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# Cellular scale mechanical model of the stratum corneum

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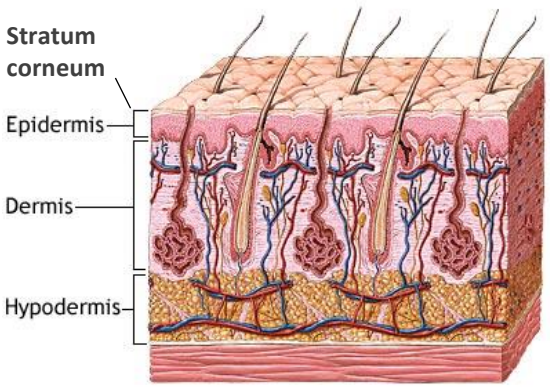
# The human skin



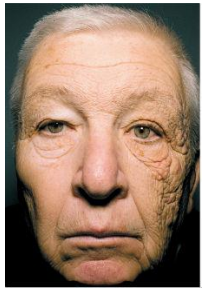

The skin acts as a protective barrier against environmental factors such as

- ❑ Physicochemical penetration of exogenous compounds
- ❑ Microbial invasion
- ❑ Mechanical insults

Skin biomechanics is affected by several factors, such as

- ❑ Ethnicity

- ❑ Aging

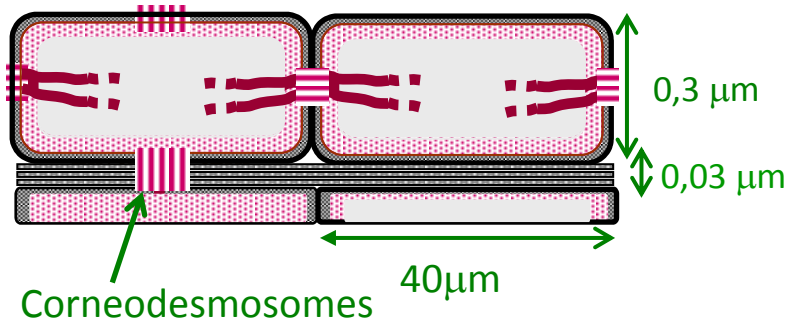


- ❑ Environmental factors (sun exposure)

cosmetics

***The evaluation and modulation of the skin biomechanics is a key issue in skin care products***

# The human stratum corneum

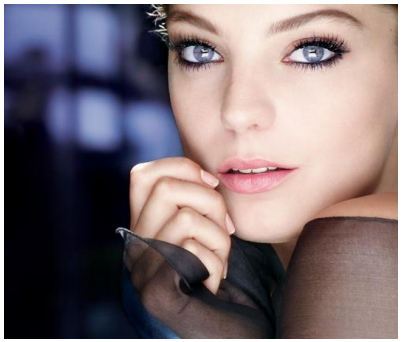



Along with the dermis, the stratum corneum (SC) plays a key role in the skin biomechanics

- ❑ Uppermost layer, 10-20 µm-thick
- ❑ Stiffest layer, E ≈ 1-100 MPa depending on RH (in vitro)

Cosmetic actives targeting the stratum corneum (SC) aim at improving

- ❑ Touch (ex. moisturizers)



- ❑ Fine lines (ex. tensile polymers)

***Better understanding the role of SC components: a prior issue in the design of new cosmetic ingredients***

# Combination of multi-scale experiments

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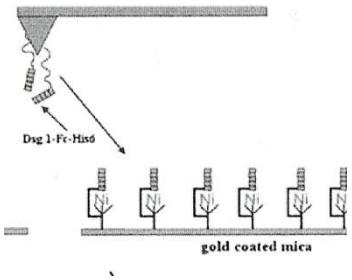
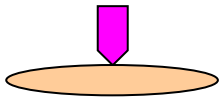
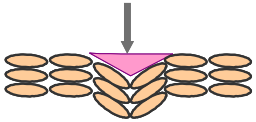
## MECHANICS



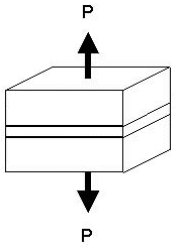

AFM on cadherins



nanoindentation upon cells



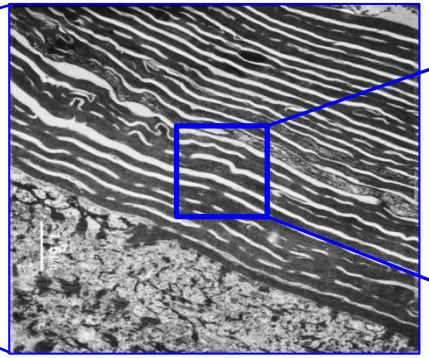
Nanoindentation on the stratum corneum




transverse traction

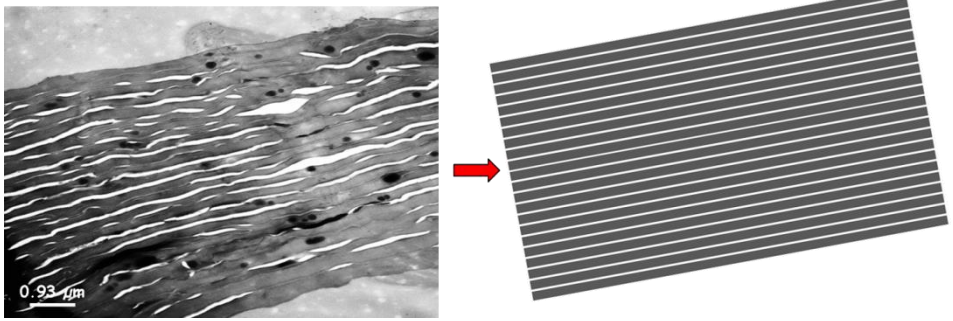
longitudinal traction

## MORPHOLOGY


To increase coherence, same sample lots were used

# Cells-to-tissue : a multi-scale model



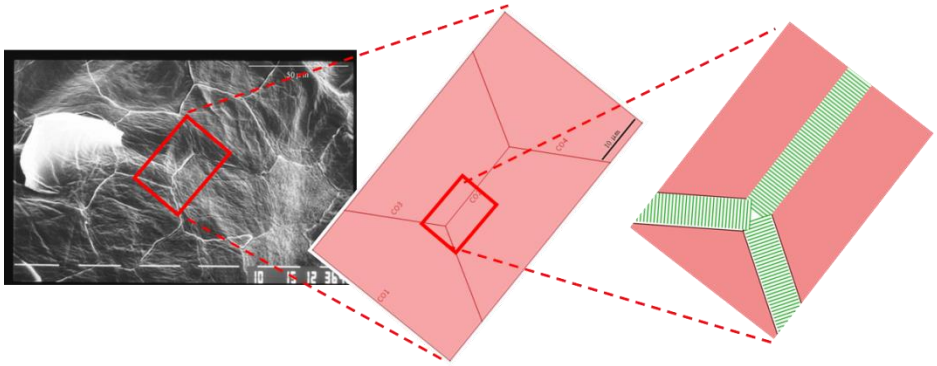

**Tissue-scale multi-layered model**

- ❑ 22 cellular and 21 lipid layers
- ❑ Cellular layers are mechanically obtained from cellular model

Numerical homogeneization of the cellular layers

**Cellular scale model**

- ❑ Brick-mortar model: corneocytes, intercellular lipids and corneodesmosomes
- ❑ Intercellular cement (lipids + corneodesmosomes) represented as an oriented fiber-reinforced material
- ❑ Elementary representative volume + periodic boundary conditions



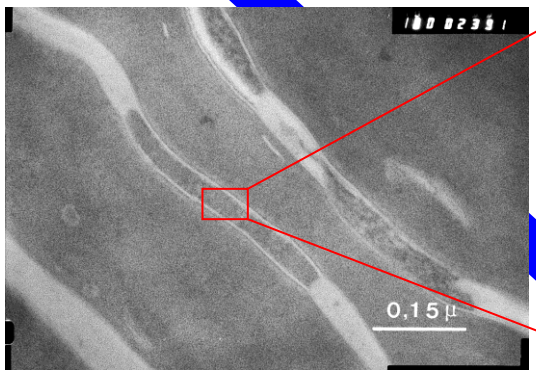
The properties of the tissue are entirely expressed in terms of cellular-scale constituents

# Validation of the model

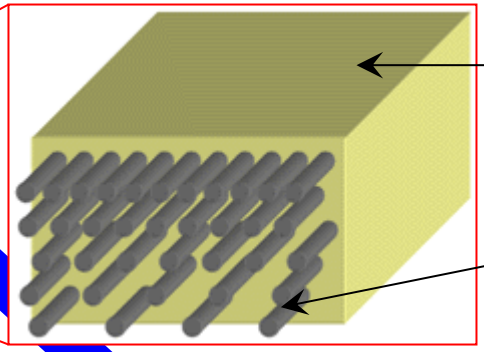
## *Calculation of the cadherin mechanical properties*

Traction (tissue) + nanoindentation (cell) data
SC cadherin mechanics unknown

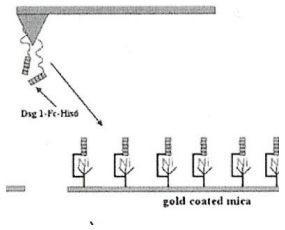
model




Fiber-reinforced intercellular material




Parameter numerical optimization



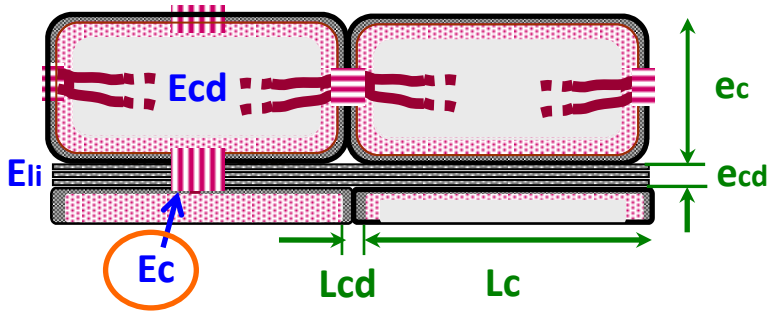

AFM on epithelial cadherins

1 pN/nm (de Roure et al., 2006)
8 pN/nm (Waschke et al., 2007)

$$k_{cad} \approx E_{cad} \frac{\pi d^2}{4L} \approx 1\text{–}10\ pN/nm$$

# Impact from the main constituents

## *Sensitivity analysis*




| | $E_{\parallel}$ (MPa) | $E_{\perp}$ (MPa) |
|---|---|---|
| $E_c \rightarrow E_c - 10\%$ | 50 → 49.7 (-0.5%) | 5.45 → 5.38 (-1%) |
| $E_{cd} \rightarrow E_{cd} - 10\%$ | 50 → 46.0 (-8%) | 5.45 → 5.07 (-7%) |
| $E_{li} \rightarrow E_{li} - 10\%$ | 50 → 48.5 (-3%) | 5.45 → 5.34 (-2%) |
| $L_{cd}/L_c \rightarrow L_{cd}/L_c$ - 10% | 50 → 53.5 (+7%) | 5.45 → 5.45 ($<10^{-3}$%) |
| $e_{cd}/e_c \rightarrow e_{cd}/e_c - 10\%$ | 50 → 50.5 (+1%) | 5.45 → 5.94 (+9%) |

Corneodesmosomes “hydration”: seems a very effective way to decrease SC stiffness

Consistent with the higher “plasticizing” effect of urea-based moisturizers as compared to glycerol-based ones.

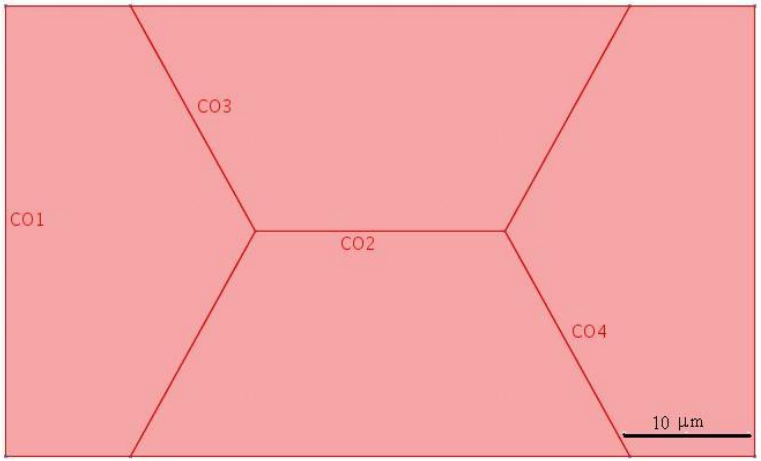
# Conclusions and perspectives

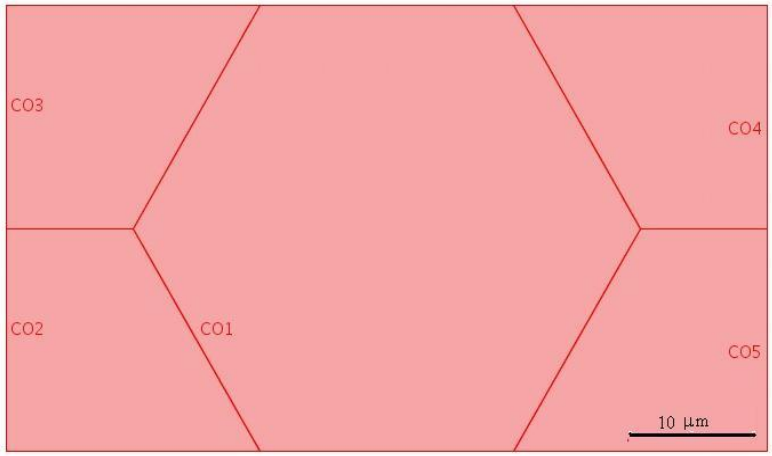
- The first biomechanical model of the stratum corneum at the cellular scale has been developed
- It allows to predict the impact upon the tissue scale mechanical properties of the modifications of the stratum corneum constituents, namely corneocytes, corneodesmosomes and intercellular lipids
- The correct order of magnitude of the cadherins elastic spring constant can be predicted
- The most effective way to decrease the stratum corneum stiffness : to act on the corneodesmosomes

- AFM pull-up or delamination experiments on human stratum corneum could be performed to improve our knowledge about the corneodesmosomes/cadherins
- More realistic material behavior laws (hyperelastic, viscoelastic) could be employed to better simulate static and dynamic mechanical behavior
- More basic constituents could be added to the model (cell's membranes, sugars, …)

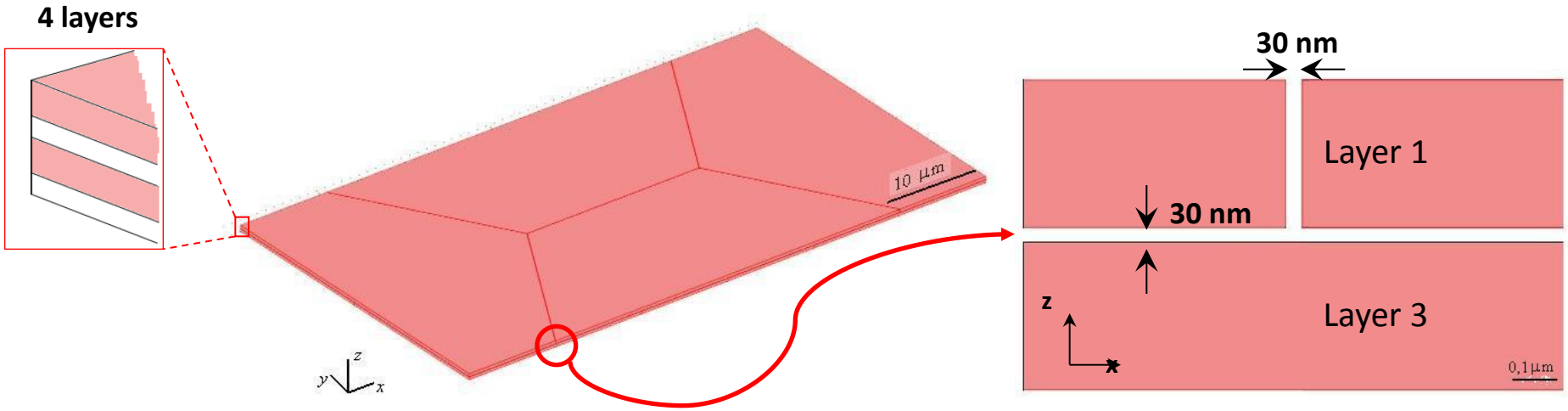
# Back-up

# Model Elementary Representative Volume

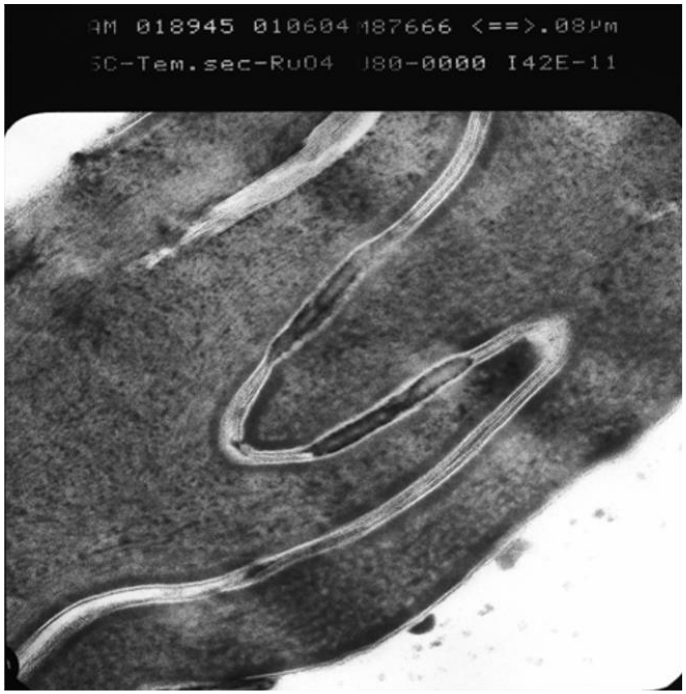



Cellular layers 1 and 3 are not piled up



# Interdigitation modeling



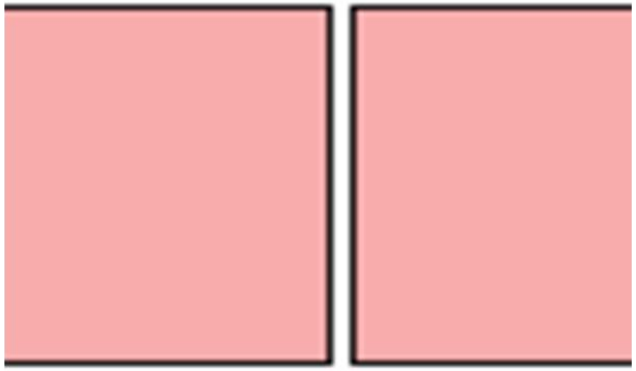

Realistic geometry

Contact length $L \sim 3$ µm

Cell thickness $e \sim 0.3$ µm

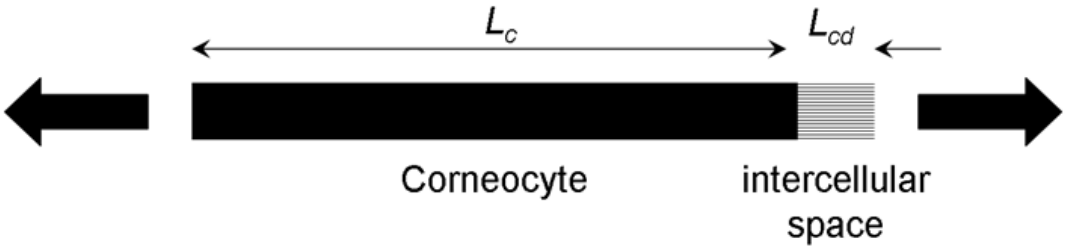
Interdigitation $L / e \sim 10$

Real Young's modulus $E$



Simulated Young's modulus $L / e \times E$

# Lumped model of the SC




$$\frac{1}{E_{\parallel}} = \frac{L_{cd}}{L_{cd}+L_c}\frac{1}{E_{cd}} + \frac{L_c}{L_{cd}+L_c}\frac{1}{E_c}$$

$$\frac{\Delta E_{\parallel}/E_{\parallel}}{\Delta E_{sc}/E_{sc}} \cong \frac{E_{sc}}{E_{\parallel}}\frac{\partial E_{\parallel}}{\partial E_{sc}} = \frac{L_{sc}\,E_c}{L_{sc}\,E_c + L_c\,E_{sc}} \approx 1$$

$$\frac{\Delta E_{\parallel}/E_{\parallel}}{\Delta E_c/E_c} \cong \frac{E_c}{E_{\parallel}}\frac{\partial E_{\parallel}}{\partial E_c} = \frac{L_c\,E_{sc}}{L_c\,E_{sc} + L_{sc}\,E_c} \approx 0.1$$