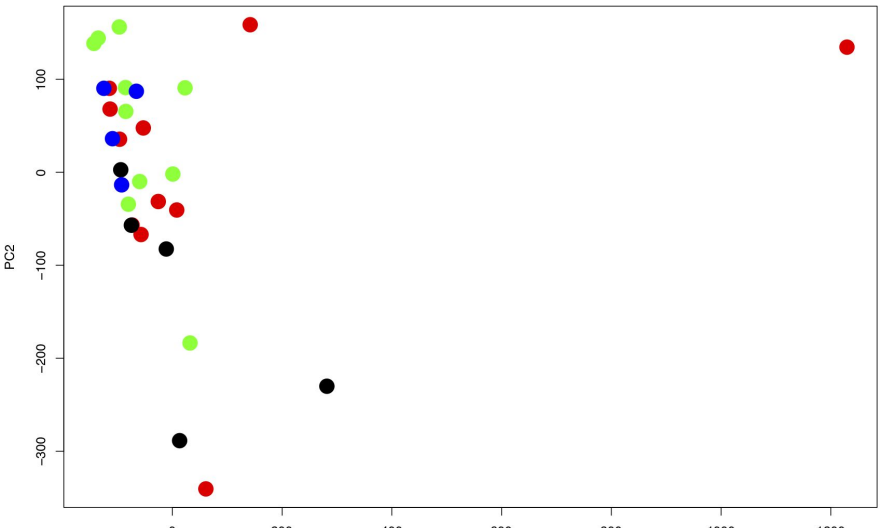
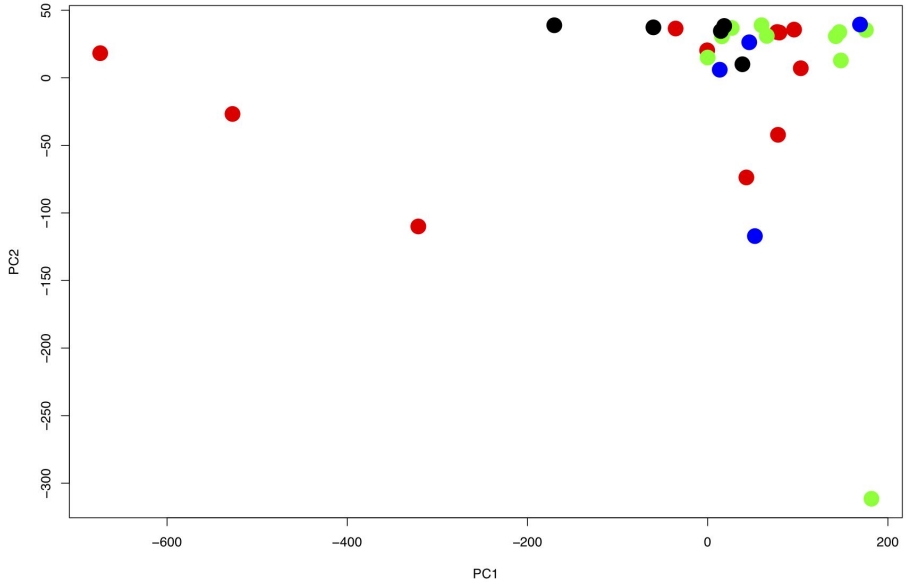
Vascular Features – Manual vs Automatic



PCA of manual features



PCA of automatic features

Vascular Features – Angiogenesis Estimators

		Water susp.		Liposome susp.	
		25 µL	50 µL	25 µL	50 µL
TP	*p*-value	0.265	0.105	1	0.122
	Stat. diff.	✗	✗	✗	✗
BP	*p*-value	0.243	0.082	0.014	0.167
	Stat. diff.	✗	✗	✓	✗
DVA	*p*-value	0.466	0.237	0.112	0.688
	Stat. diff.	✗	✗	✗	✗
DVN	*p*-value	1	0.342	0.030	0.215
	Stat. diff.	✗	✗	✓	✗

		Water susp.		Liposome susp.	
		25 µL	50 µL	25 µL	50 µL
BI (mean)	*p*-value	0.926	0.363	0.010	0.030
	Stat. diff.	✗	✗	✓	✓
BA (mean)	*p*-value	1	1	0.351	0.470
	Stat. diff.	✗	✗	✗	✗
DR (mean)	*p*-value	0.422	0.693	1	0.125
	Stat. diff.	✗	✗	✗	✗
DR (mean)	*p*-value	0.592	1	0.671	0.073
	Stat. diff.	✗	✗	✗	✗

Conclusions

Contributions

- Vessel segmentation method
  - Validation
- Power of vascular features
- Similarity of automatic and manual vascular features

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- ⇛ Fuzzy vascular segmentation
  - ↦ Account the gradualness of images

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  - ↦ Crisp vascular mask
  - ↦ Crisp features

Conclusions

- ⇛ Fuzzy vascular segmentation
  - ↦ Account the gradualness of images
  - ↦ Crisp vascular mask
  - ↦ Crisp features
- ⇛ Vascular features are hard to replicate
  - ↦ Designed by/for humans

Thank you


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