Observation of the microstructure evolution during a mechanical assay on cardiac tissue

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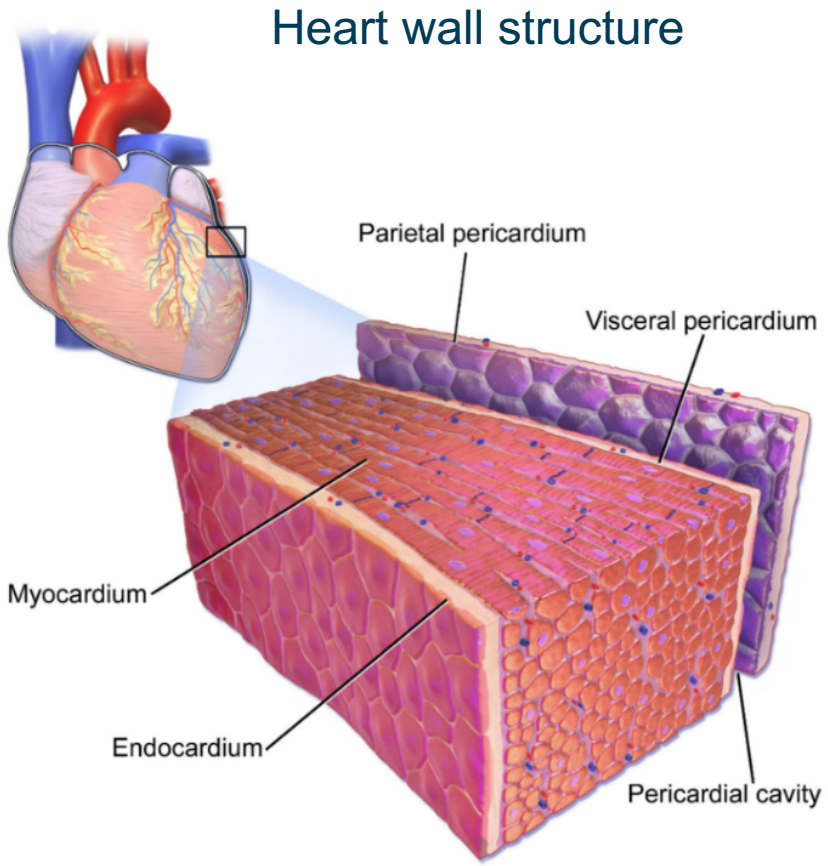
Introduction

Heart wall:

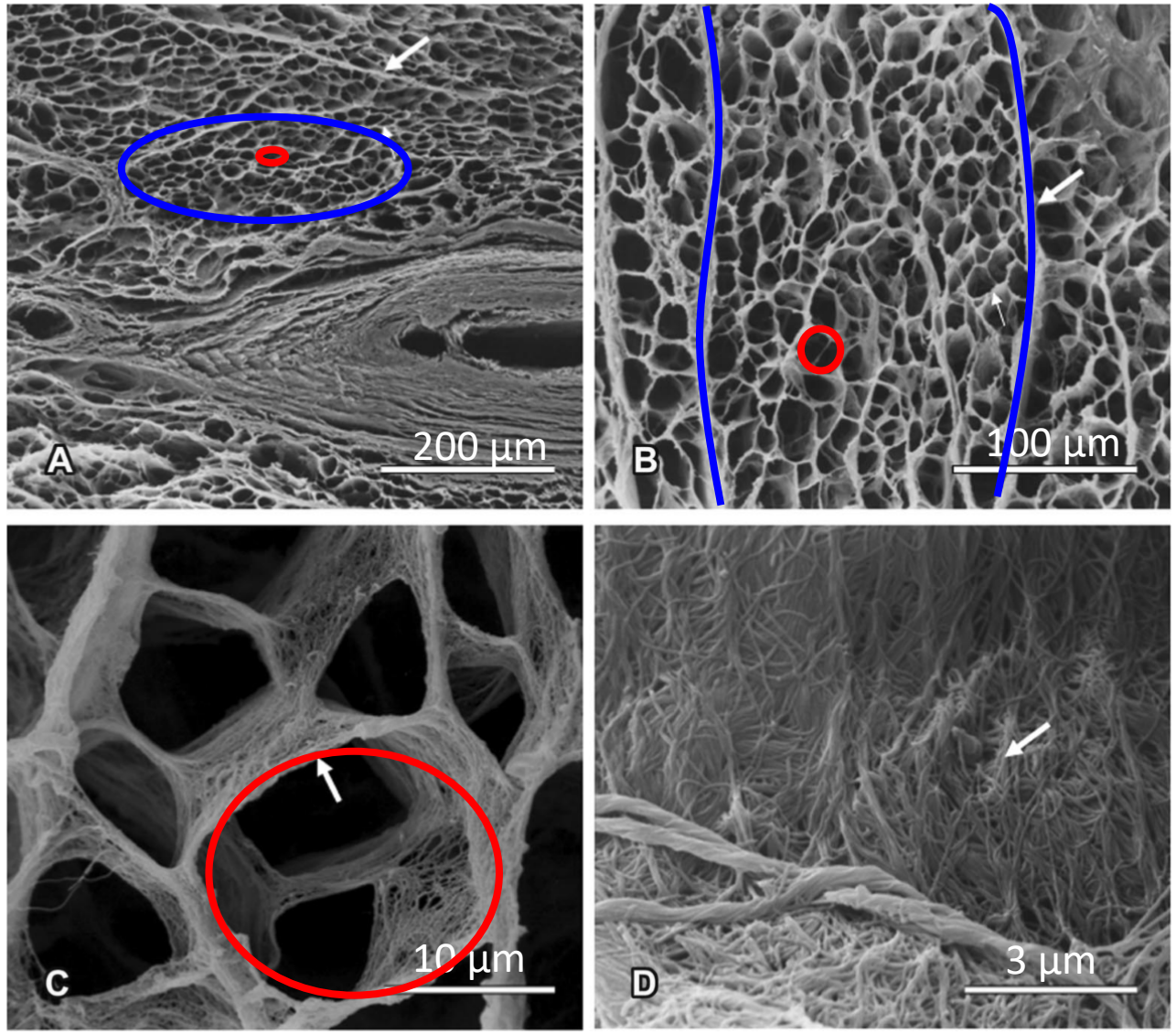


- Cardiovascular diseases: leading cause of death in Europe
- Modification of the myocardium:
  - Structure and function closely related
  - Multiple spatial and temporal scales

⇨ Link between microscopic structure and macroscopic mechanical properties

Introduction

Microscopic structure: SEM observations



Kanzaki et al., Circulation, 2010

Fiber scale

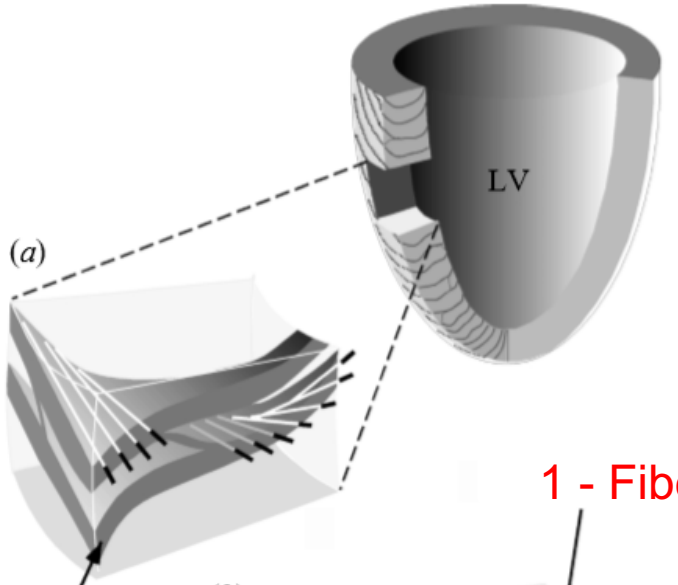
Cardiomyocyte + ECM layer

Mesoscopic scale

Cardiomyocyte bundle
+ thick collagen layer

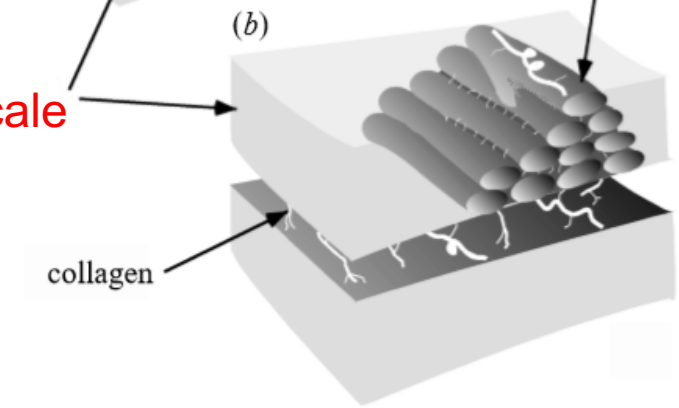
Introduction

Multiscale organization



1 - Fiber scale

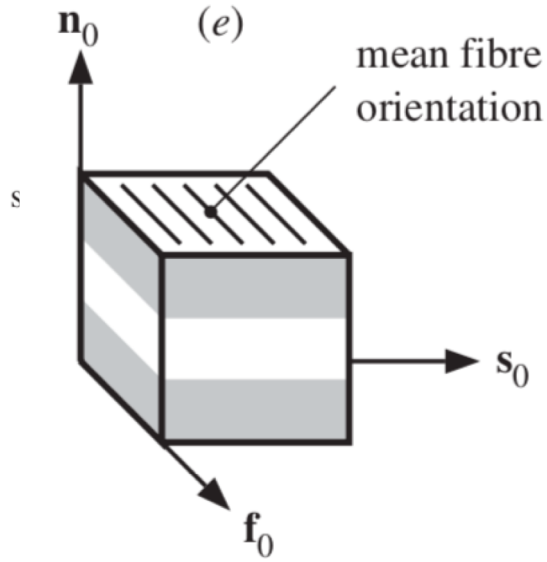
2 - Sheetlet scale



The Auckland laminar sheet model,
LeGrice et al., 1995

Ex. of model:

Holzapfel & Ogden, Proc. Roy. Soc. A 2009



Fiber motion: affine assumption

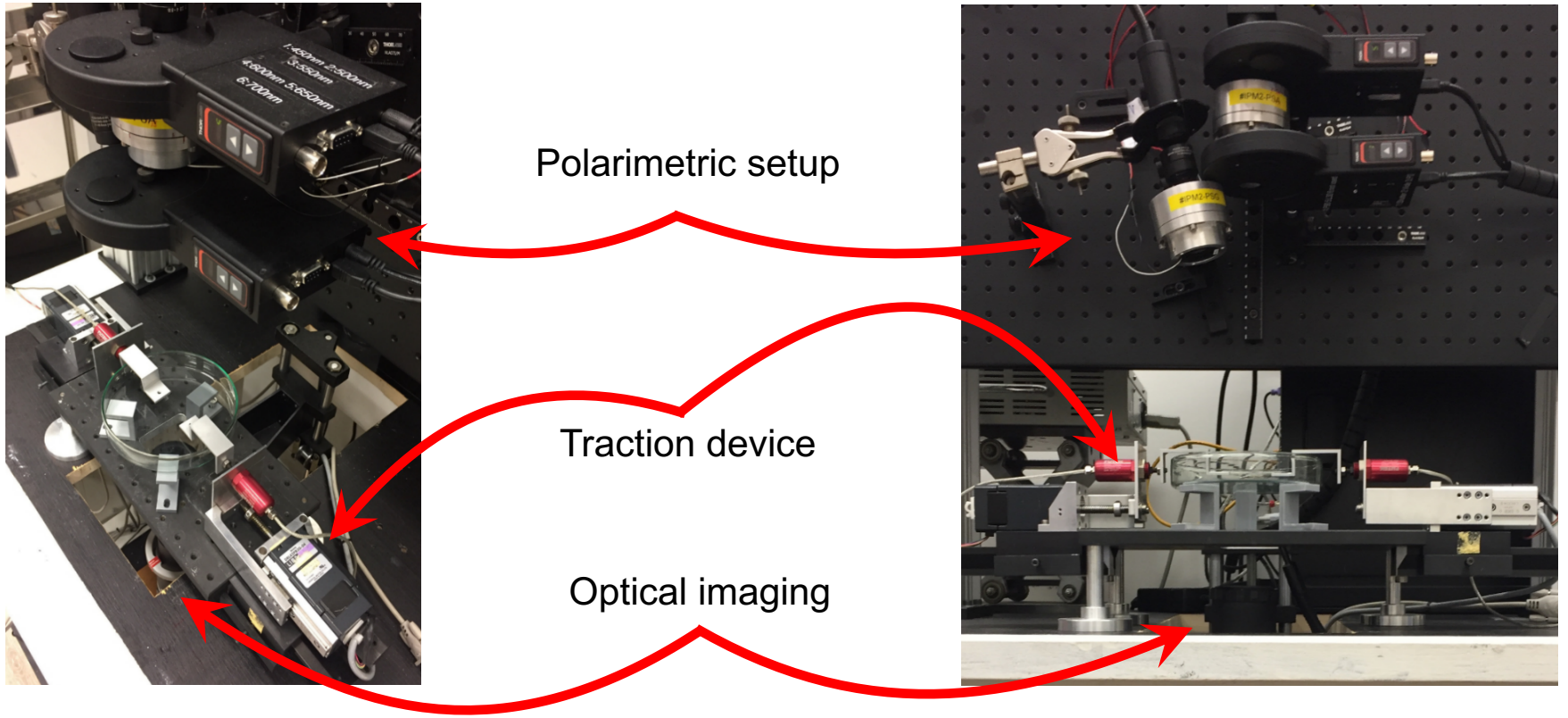
⇨ Observation of the microstructure evolution during a mechanical assay

Experimental approach

Tueni *et al.*, Sci. Report, in press

Simultaneous observations of the mechanical properties and of the tissue microstructure

Coupled traction device with polarimetric microscope



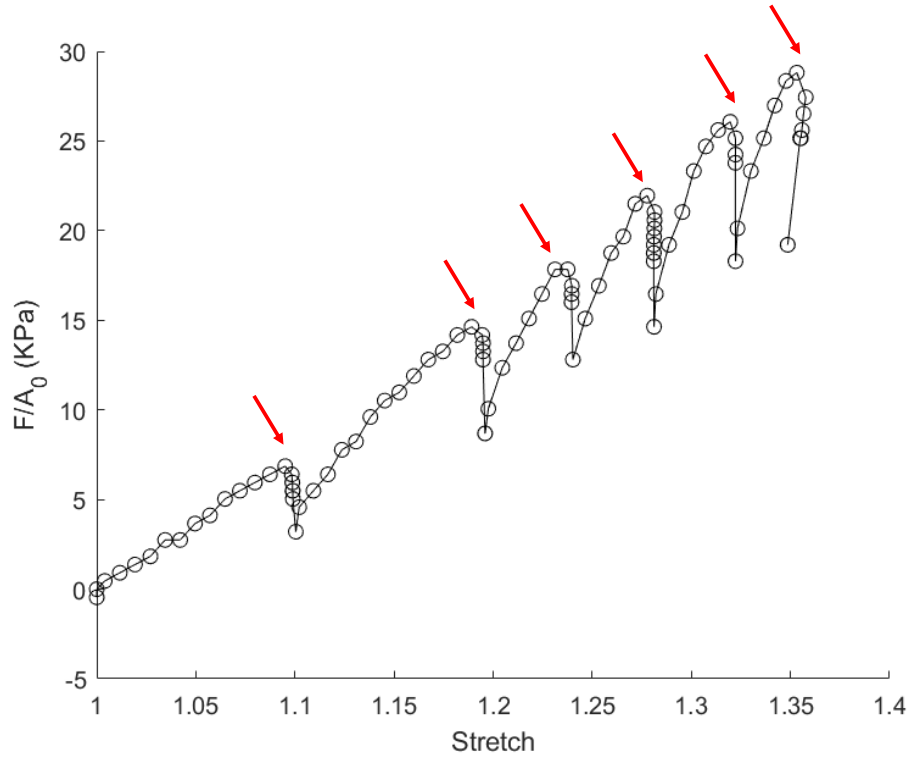
Experimental approach

Tueni *et al.*, Sci. Report, in press

Traction

- Sample: pig left ventricle (30x20x2 mm)
- Sample immerged in PBS

- Loading velocity: 0.1mm/s (0.04 %/s)
- Force recorded every second
- Deformation by DIC
- Pause every 10% for imaging



9 samples with different initial orientations

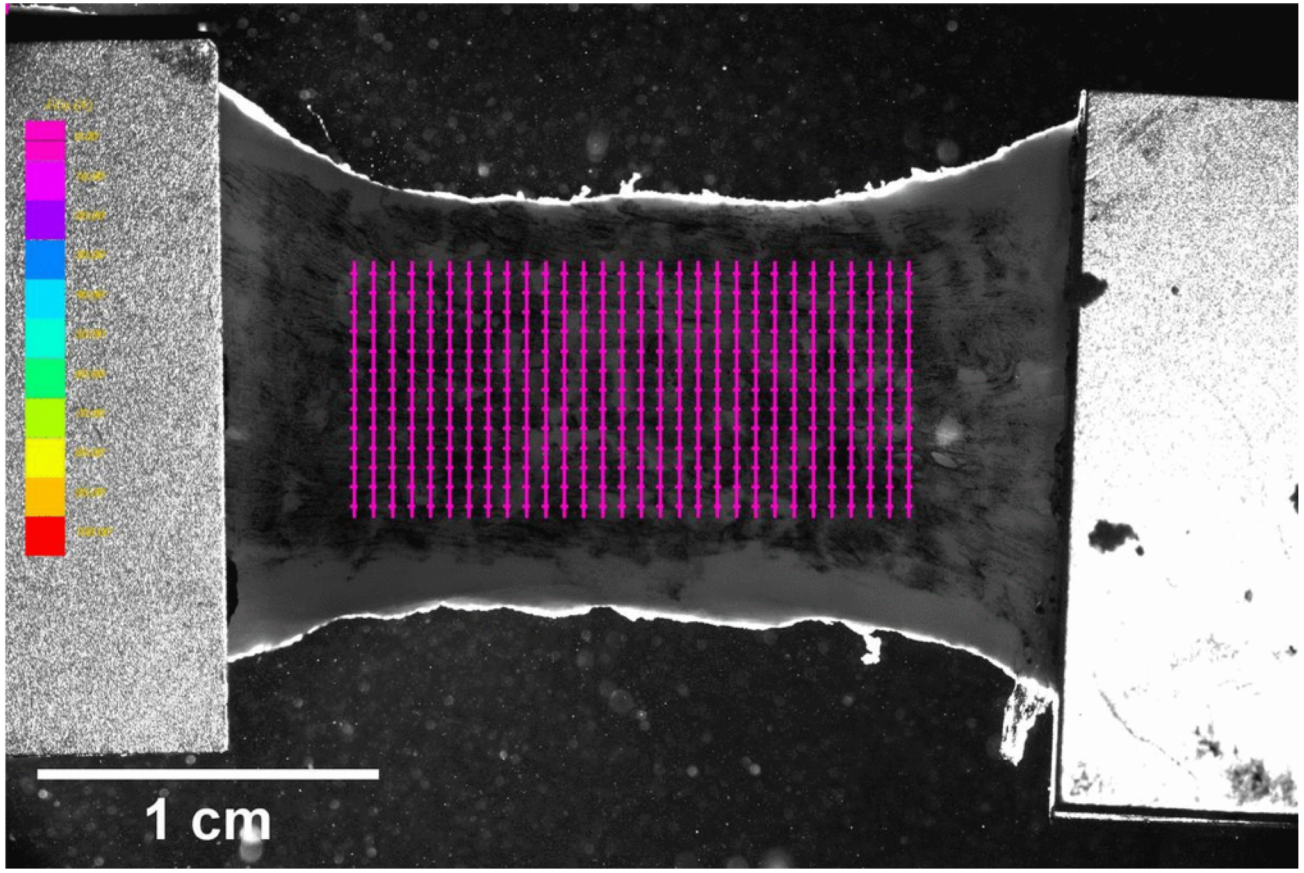
Experimental approach

Tueni *et al.*, Sci. Report, in press

Stretch map

- On the lower side
- Pixel size: 5.5x5.5 μm^2
- Image every 15s (0.6%)

- ROI ~ 16*8cm
- Correlation domain: 550*550µm



Maps of local deformation at different stretch levels

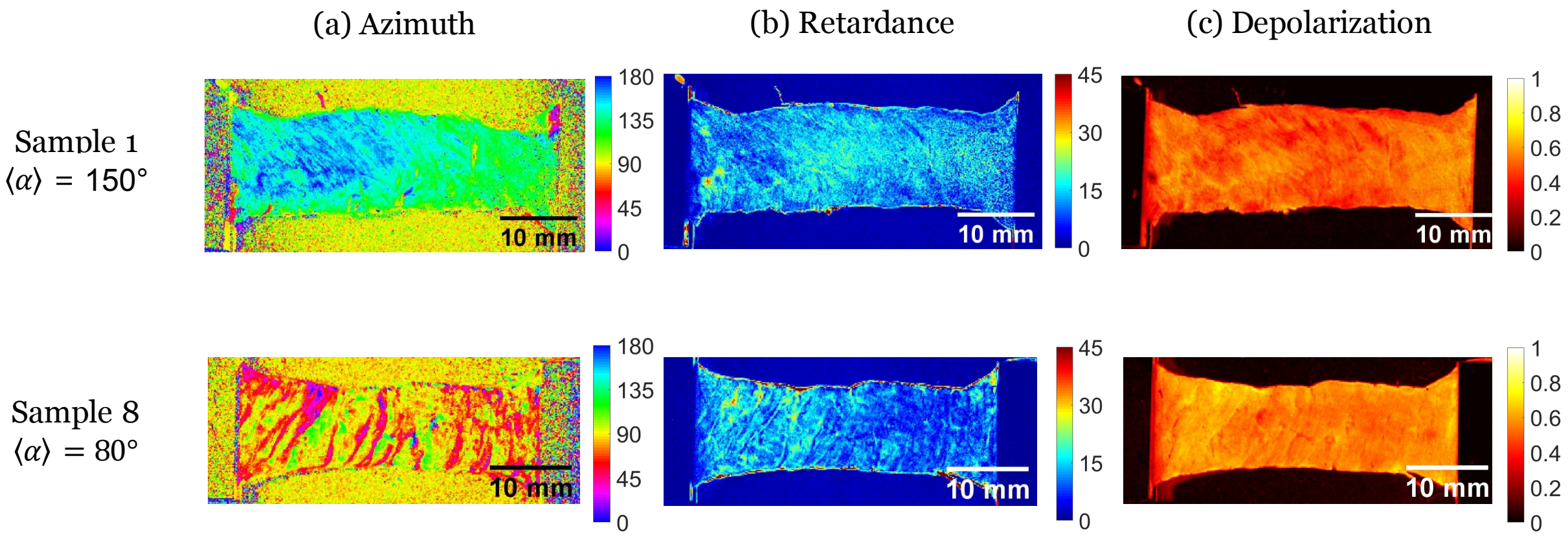
- Heterogeneities
- Stretch comparable on upper and lower faces

Experimental approach

Tueni *et al.*, Sci. Report, in press

Polarimetric measure

- On the upper side
- Image every 10%
- Image: 515x385 pixels
- Pixel size: 100x100 µm² (sheetlet)

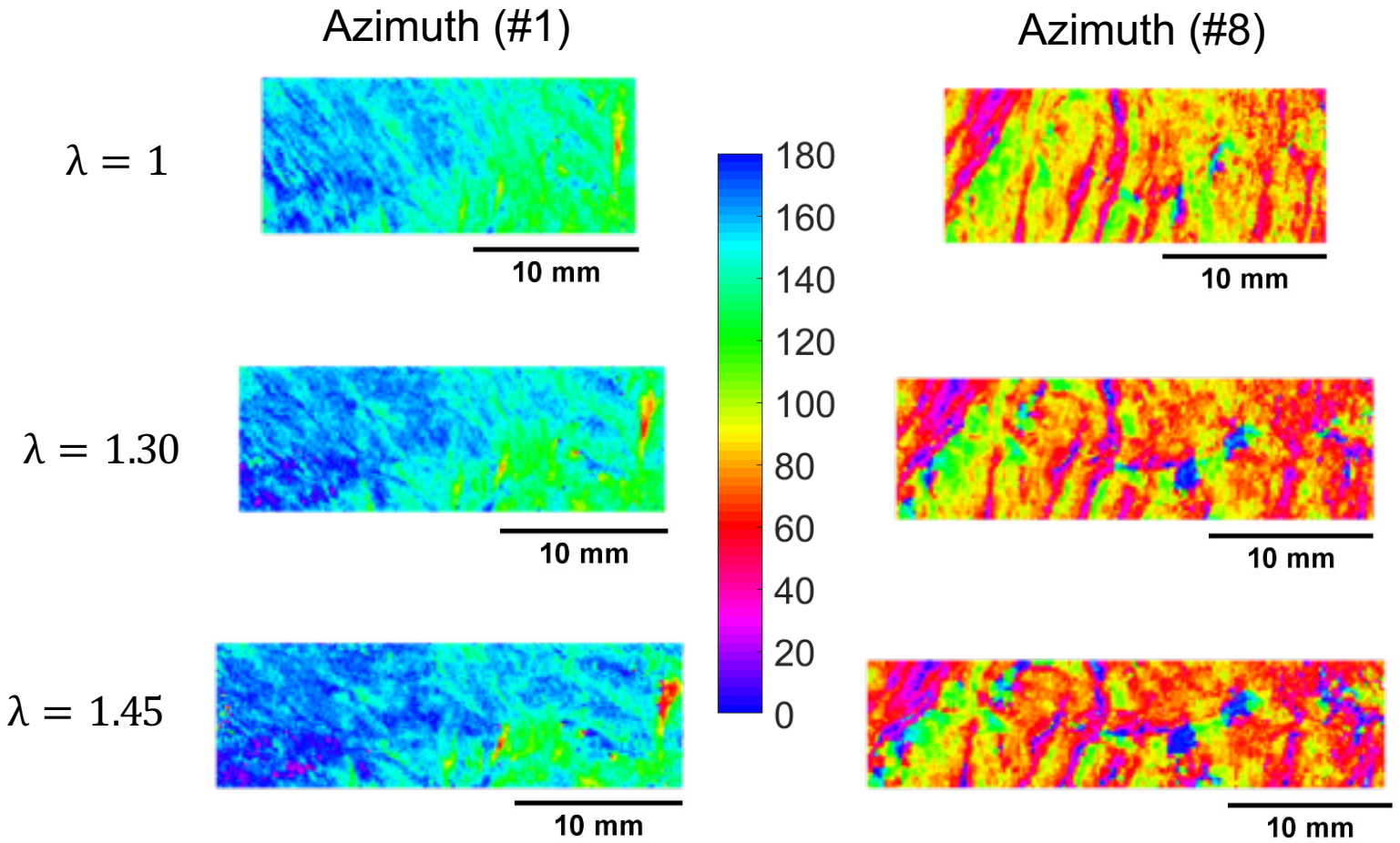


⇨ Separation lines

Results

Tueni *et al.*, Sci. Report, in press

Evolution of the polarimetric parameters



- No change in retardance
- No change in depolarization

- Azimuth aligns in traction direction
- Opening of the separation lines (<α> ~ 90°)

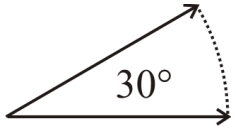
Results

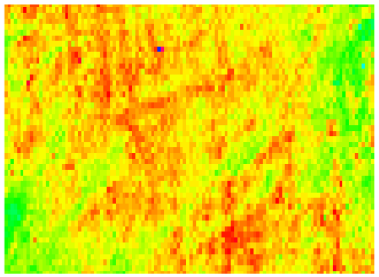
Tueni *et al.*, Sci. Report, in press

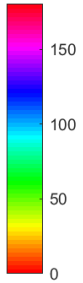
Comparison with an affine model

Sample #1

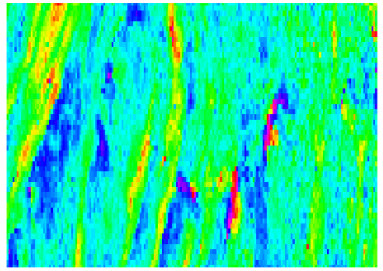
Sample #8

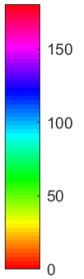


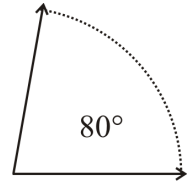


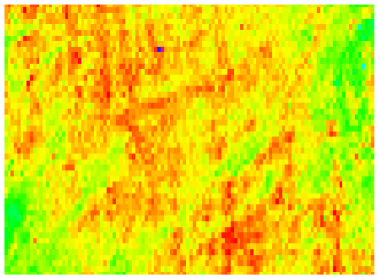


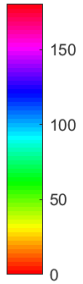
Measured angles (in °)



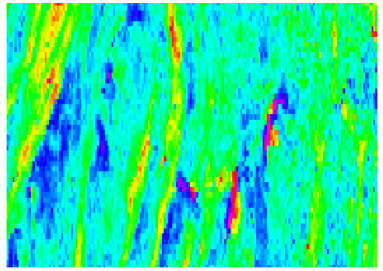


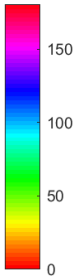


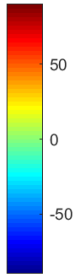




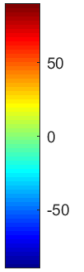
Predicted angles (in °)







Angular difference (in °)

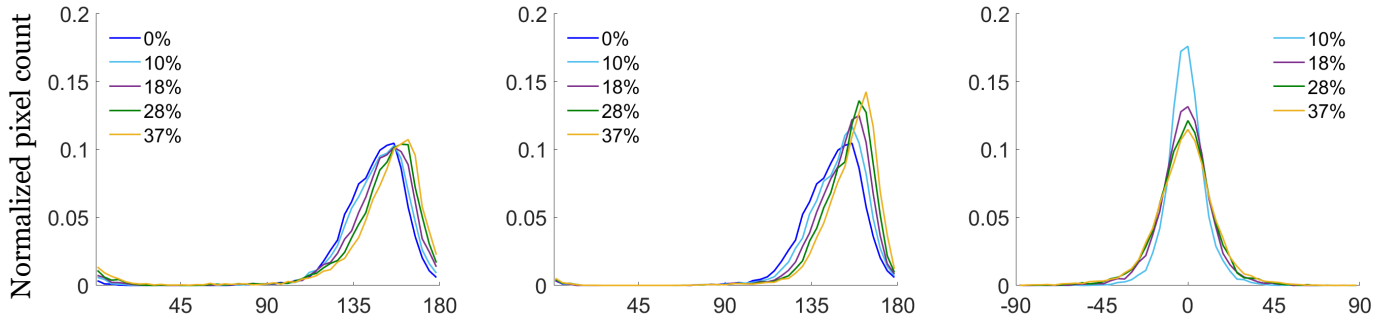


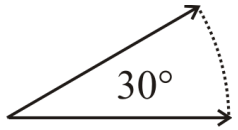
Results

Tueni *et al.*, Sci. Report, in press

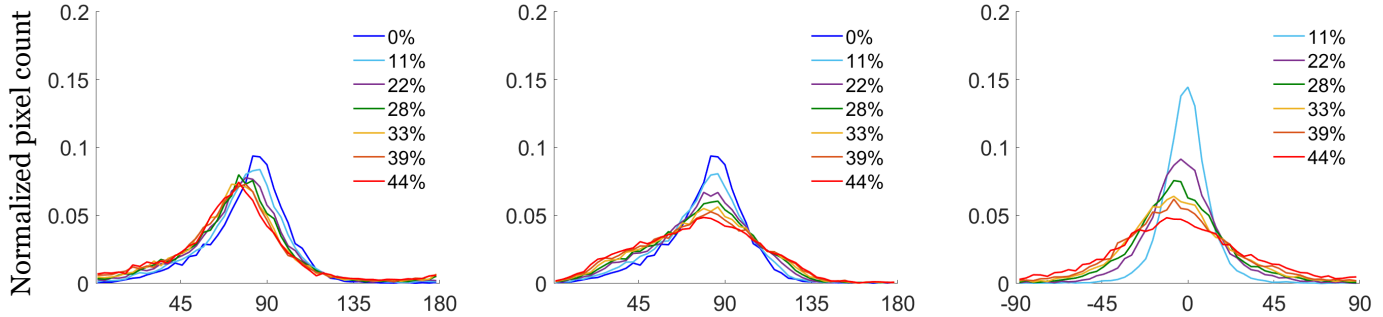
Comparison with an affine model

Sample #1

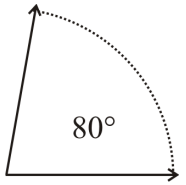




Sample #8



(a) Measured azimuth (°) (b) Predicted azimuth (°) (c) Distance (°)

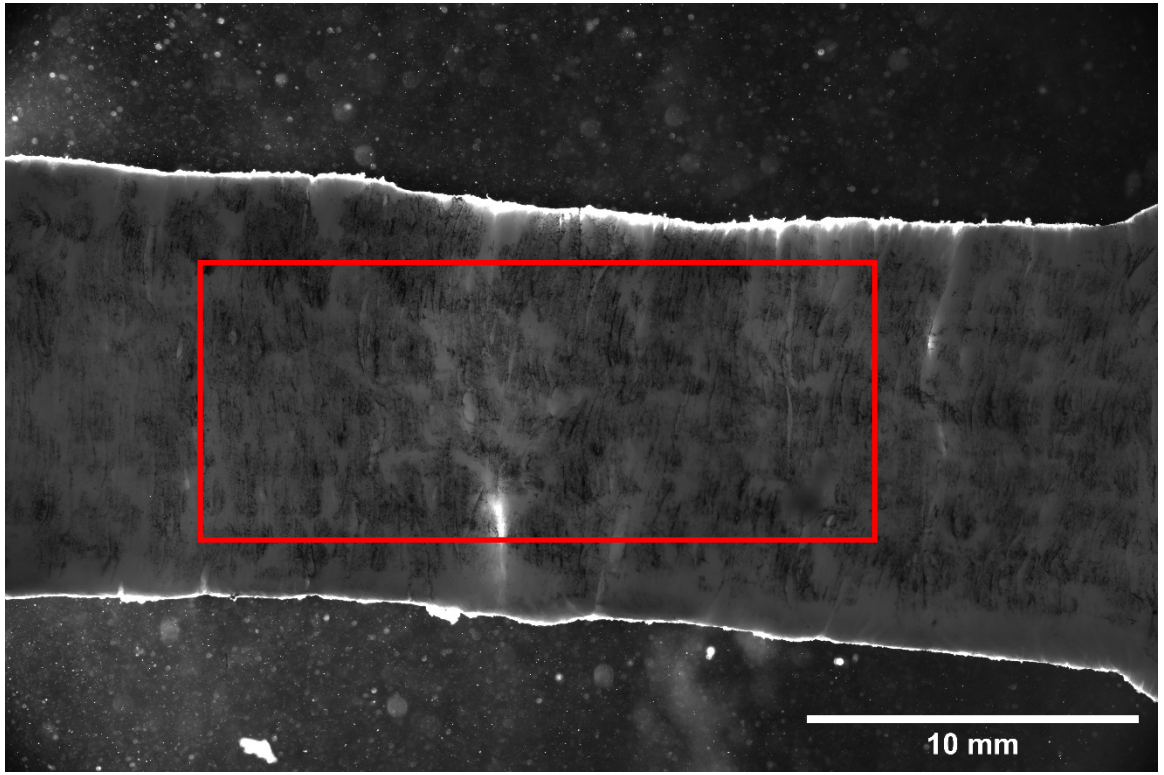


⇨ Affine model works correctly
apart for samples with orientation near 90°

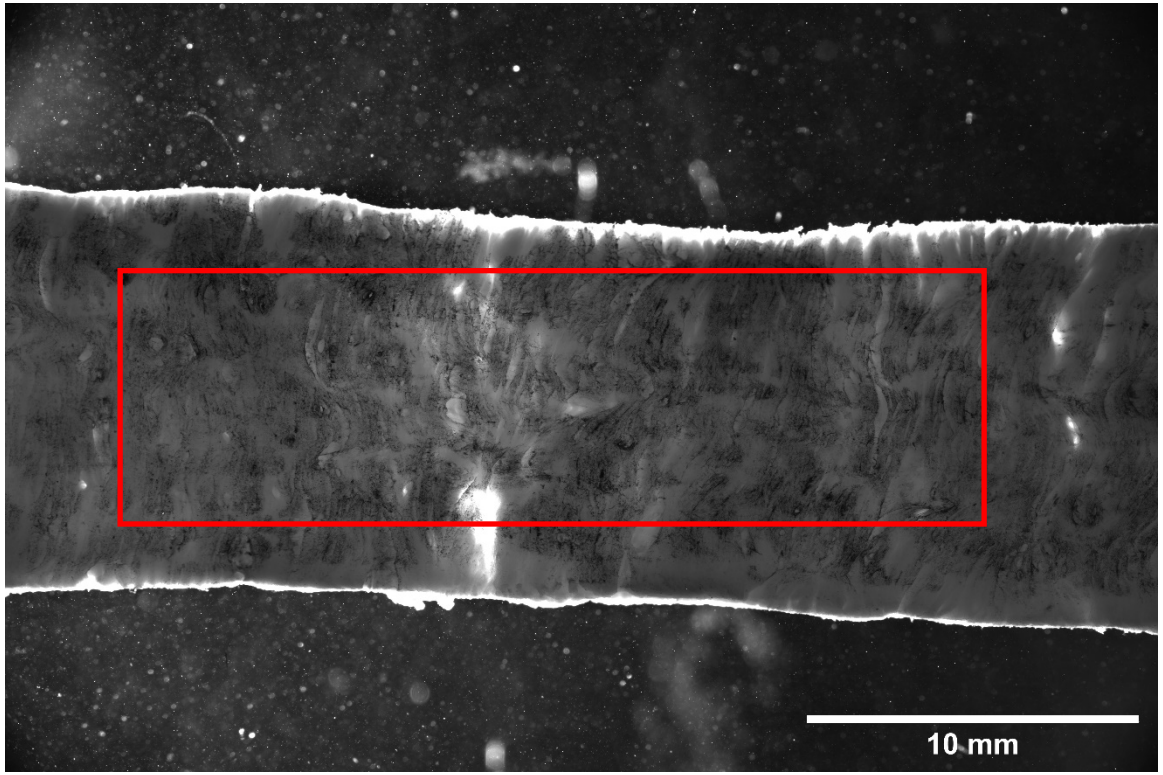
Results

Tueni *et al.*, Sci. Report, in press

Samples perpendicular to traction?



$\lambda = 1$



$\lambda = 1.35$

⇨ Separation lines open during traction

Conclusions & perspectives

➢ Conclusions

- Multiscale observations of myocardium
- Affine assumption: valid almost everywhere
- Separation lines open under traction (not shear or compression)

➢ Perspectives

- Other cutting orientations (of tissue)
- 3D organization of the separation lines
- Modeling of the polarimetric signal
- Modeling of the anisotropy of the tissue

Acknowledgments

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