

# VORLESUNG 10

Vorlesung  
Humboldt-Universität zu Berlin  
Institut für Physik

## Biologische Physik

Die Dynamik biologischer Prozesse im menschlichen Körper

Richard Weinkamer

Max Planck Institute of Colloids and Interfaces  
Department of Biomaterials  
Potsdam

[richard.weinkamer@mpikg.mpg.de](mailto:richard.weinkamer@mpikg.mpg.de)



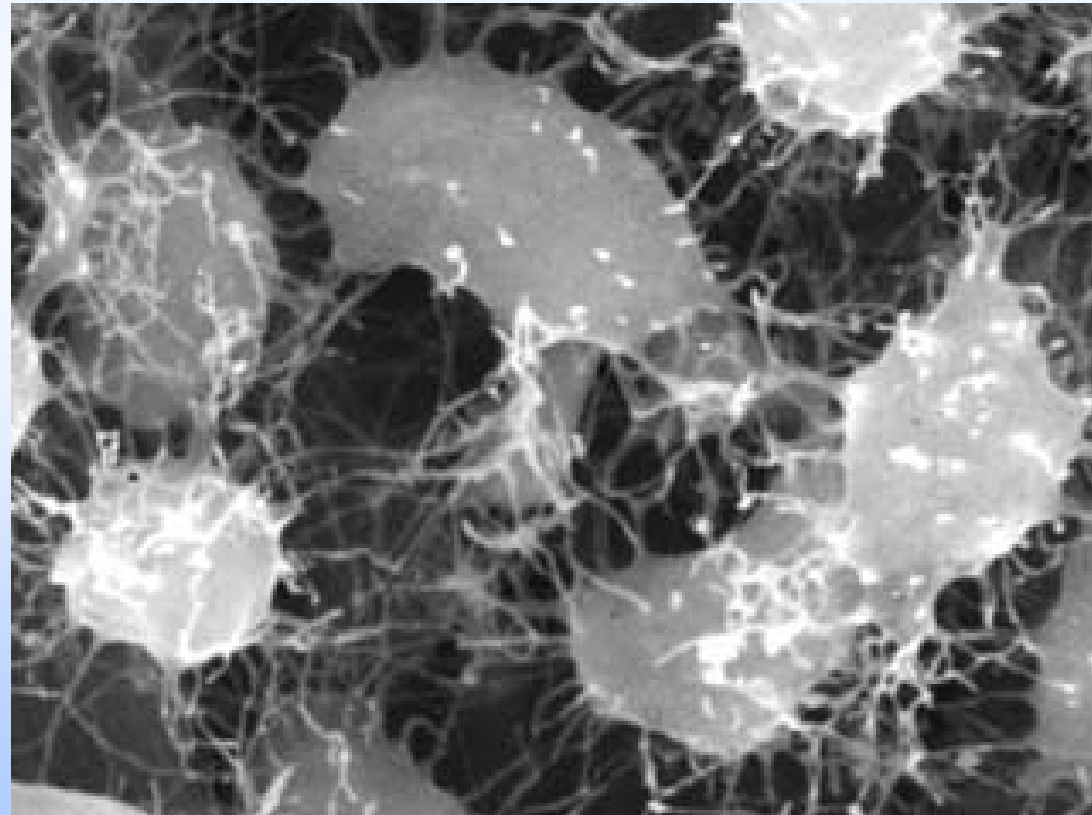
**Max Planck Institute  
of Colloids and Interfaces**



## 5.6 bone remodeling

- reason for bone remodeling?
- the nature of the signal?
- what is the mechanical stimulus the cells are reacting to?
- what is the connection between dysfunctions of the control system and bone diseases like osteoporosis?

open questions:



osteocytes  
inside bone

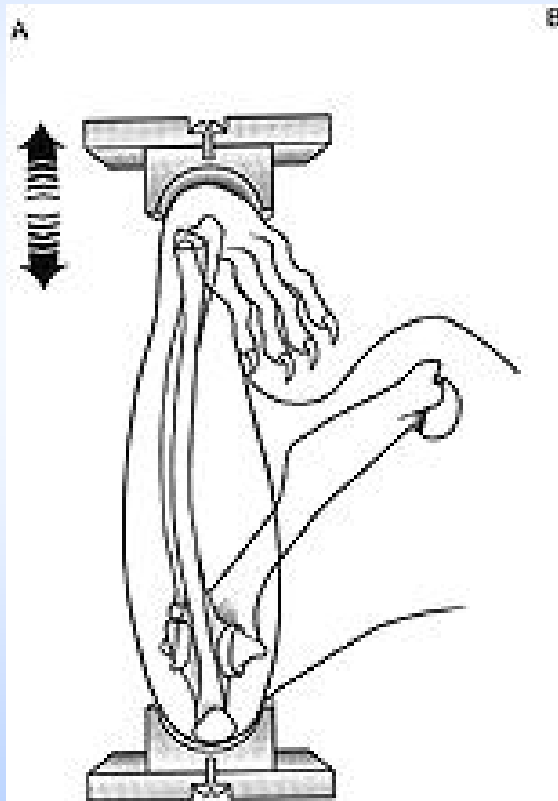




## 5.7 bone remodeling - experiments

in vivo experiments:

mechanical loading → structure

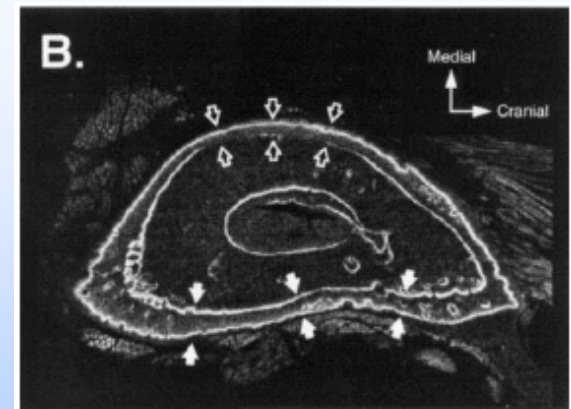
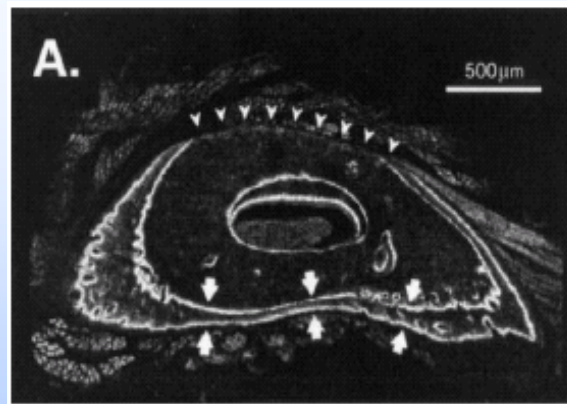


increased loading:

- exercise
- osteotomy
- devices to apply controlled loading

decreased loading:

- casting
- hindlimb suspension
- space flight
- bedrest



Mosley and Lanyon, Bone 23 (1998)

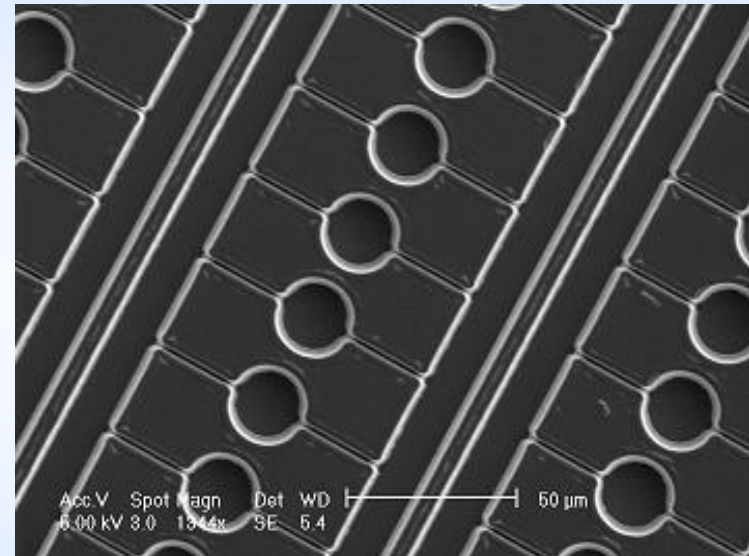
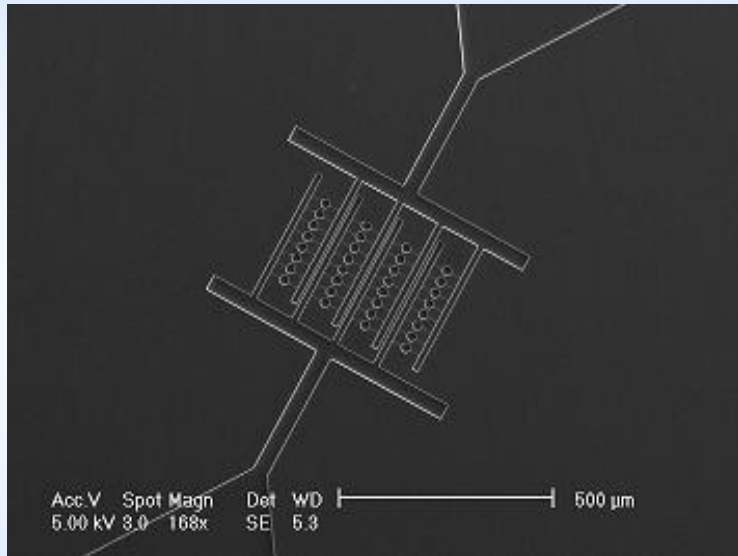




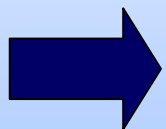
## 5.7 bone remodeling - experiments

in vitro experiments:

3D microfabricated flow system:



Jacobs et al., The Cell and Molecular Biomechanics Laboratory at Stanford University



response of the osteocyte processes to fluid flow



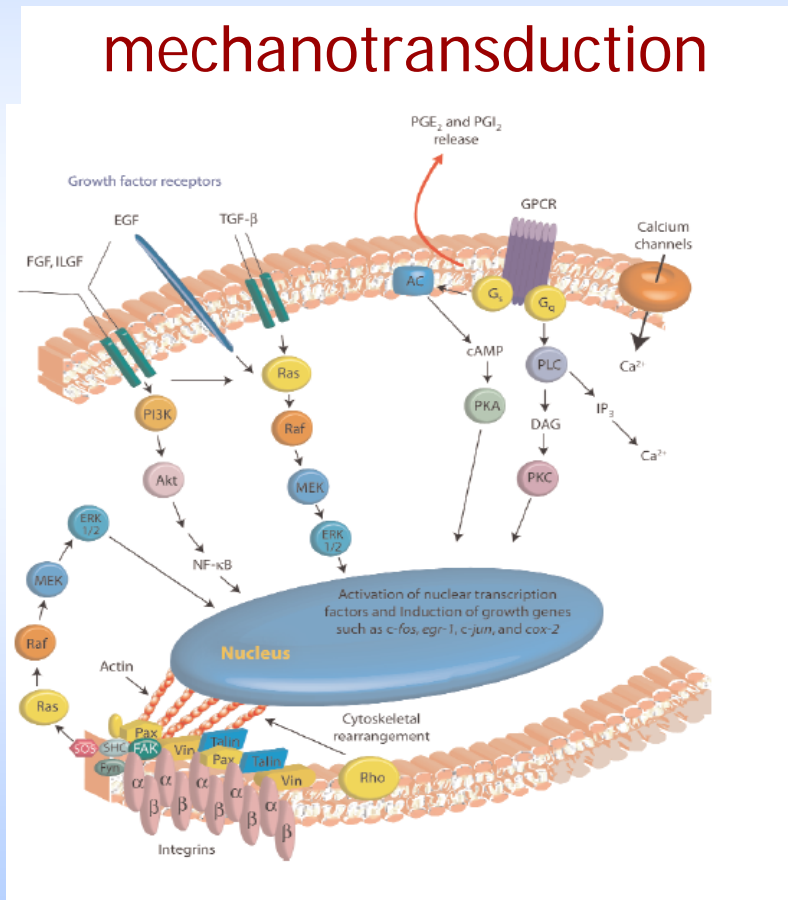


# 5.7 bone remodeling - experiments

in silico experiments:

„realistic“ description:

mechanical  
stimulus



cell reaction  
local bone  
resorption/deposition

Hughes-Fulford,  
*Science's STKE* (2004)

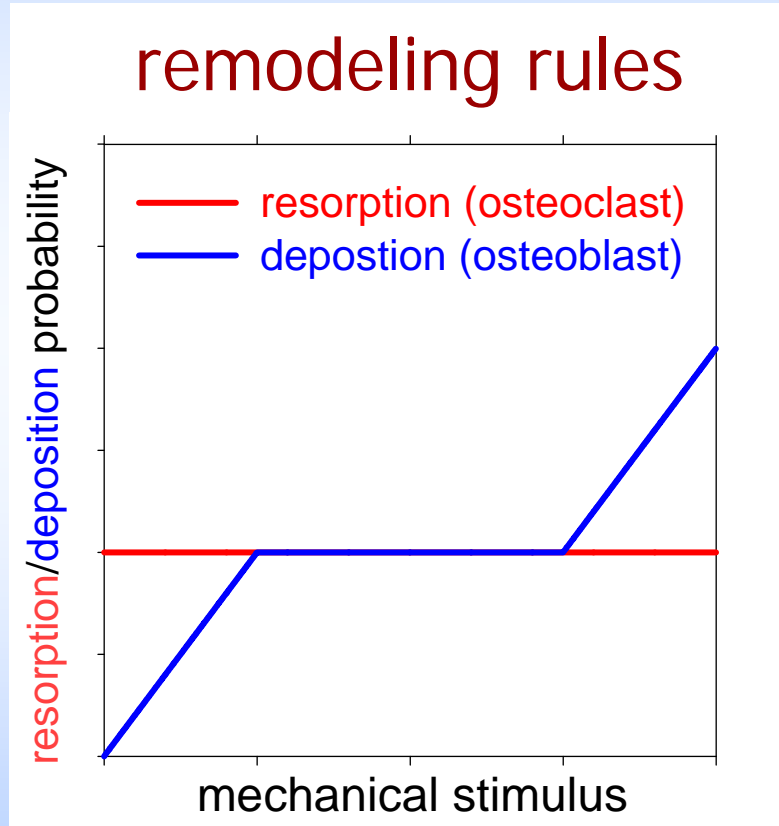






## 5.7 bone remodeling - experiments

phenomenological description:

mechanical  
stimulus



cell reaction



local bone  
resorption/deposition





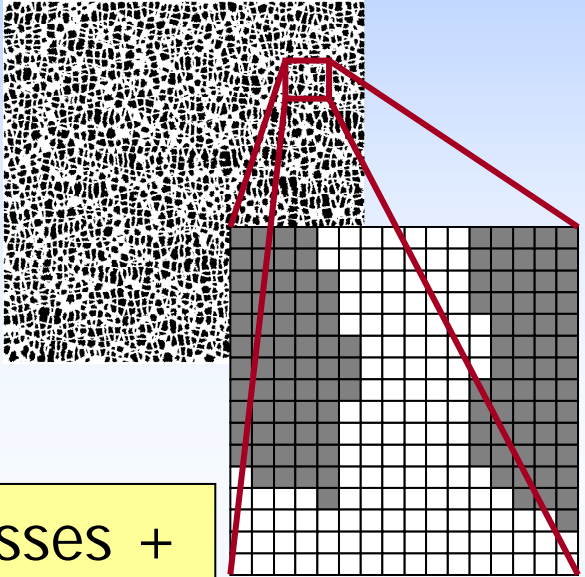
# 5.7 bone remodeling - experiments

## feedback loop of bone remodeling:

deposition/resorption of bone volume element at bone/marrow interface

bone structure + material properties

loading history



lattice model

change in structure

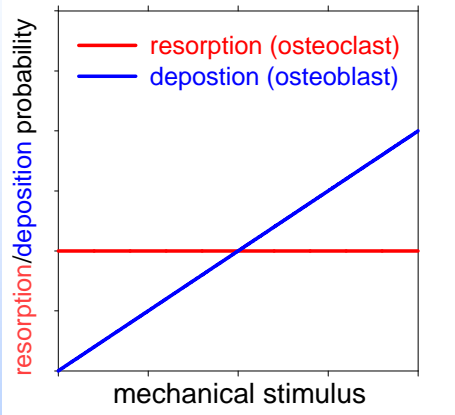
stresses + strains

via fast algorithm

mechanotransduction

mechanical stimulus

total volume change

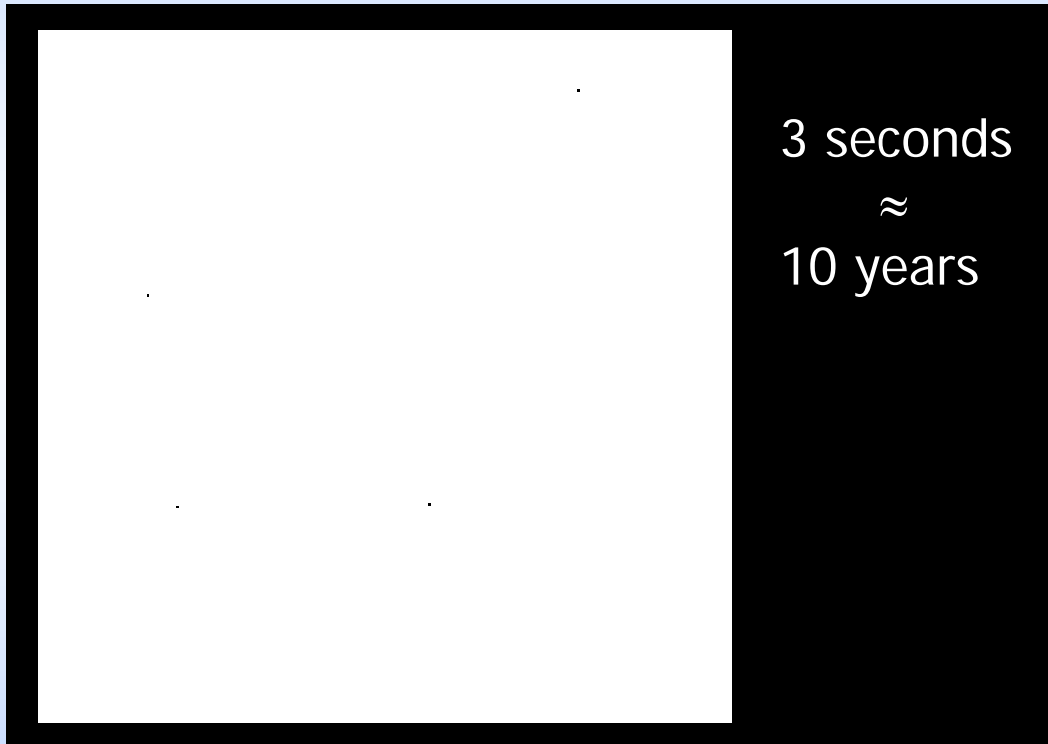


remodeling rule

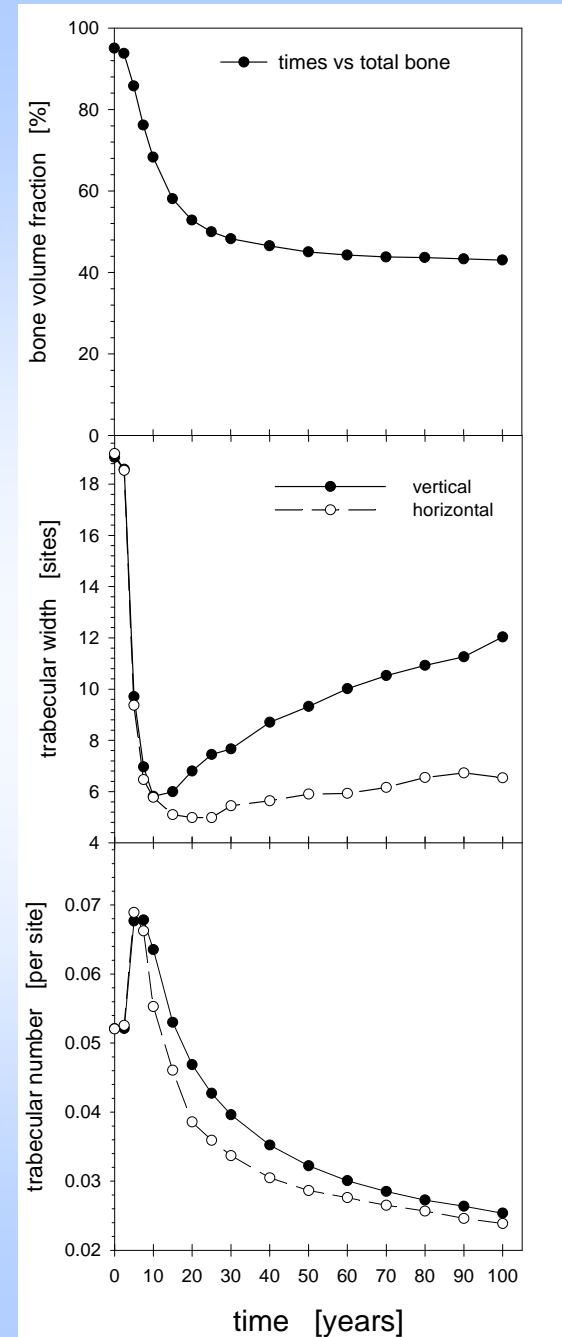


# 5.7 bone remodeling - experiments

## TIME EVOLUTION



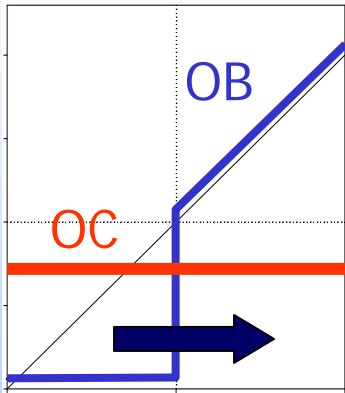
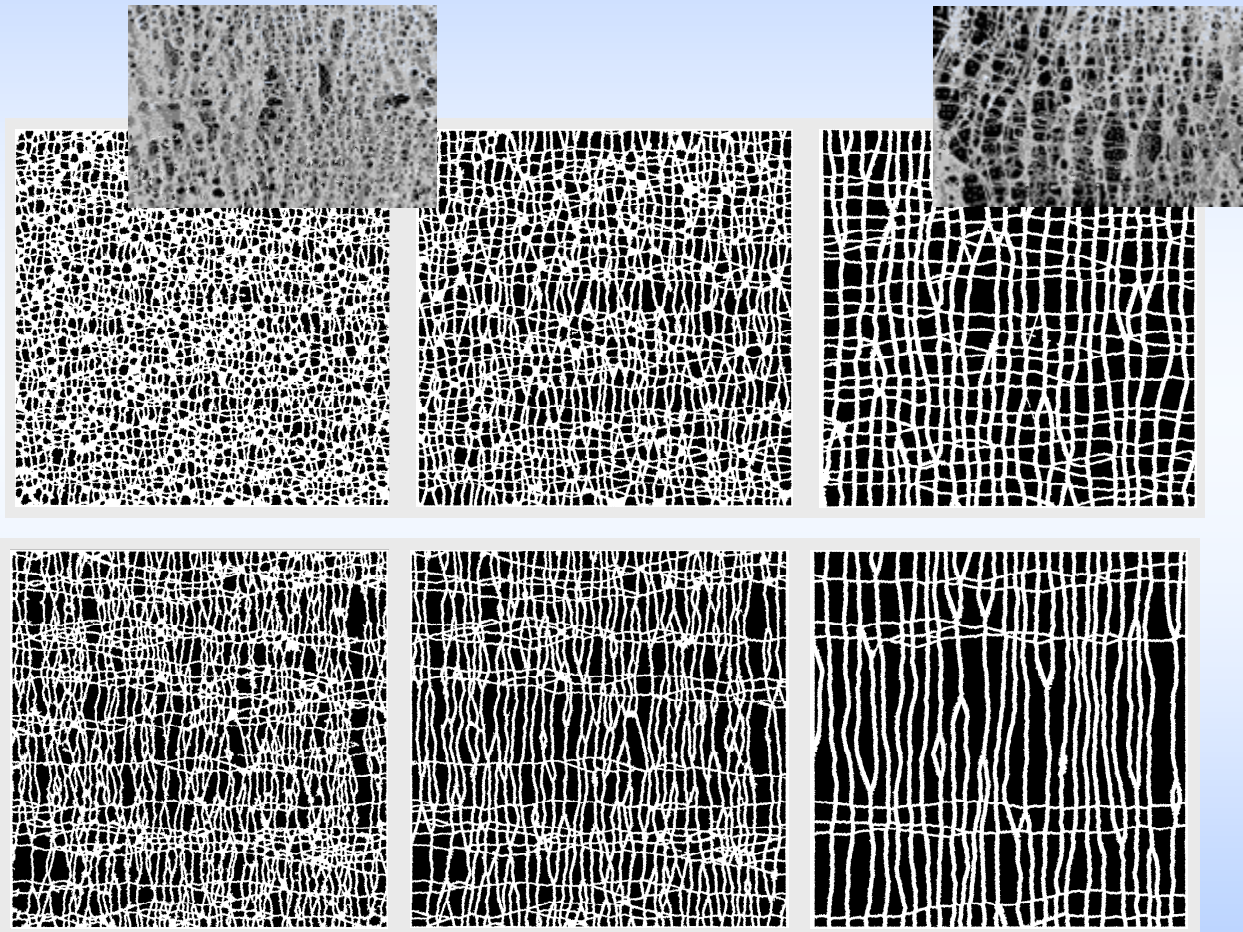
**COARSENING**





## 5.7 bone remodeling - experiments

aging vs disease:



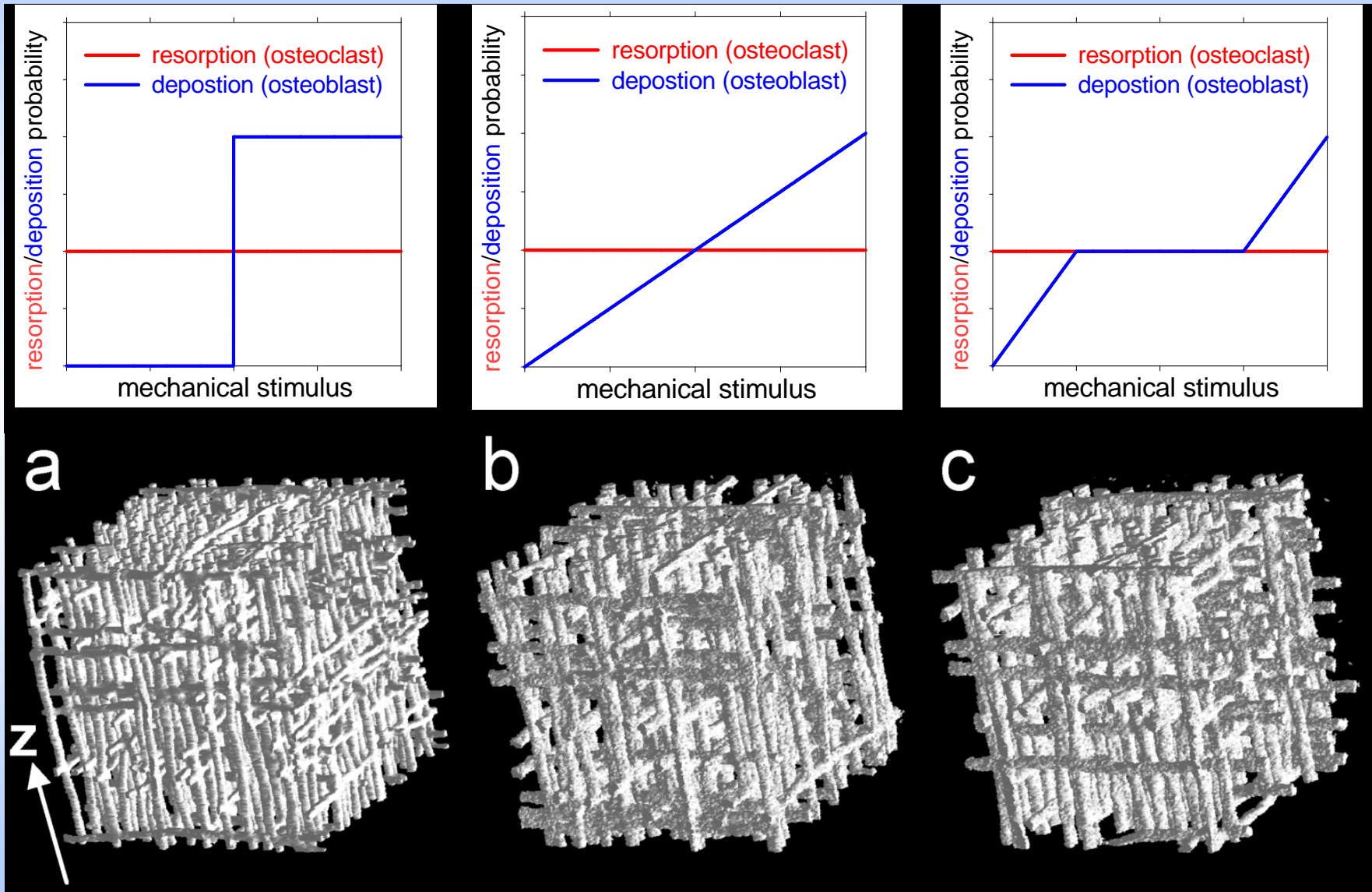
Weinkamer et al., Phys. Rev. Lett. (2004)  
Mater. Res. Soc. Proc. (2005)

Department of Biomaterials





# 5.7 bone remodeling - experiments

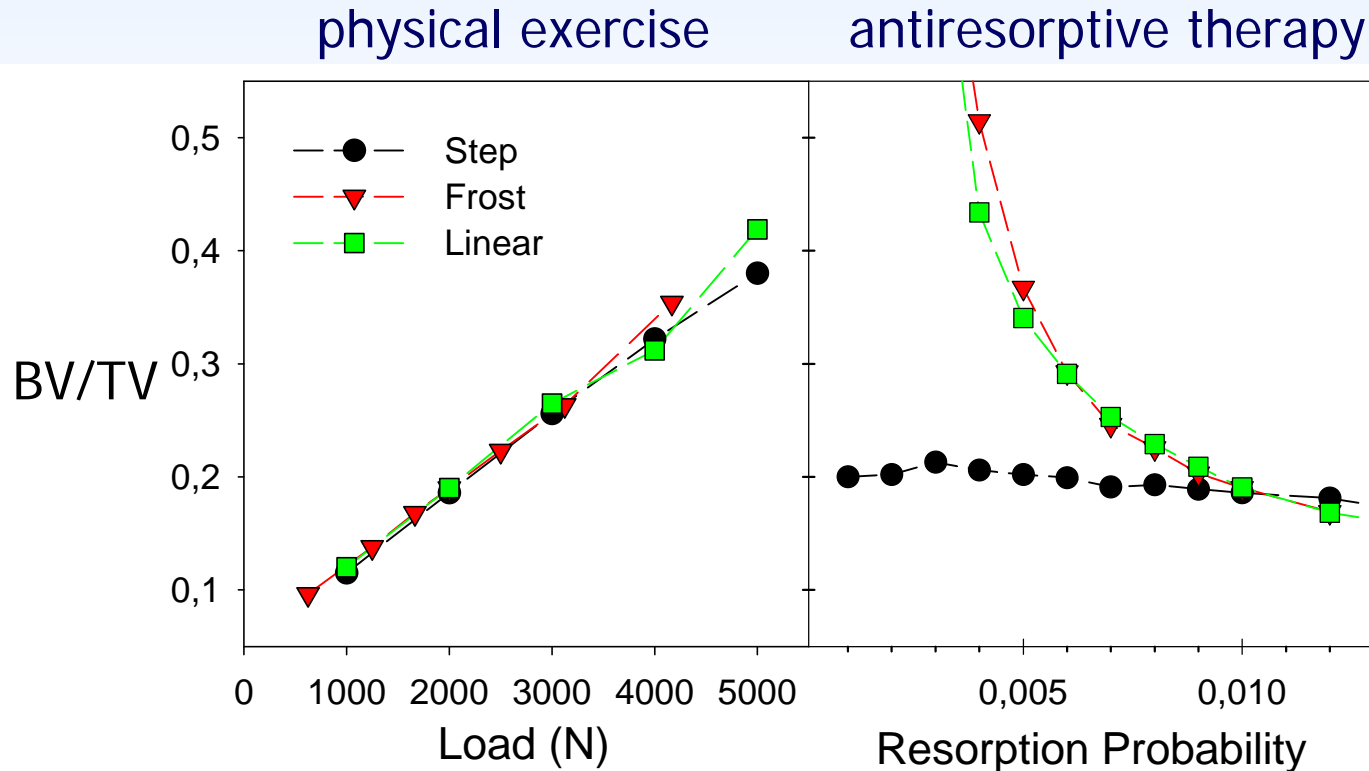




## 5.7 bone remodeling - experiments

### QUESTION:

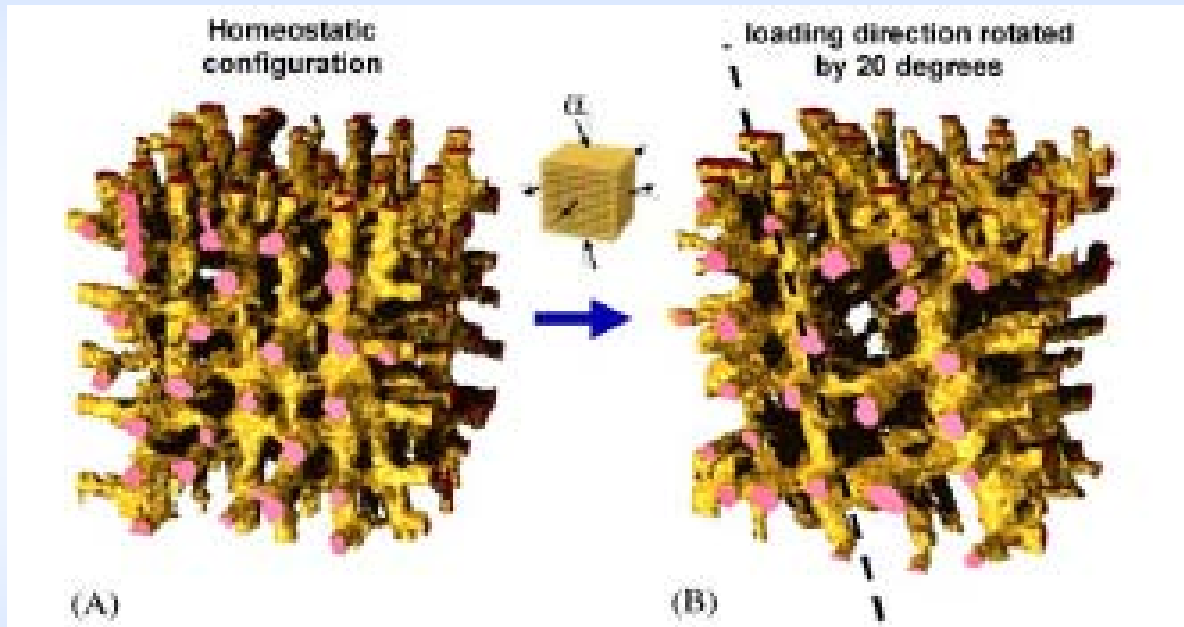
what is the effect of different therapies on the virtual bone with different remodeling rules?





## 5.7 bone remodeling - experiments

adaptation to alternative loading directions:  
(bone modeling)



Ruimerman et al., J Biomechanics 38 (2005)

reorientation of the trabecular structure  
after 12 simulated years still not completed !



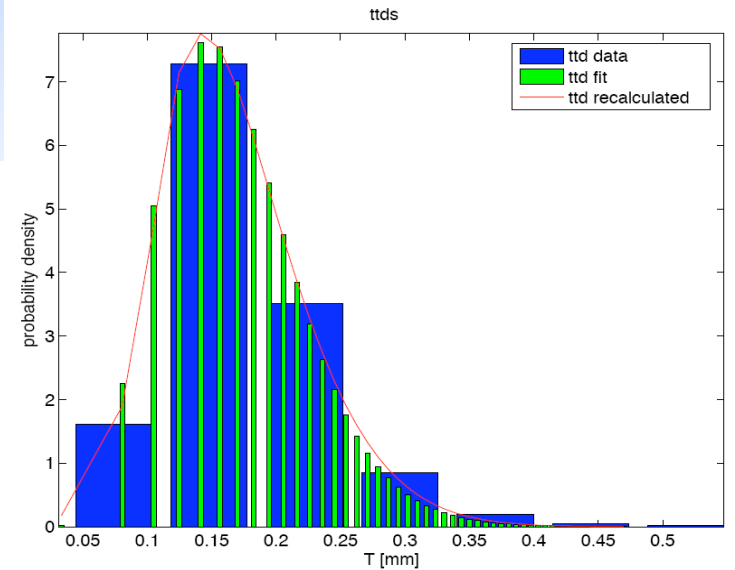
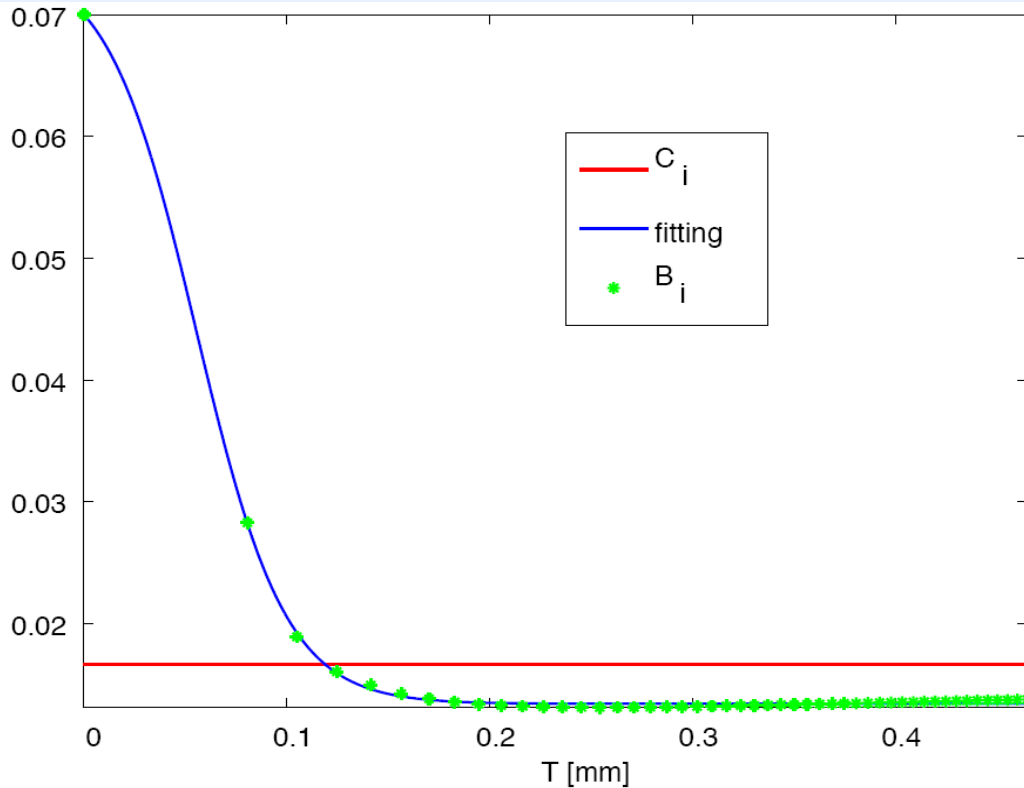


# 5.8 Markov model for bone remodeling

remodeling rules:

$$s(T) = a + \frac{b}{1 + e^{-\frac{T-c}{d}}}$$

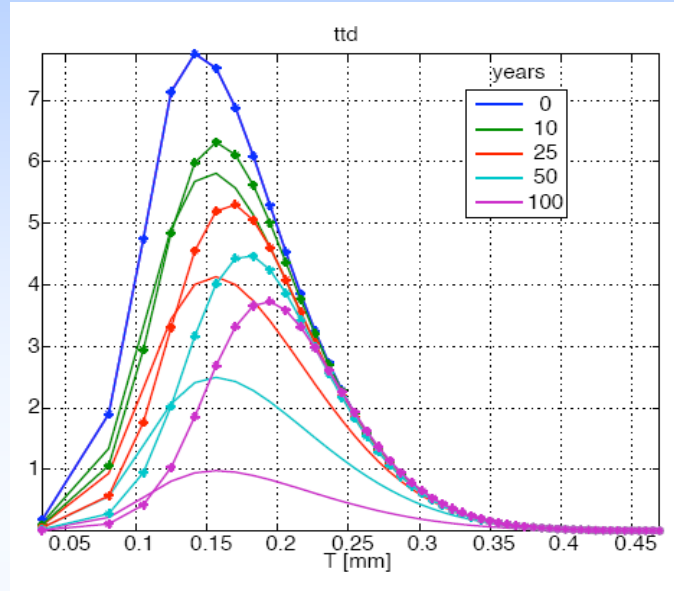
$$F(X) = aX^b \exp(-cX)$$





## 5.8 Markov model for bone remodeling

time evolution:



comparison between two different life styles:

- lazy (loading reduced with age)
- active (constant loading with age)

