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Modeling Fluid-Induced Porous Scaffold Deformation

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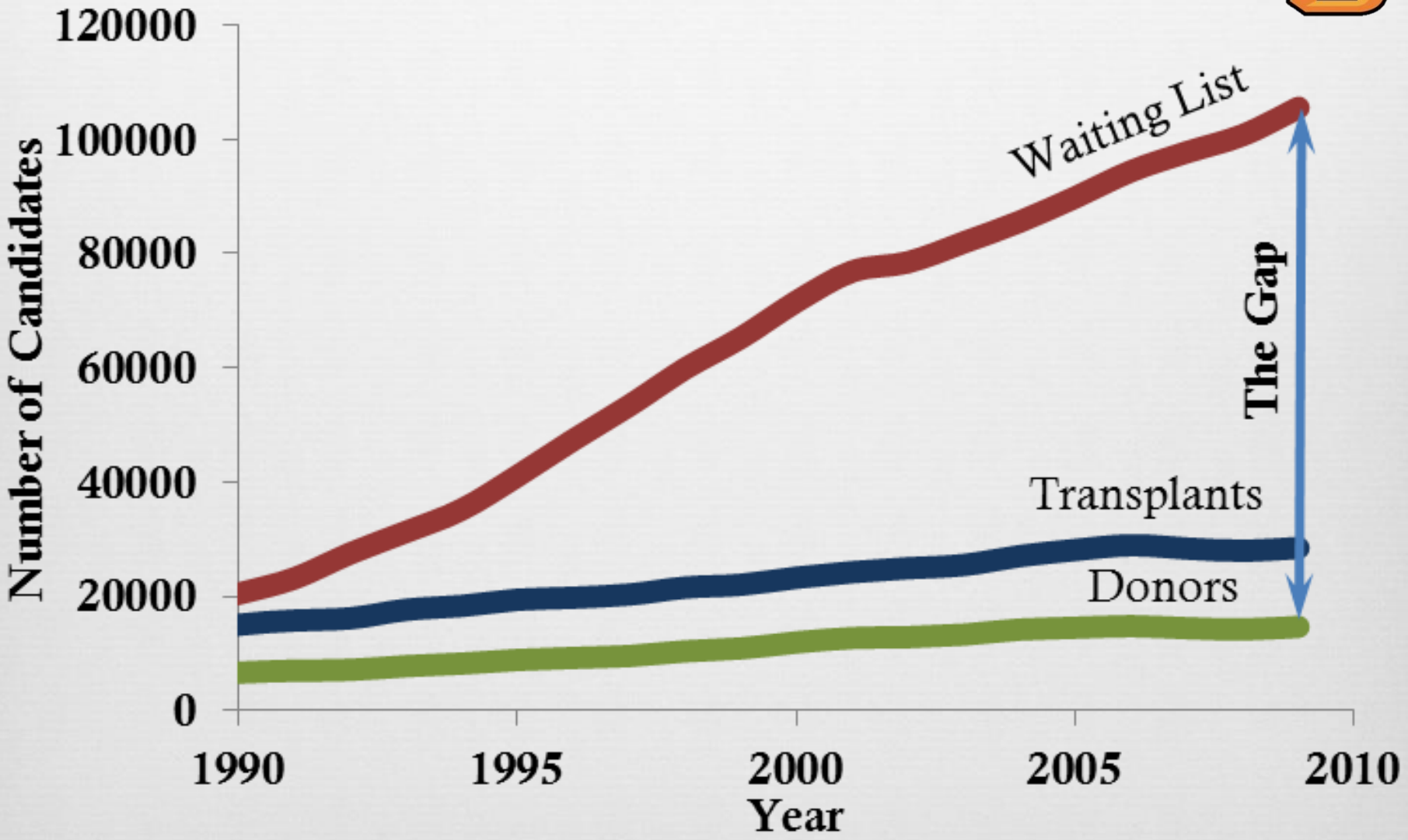
Excerpt from the Proceedings of the 2012 COMSOL Conference in Boston

Why demand for organs and tissues?

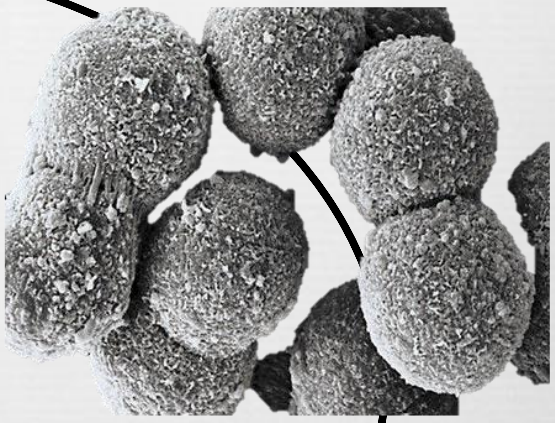


* Based on OPTN data (http://optn.transplant.hrsa.gov/data/)

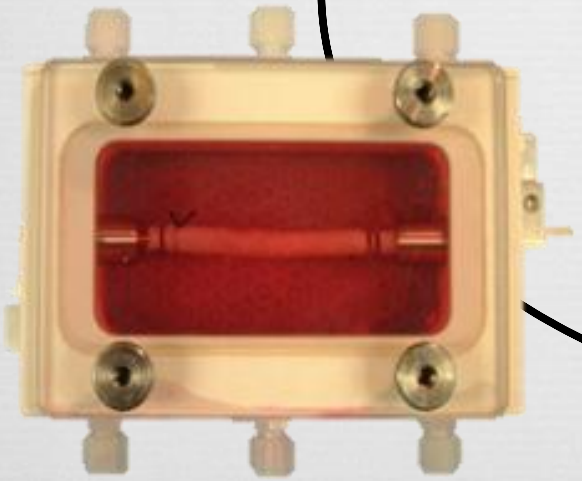
What is Tissue Engineering ?

Regenerated tissue

Harvest cells



Patient



Culture cells in bioreactor

Populate cells

Tracheal Tissue Engineering

http://news.bbc.co.uk/2/hi/health/7735696.stm

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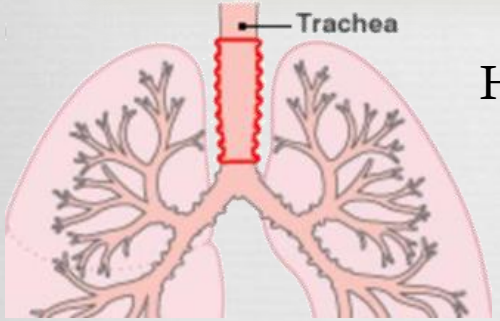
Windpipe transplant breakthrough

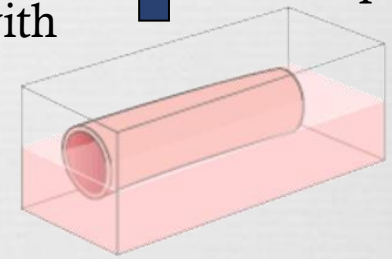
By Michelle Roberts
Health reporter, BBC News

"I was a sick woman, now I will be able to [illegible] normal life"



Harvest from Cadaver

Incubate with Cells



Transplant

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Windpipe transplant success in UK child

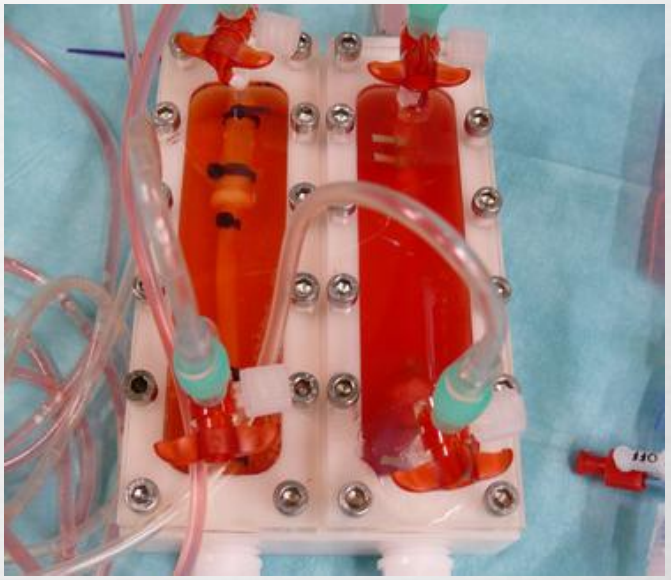
David Green, Harvard Bioscienc

Bioreactors

Systems for regenerating tissues under physiological conditions

Perfusion (heart valve)[1]

Hollow fiber (heart valve)[2]



Pulsatile flow (Vascular grafts)[3]

Flow-through (small construct)[3]

1. Deutsches Herzzentrum Berlin®
2. Monoclonal antibody facility, Univ of Chicago, IL
3. Applied Medical Engineering, Helmholtz Institue of RWTH Aachen University and Hospital

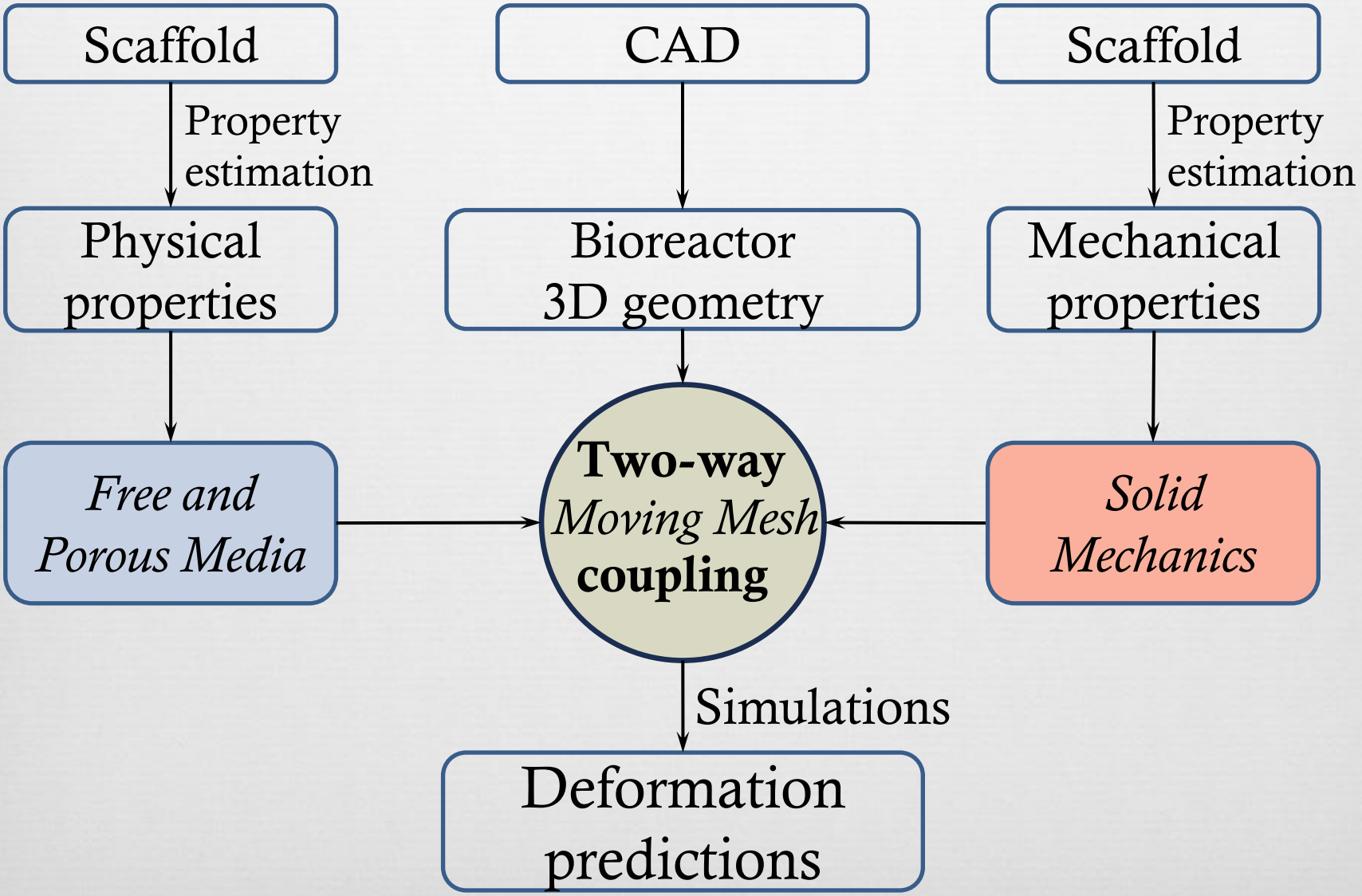
Objective

We have design and tested nearly **50** bioreactor designs

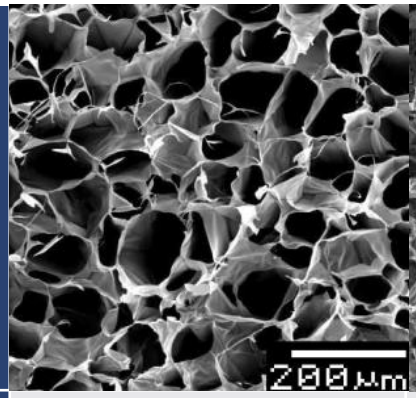
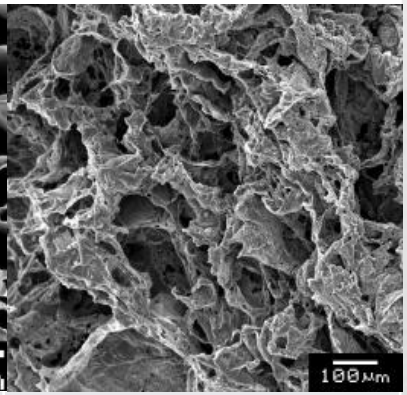
1. Lawrence et al. *Biotechnology/Bioengineering*. 2009
2. Devarapalli et al. *Biotechnology/Bioengineering*. 2009
3. Pok S et al. *Computer Methods in Biomechanics and Biomedical Engineering. 2011*
4. Podichetty et al. *Biotechnology Progress*. 2012
5. Patrachari et al. *Journal of Bioscience and Bioengineering*. 2012

Apply fundamental concepts to tissue bioreactor design to understand fluid induced scaffold deformation

Scaffold deformation using 3D modeling

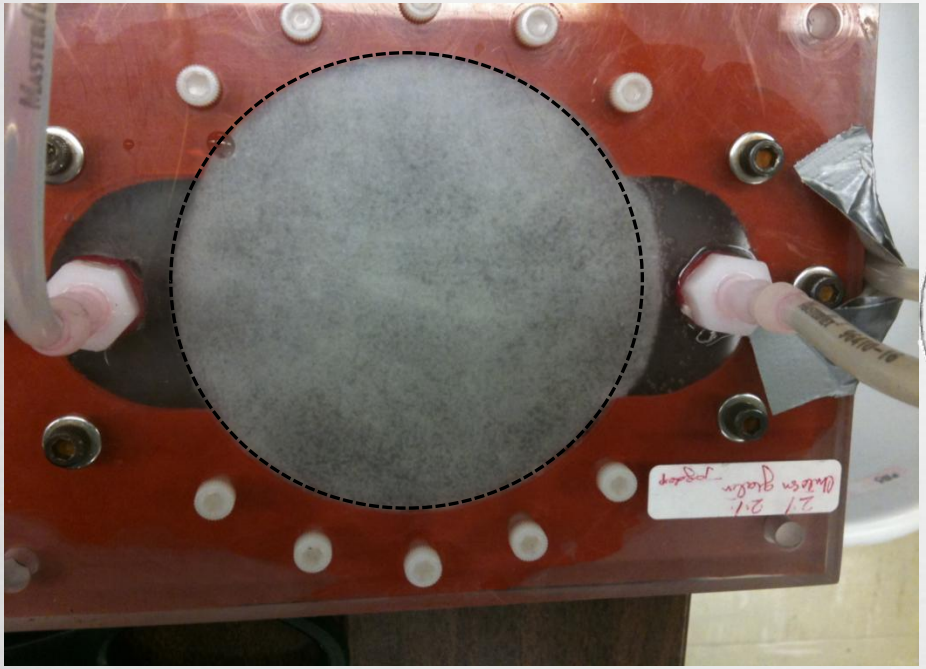


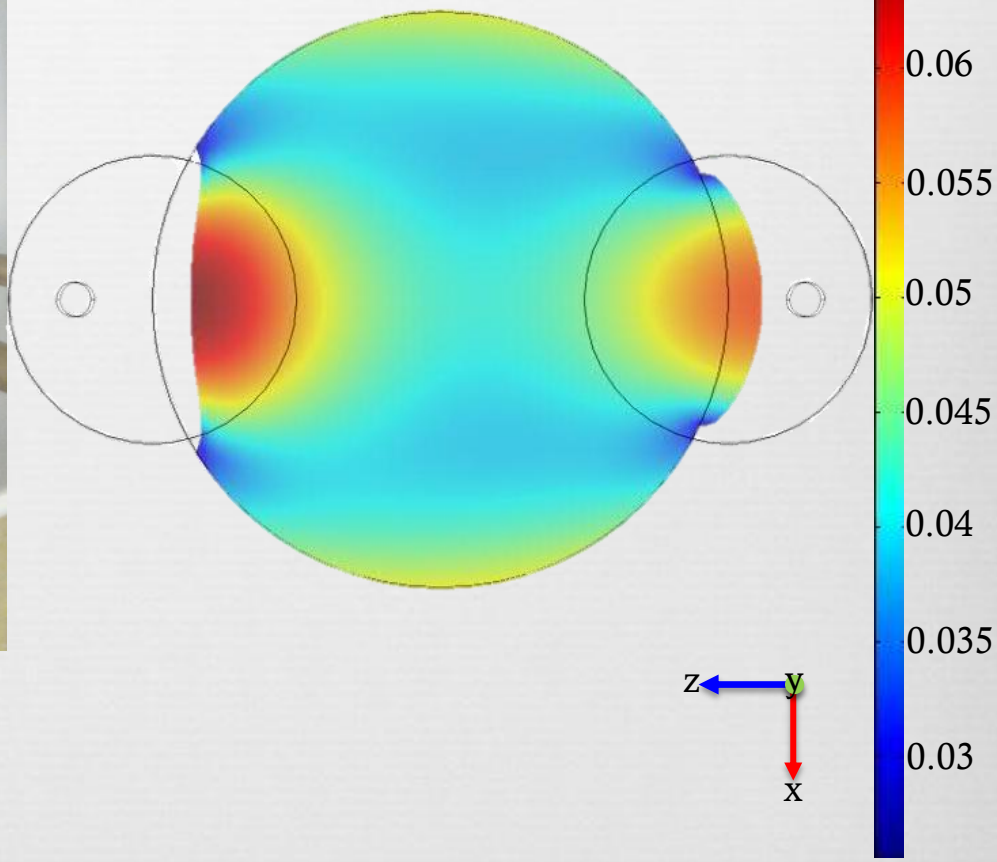
Scaffolds properties

Method of making the scaffold	Freeze-drying	Salt-leaching
Scanning electron micrographs showing pore morphology (dry).		
Pore morphology	Circular	Rectangular
Permeability determination [1]	$\kappa = \frac{\pi}{128} n_A d^4$	$\kappa = \frac{n_A L W^3}{12}$
Calculated Permeability value	$k=7\times10^{-11}$ m^2	$k=7\times10^{-10}$ m^2
Elastic modulus (experimentally determined at physiological condition)	2 (±0.5) kPa	7000 (±1000) kPa
Poisson ratio [1] (experimentally determined using ASTM E132-4 (or ASTM E1876–09))	1 (±0.1)	0.3 (±0.1)

1. Podichetty et al. *Biotechnology Progress*. 2012

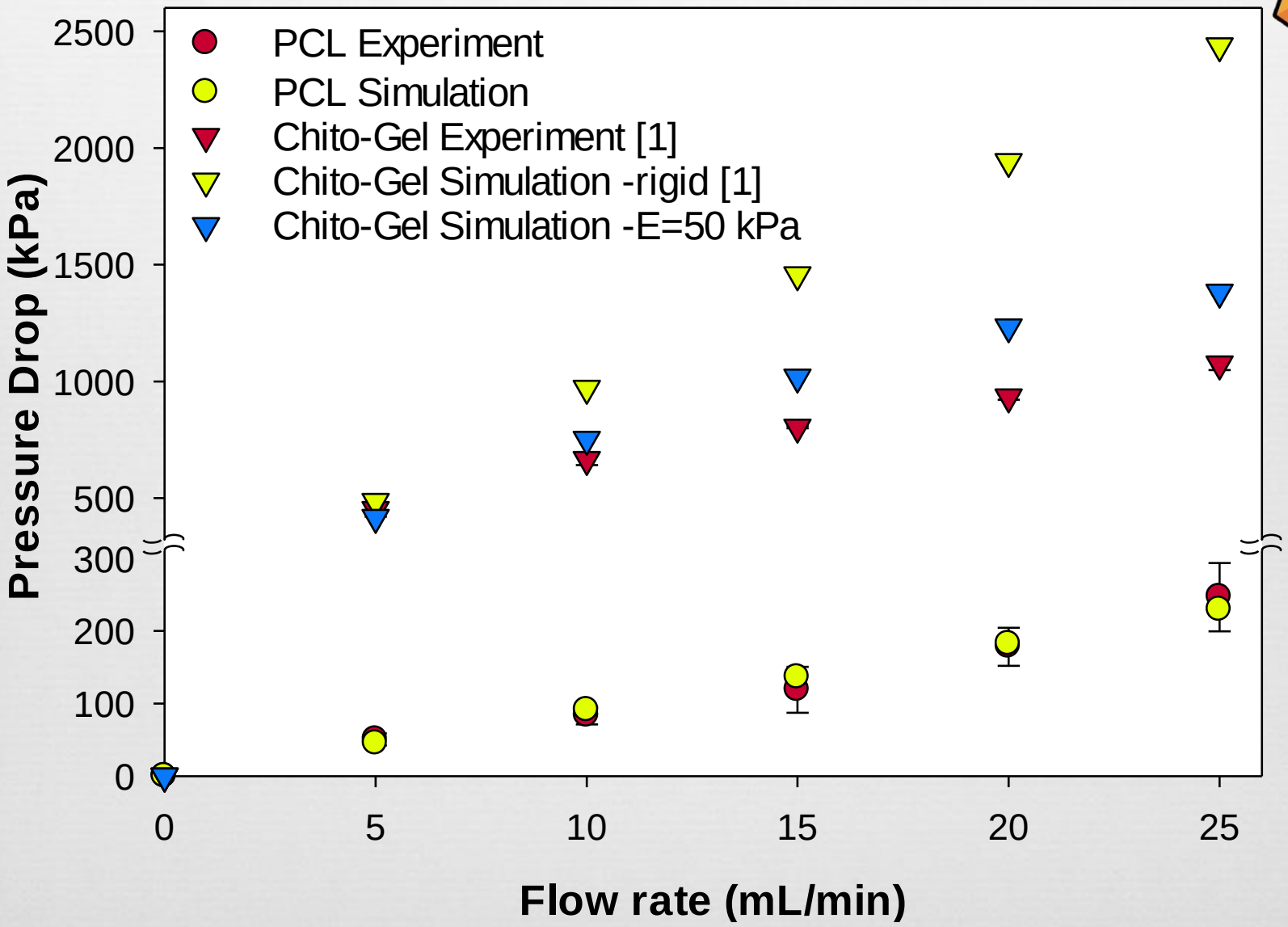
Scaffold deformation using 3D modeling





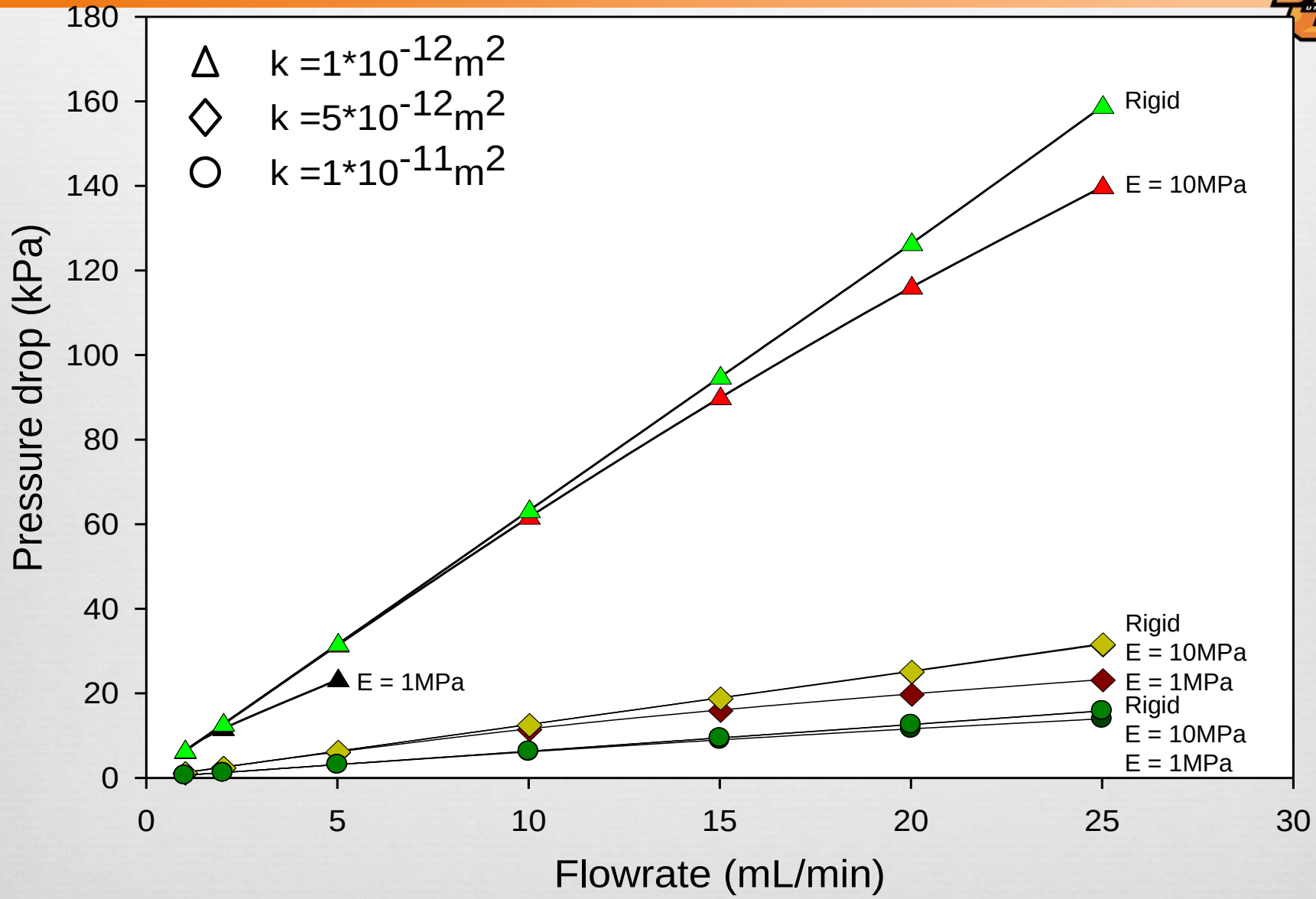
Noticeable Deformation @ 20 mL/min

2-way coupling predicts pressure drop



[1] Podichetty et al. *Biotechnology Progress*. 2012

A non-invasive way of monitoring tissue growth



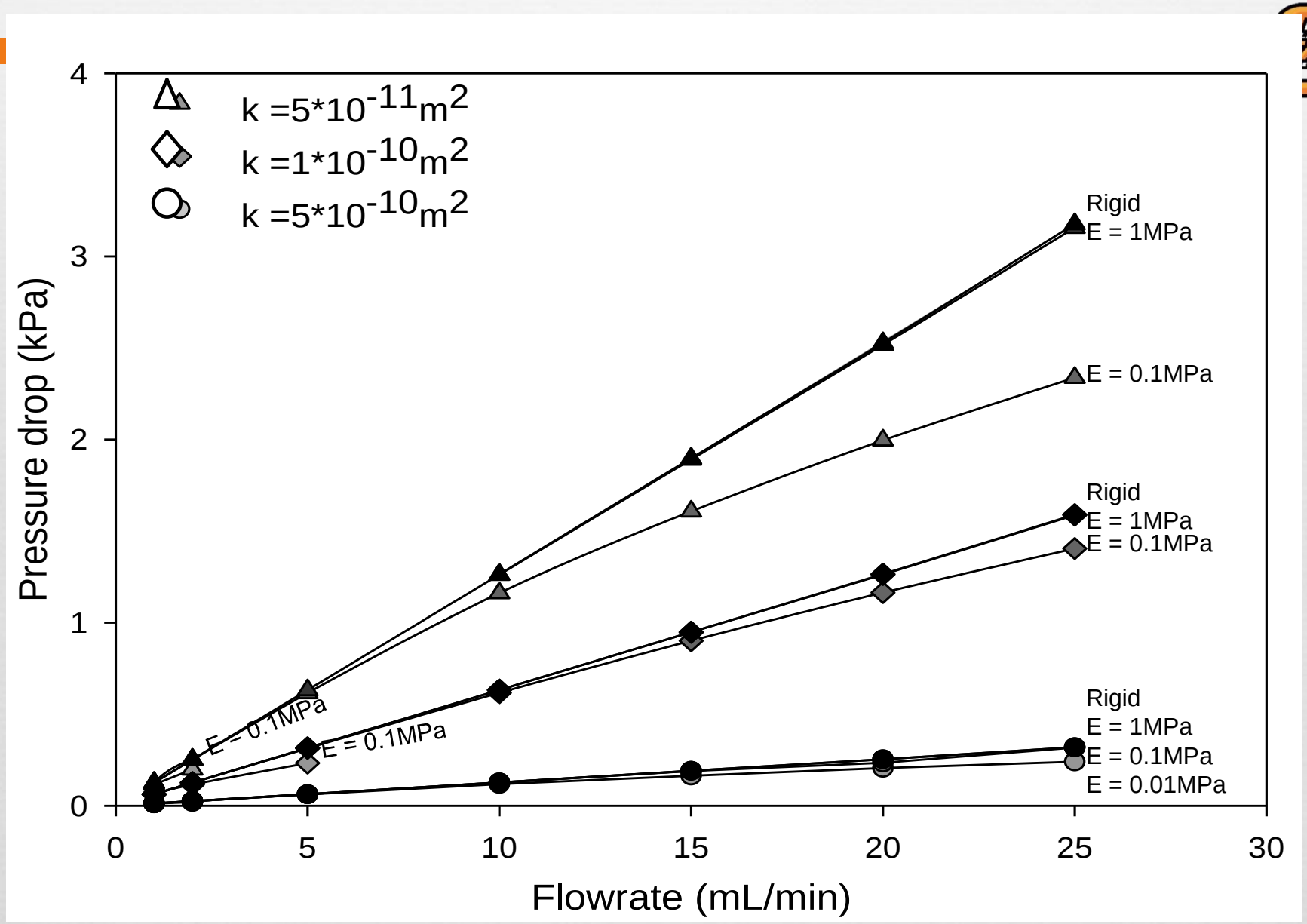
Summary

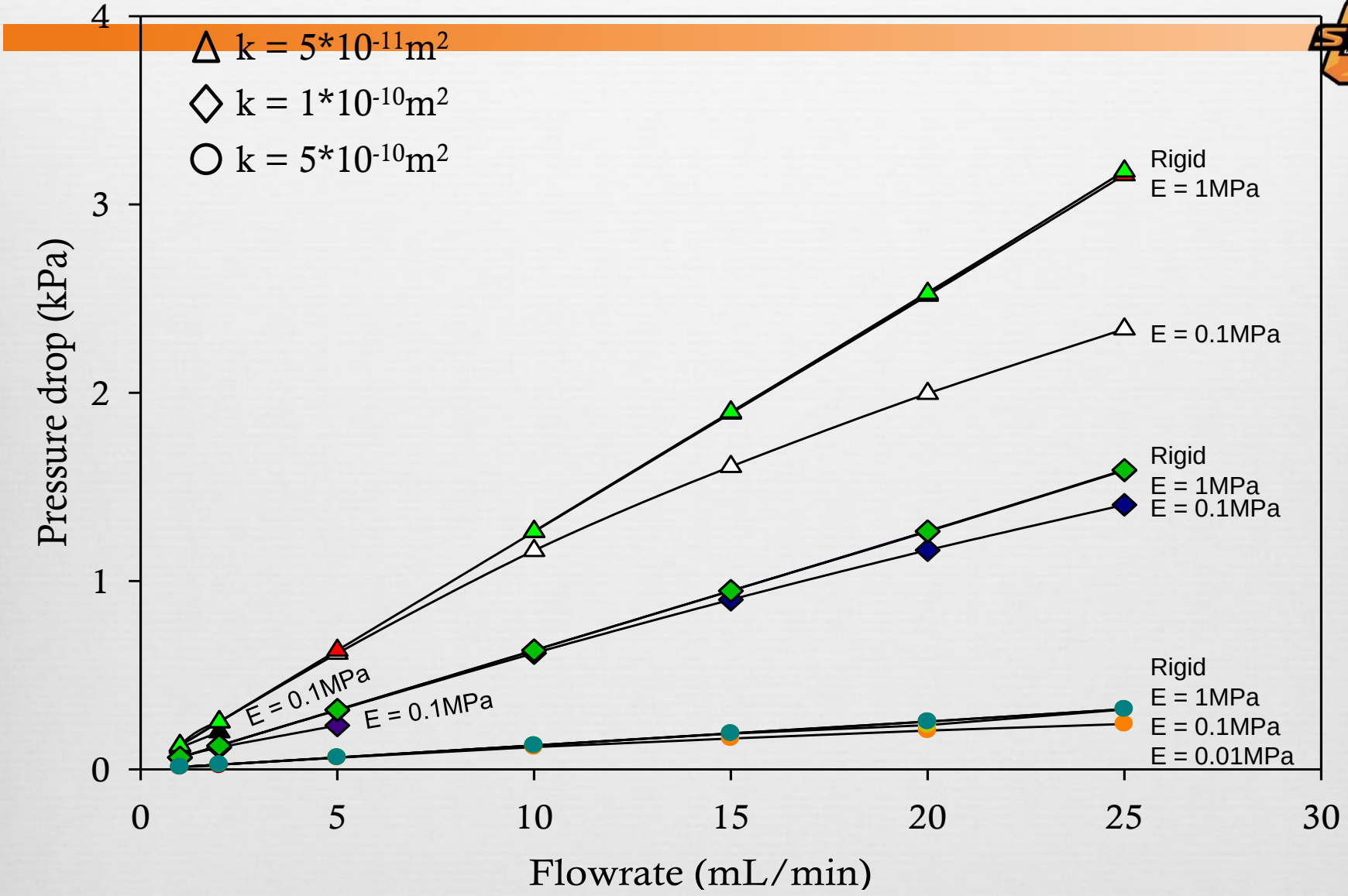
- Rigid scaffold assumption
  - Large deviation from experimental results
  - Inaccurate prediction of pressure drop
- Two-way coupling of structural mechanics with fluid flow
  - Satisfactorily predicts experimental pressure drop for a boarder range of scaffold properties
  - Extended to tissue properties range

Thank you for your time

Questions

A non-invasive way of monitoring tissue growth

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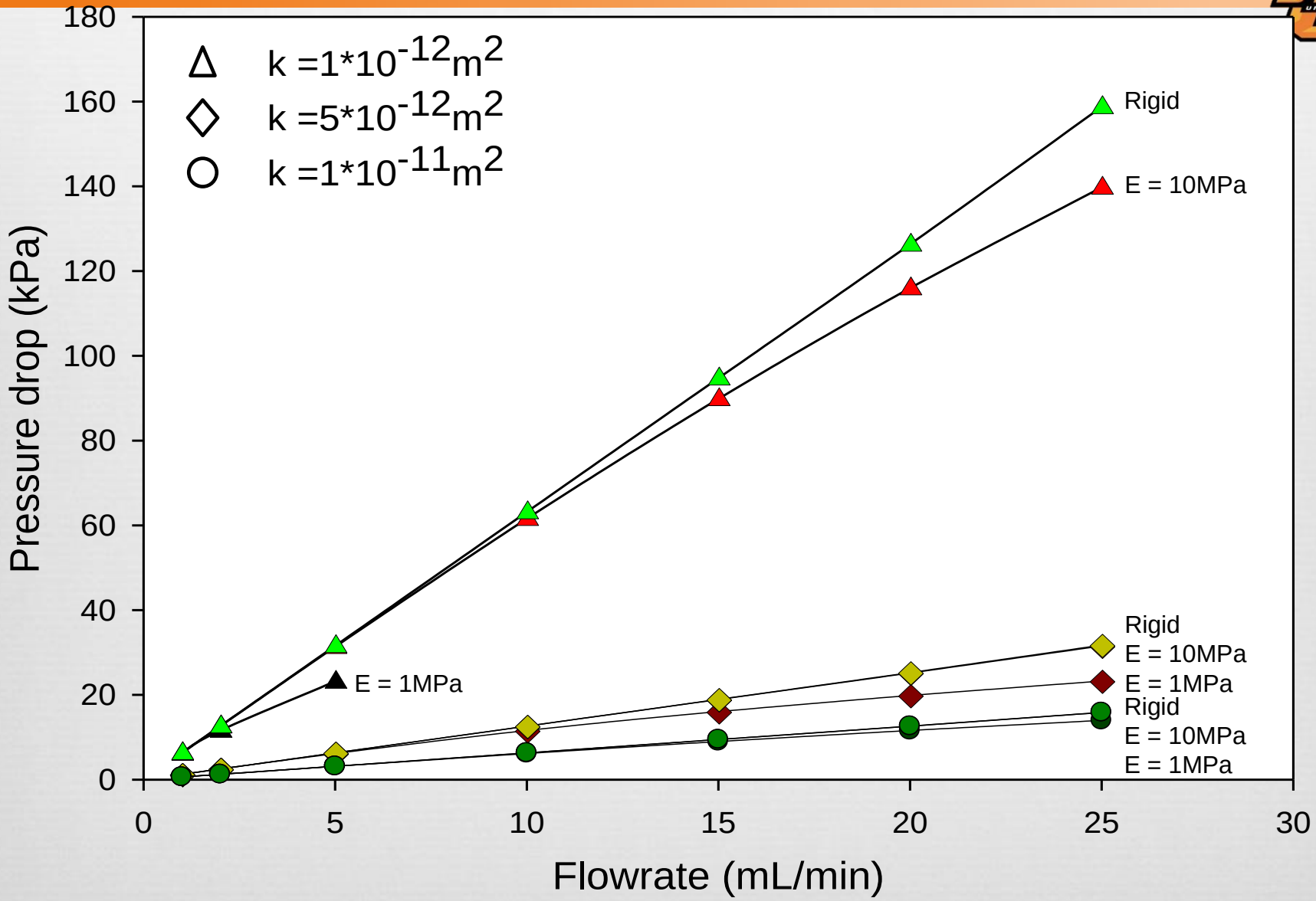
k = 1*10-10m2
k = 5*10-10m2
Rigid
E = 1MPa
E = 0.1MPa
Rigid
E = 1MPa
E = 0.1MPa
Rigid
E = 1MPa
E = 0.1MPa
E = 0.01MPa
E = 0.1MPa
E = 0.1MPa
Pressure drop (kPa)
Flowrate (mL/min)
0
1
2
3
4
0
5
10
15
20
25
30


k =1*10-12m2
k =5*10-12m2
k =1*10-11m2
Rigid
E = 10MPa
E = 1MPa
Rigid
E = 10MPa
E = 1MPa
Rigid
E = 10MPa
E = 1MPa
Pressure drop (kPa)
Flowrate (mL/min)
0
20
40
60
80
100
120
140
160
180
0
5
10
15
20
25
30