Skin, scars, wrinkles, and robots

Characterising the mechanical properties of skin

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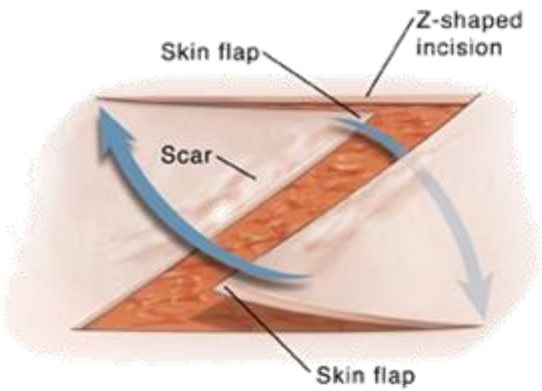
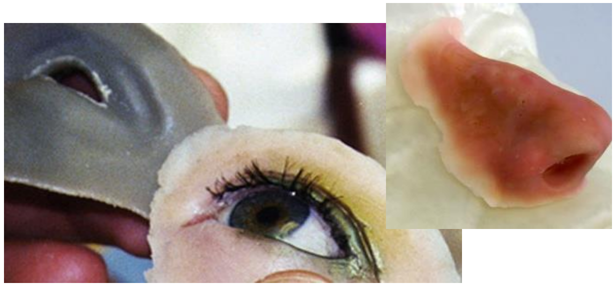
Manukau Institute of Technology 13th June 2016

Why measure the skin properties?

Superior surgical incision methods to reduce scarring



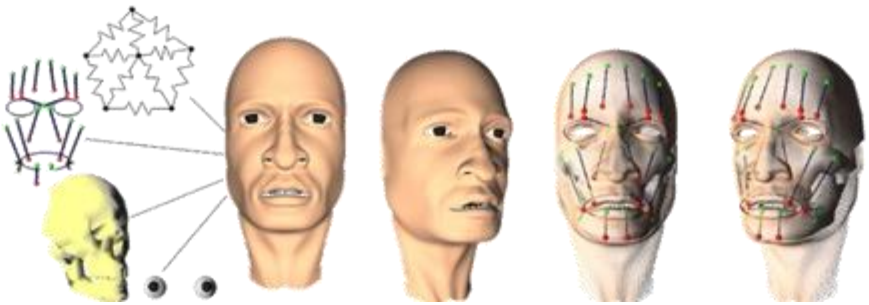
Improved prosthesis design



www.cartis.org

Why measure the skin properties?

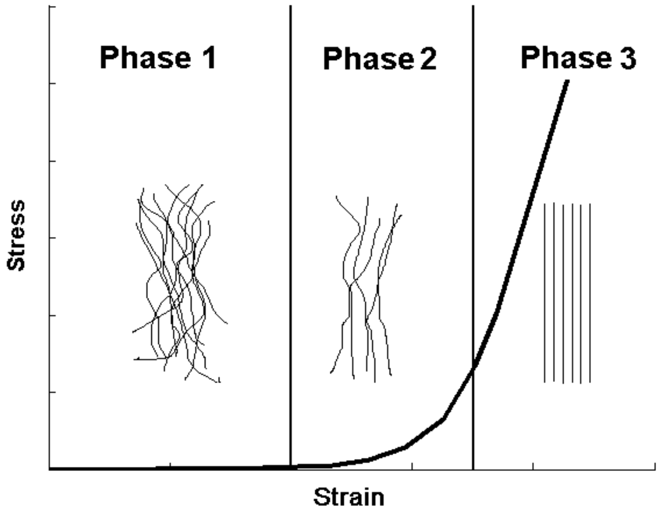
Physically-based animation



Zhang et al (2006)

Personal care product development

Mechanical Properties of Skin



Non-linear stress-strain response

Direction and time-dependent

In vivo tension

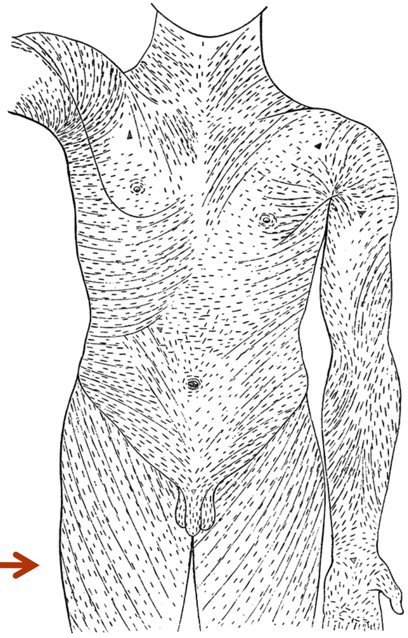
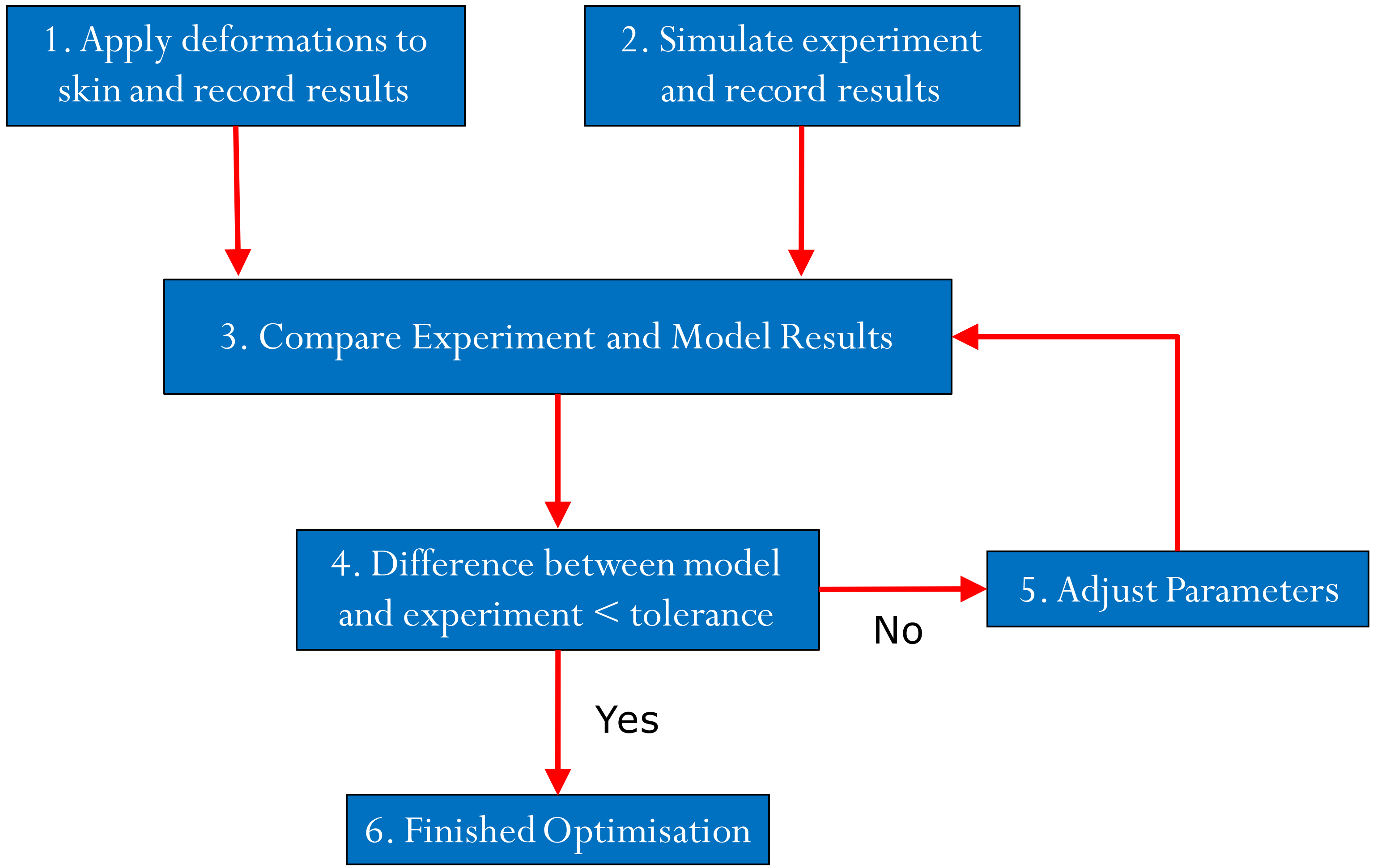


Fig. 838.

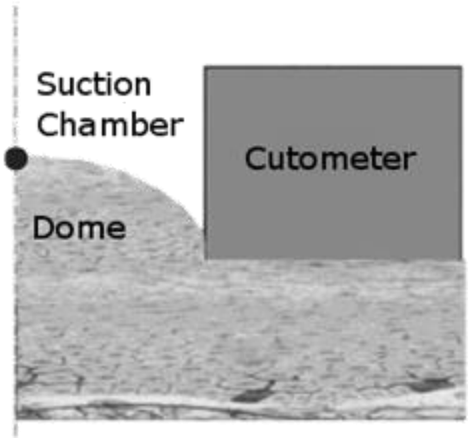
Die Spaltrichtungen der Haut. (C. Langer.)

How Do We Characterise Skin?



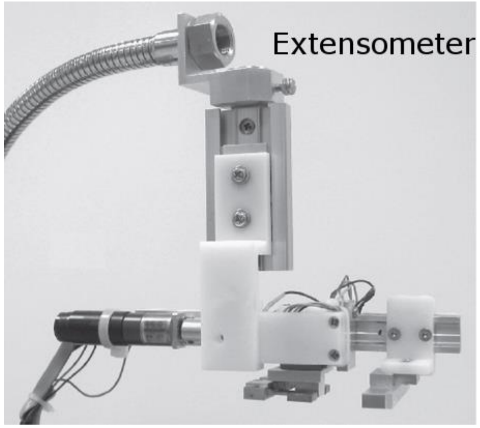
Previous Experimental Protocols

Suction



Delalleau *et al*, 2008

Biaxial tension



Lim *et al*, 2008

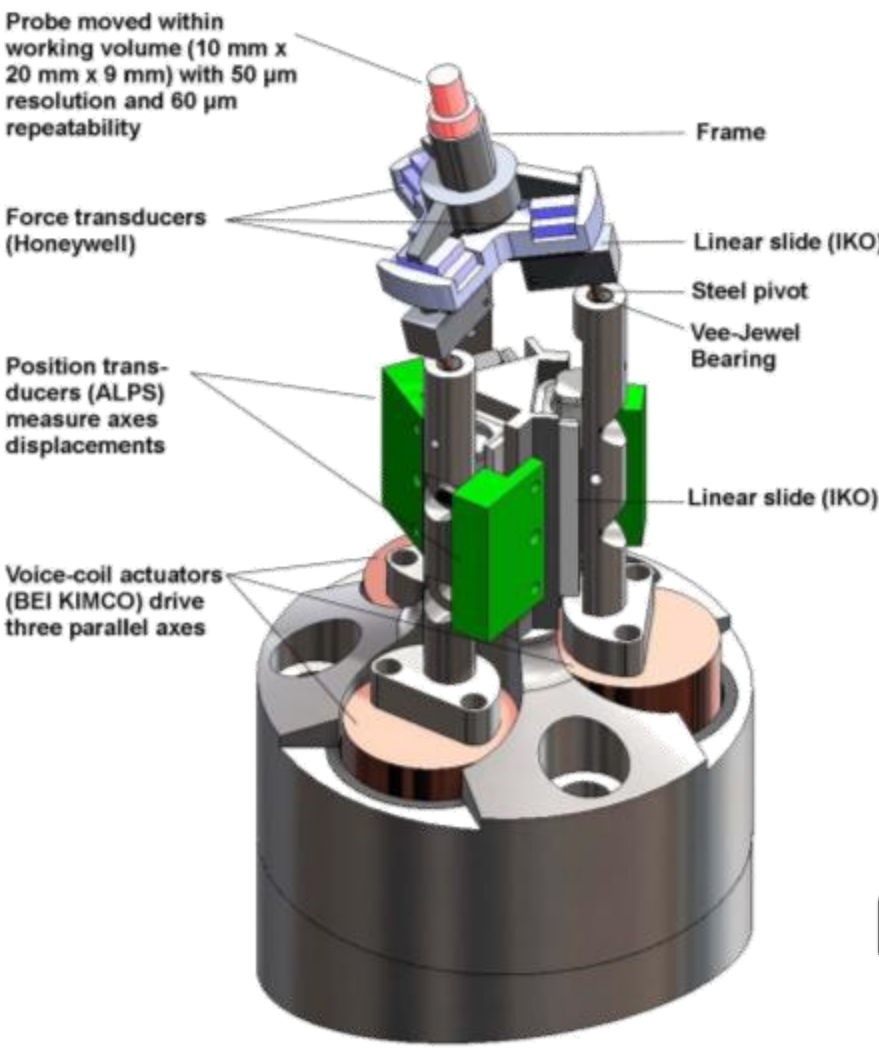
Indentation

Pailler-Matai *et al*, 2008

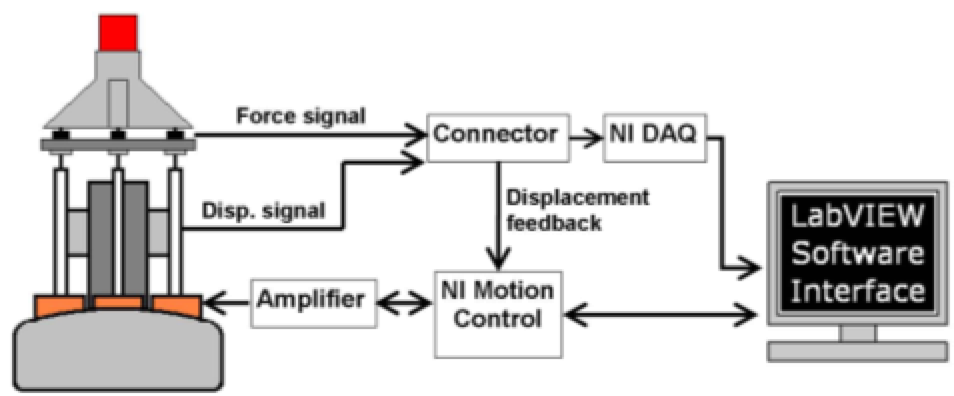
Drawbacks of Previous Protocols

- Some methods cannot characterise anisotropy
  - Suction, torsion, normal indentation
  - Axi-symmetrical loading
- Extensometry methods
  - Only in-plane loading in one or two directions
- Complex mechanical properties of skin
  - Need to apply rich set of deformations to skin area

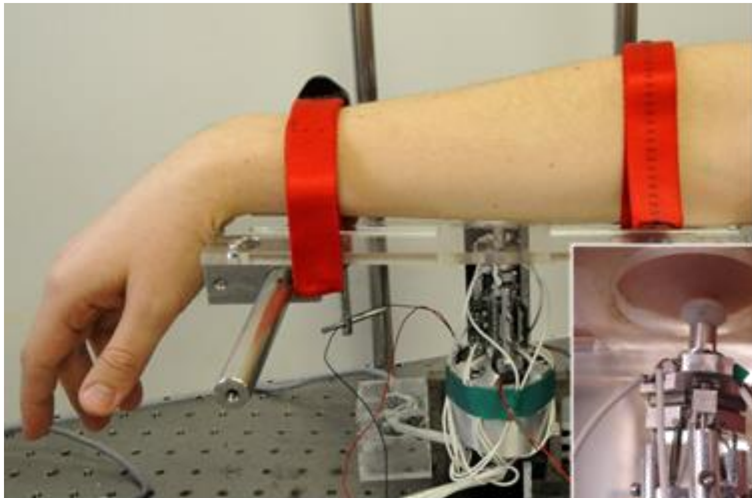
3D Force-Sensitive Micro-robot



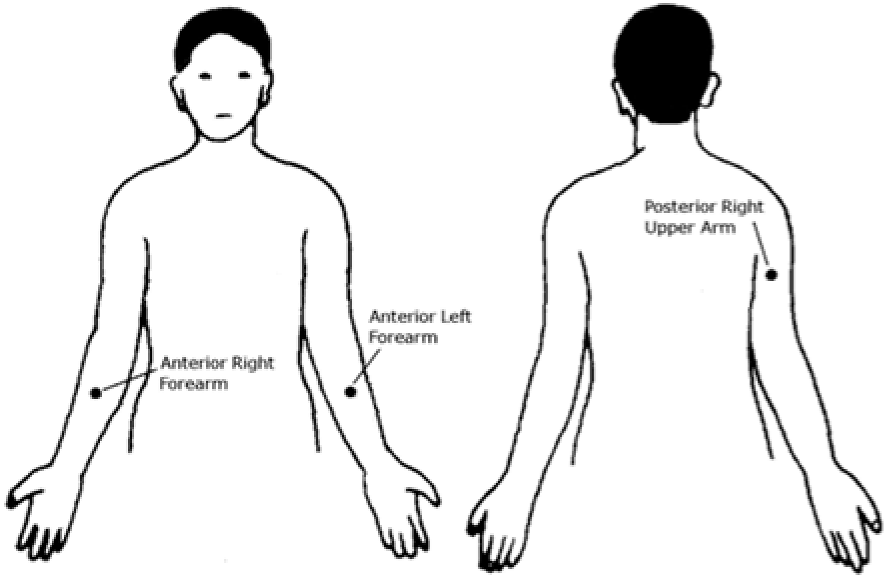
- Rich set of deformations applied to skin surface
- Position of probe tip known
- Force on probe tip known



In Vivo Deformation of Arm Skin

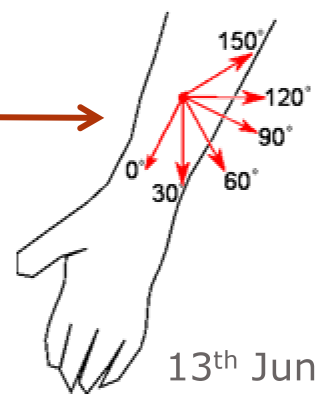


Arm resting on plate above robot with probe attached



Three areas of skin studied

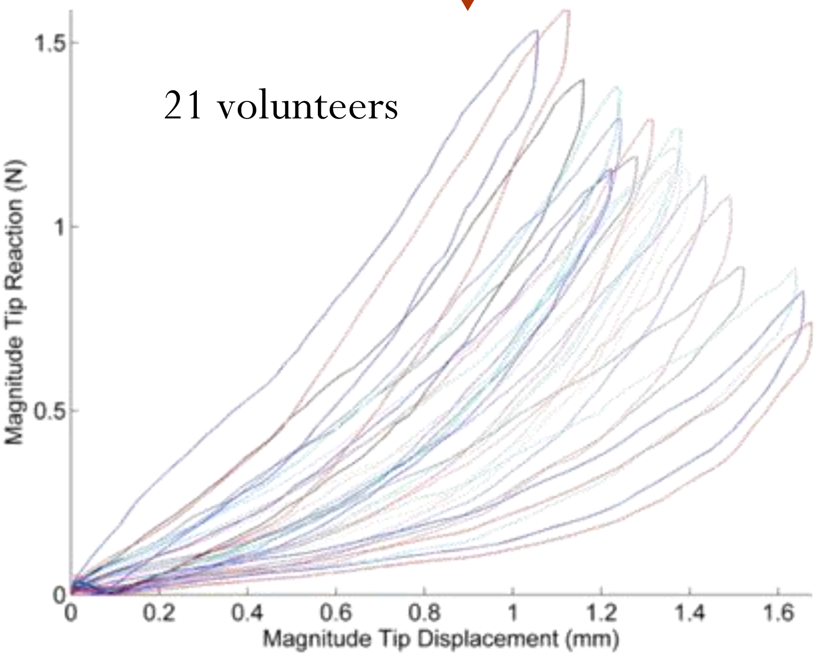
In-plane and out-of-plane deformations applied in many directions



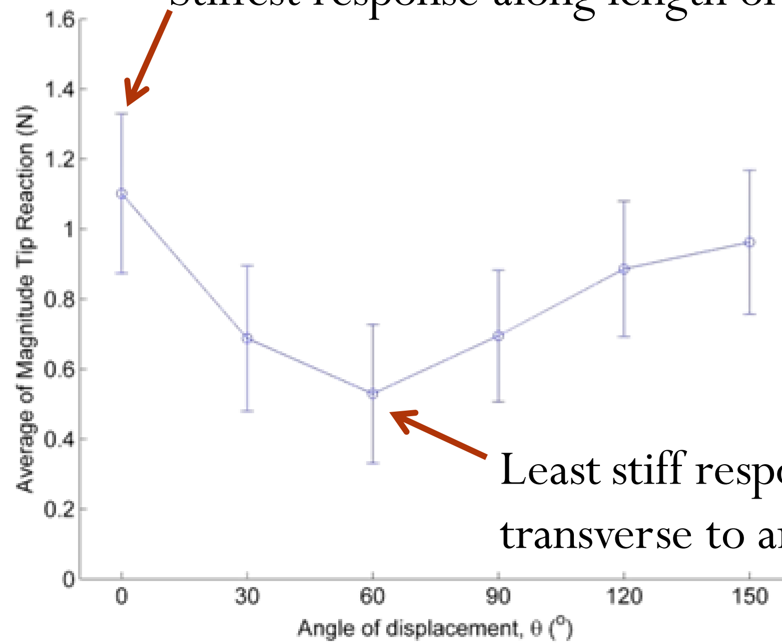
Flynn et al, 2011. Annals of Biomedical Engineering, 39(7), pp. 1935-1946

Forearm Skin Results

Wide inter-volunteer force response



Stiffest response along length of arm



Least stiff response transverse to arm

Direction of stiffest response the same for all volunteers

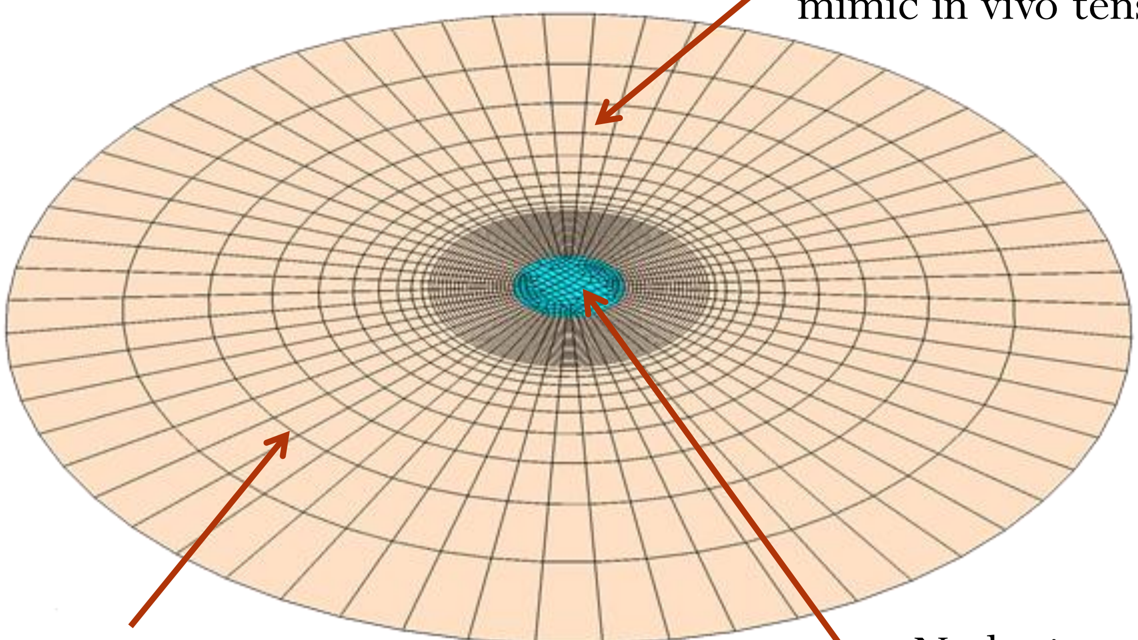
In Vivo Arm Experiment Conclusions

- Skin is anisotropic and viscoelastic
  - Device must be capable of measuring these characteristics
- Experimental method is repeatable
- Wide inter-volunteer variation
  - Age, build, gender, lifestyle
- Similar qualitative characteristics
  - Forearm stiffer than upper arm
  - Anisotropic characteristics

Simulating the Experiment

ABAQUS Finite Element Model

Pre-stress applied to model to mimic in vivo tension

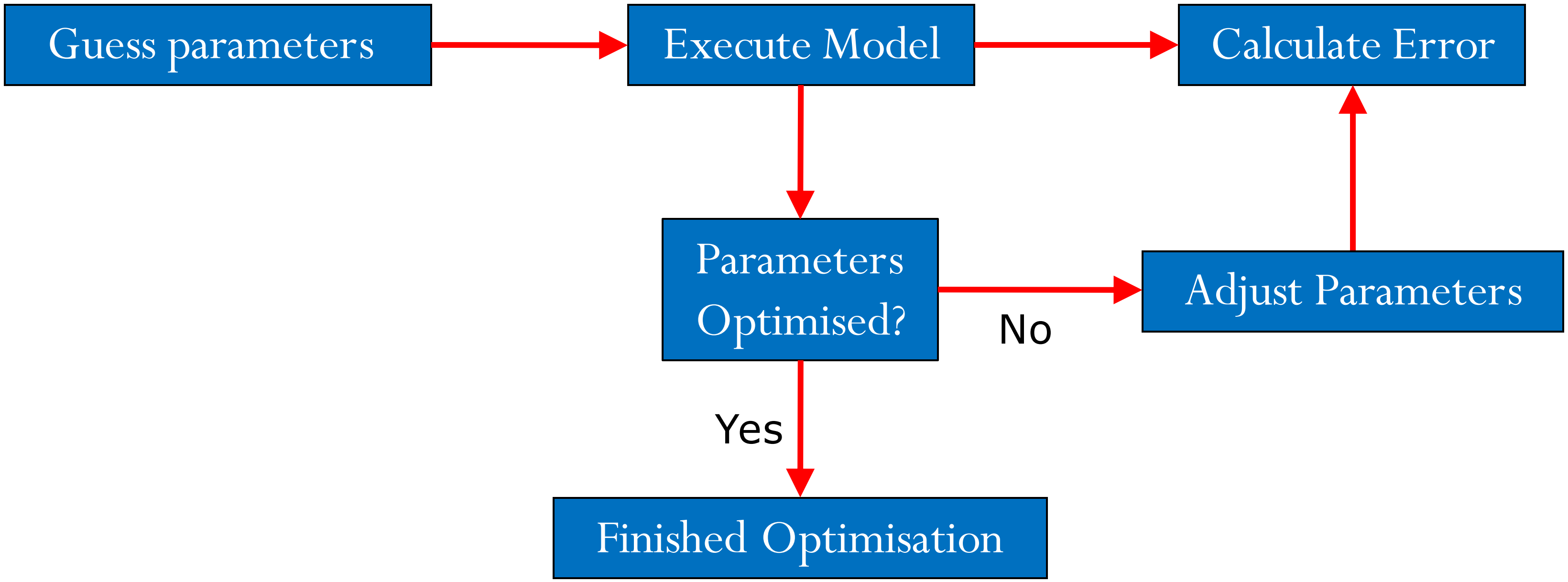


Skin represented by Tong and Fung model and quasi-linear viscoelasticity

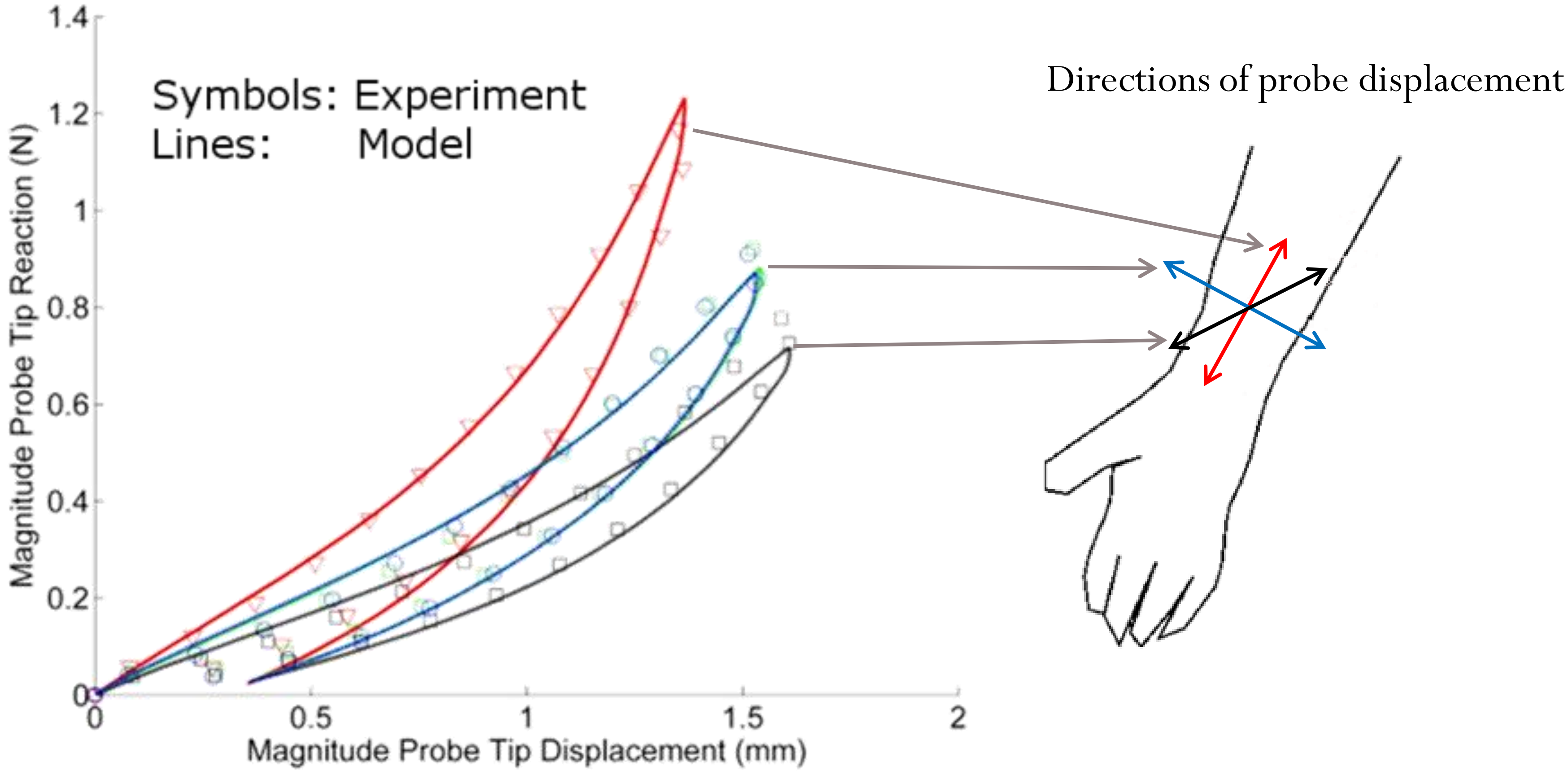
Nodes in region displaced as per probe in experiment

Fitting the Model to the Experiments

- Determine material parameters and in vivo tension
- Optimise using Matlab routines
  - Levenberg-Marquardt algorithm



Force-Displacement Response of Forearm Skin

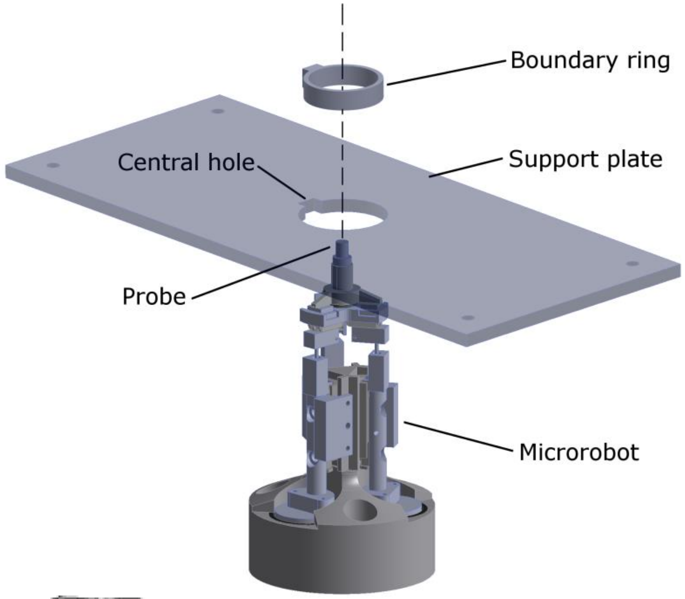


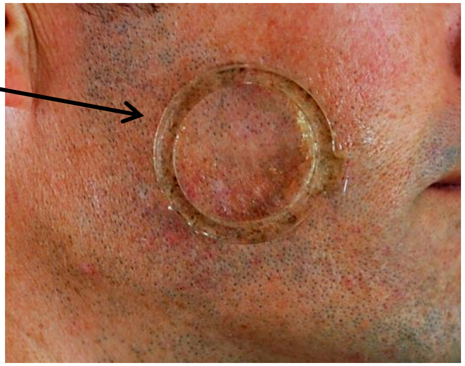
Flynn et al, 2011. Annals of Biomedical Engineering, 39(7), pp. 1935-1946

Modelling Conclusions

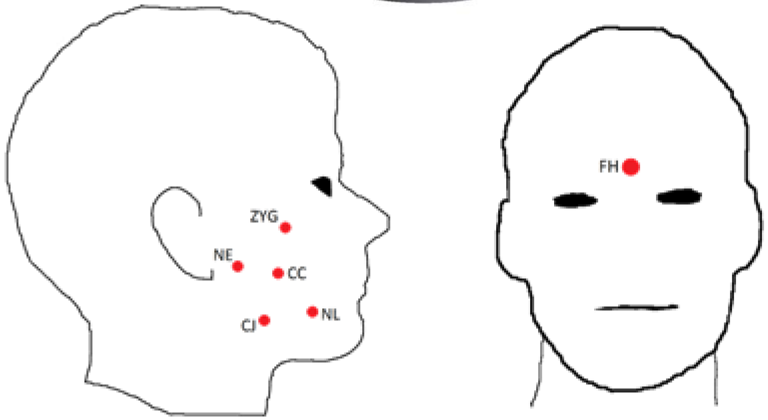
- Volunteer-specific model parameter sets
  - Error ranges from 14% to 22%
- Tong and Fung model with QLV – good results
  - neo-Hookean model – not good
- In vivo tensions range from 15 kPa to 95 kPa
  - Similar to Evans and Holt (2010)
- Need out-of-plane deformations to estimate in vivo tension of skin
- Richer deformation database
  - Improves determinability of model parameters

In Vivo Deformation of Facial Skin

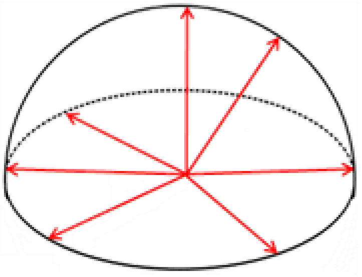




Boundary ring attached to position face relative to robot



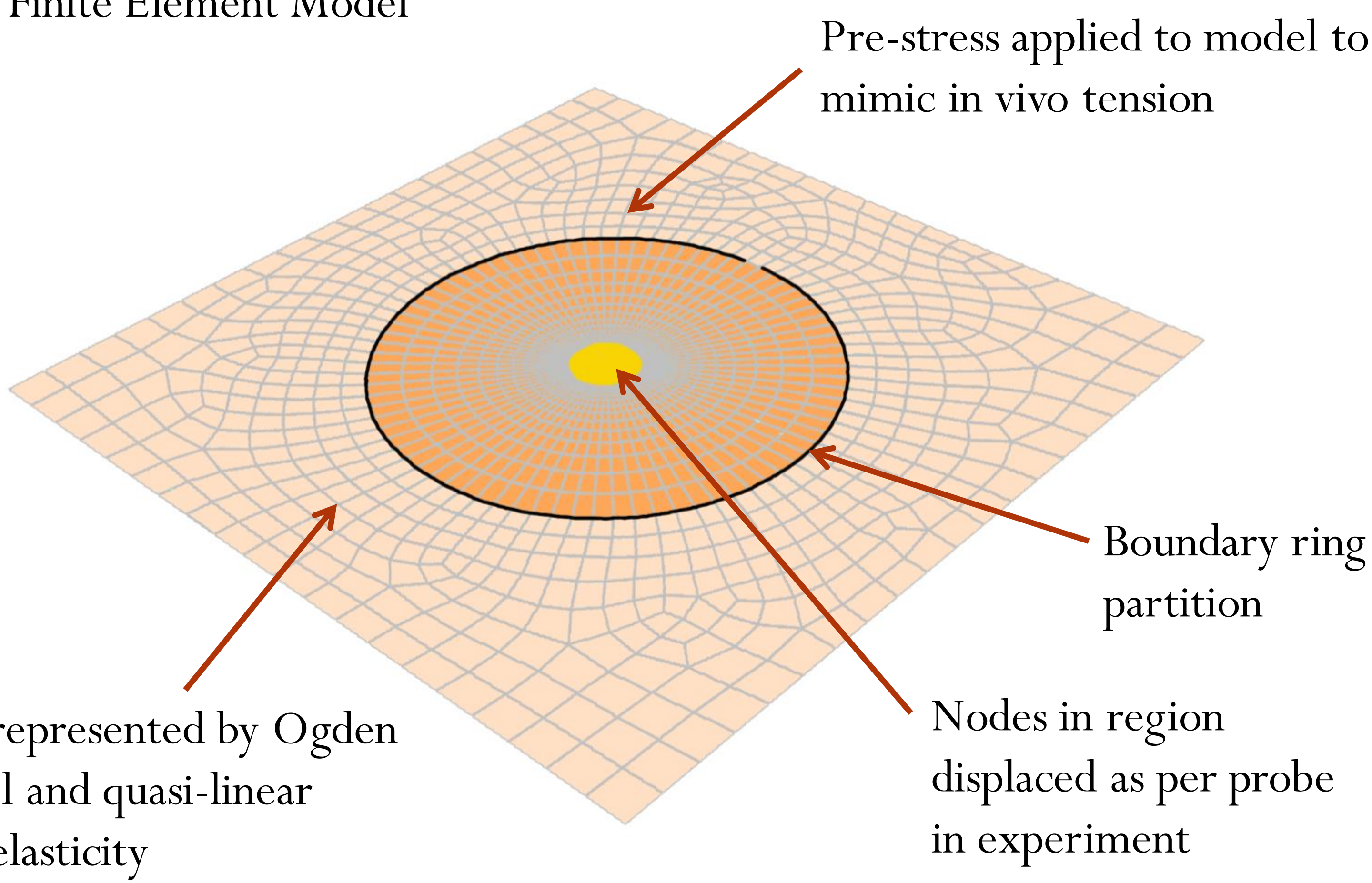
Six points on the face tested



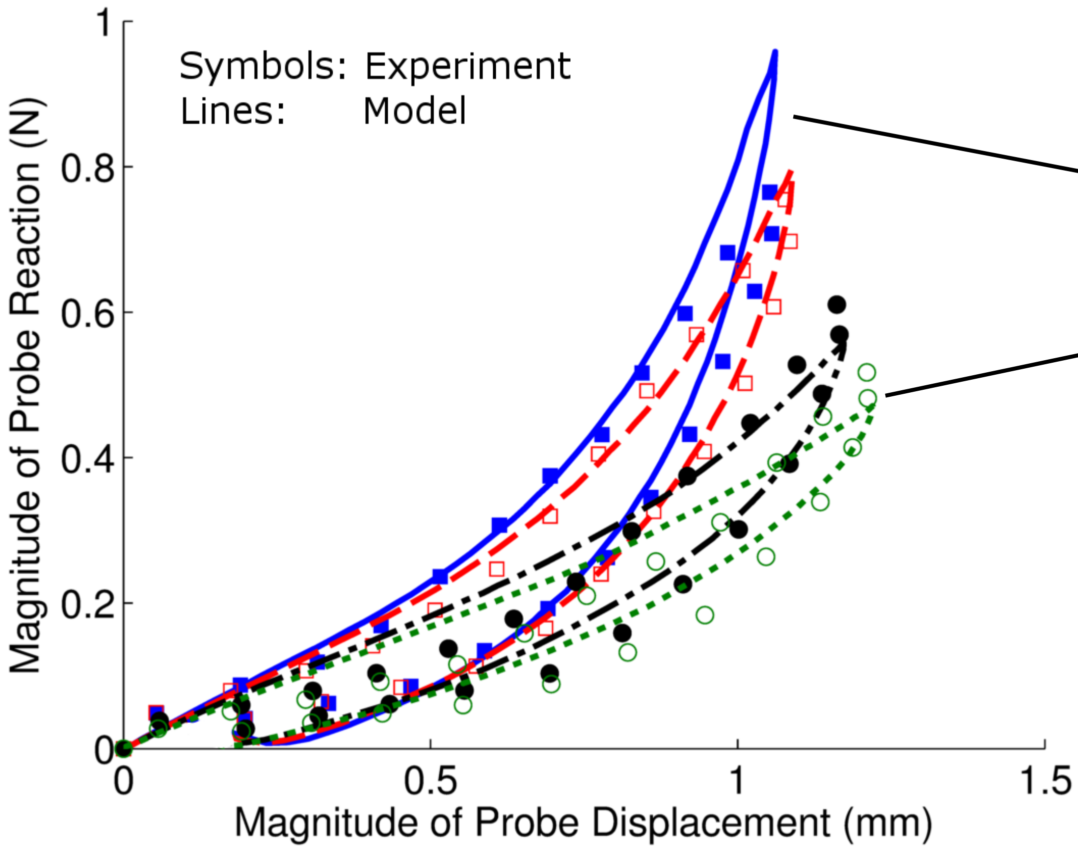
Probe displaced in 16 directions

Simulating the Face Experiments

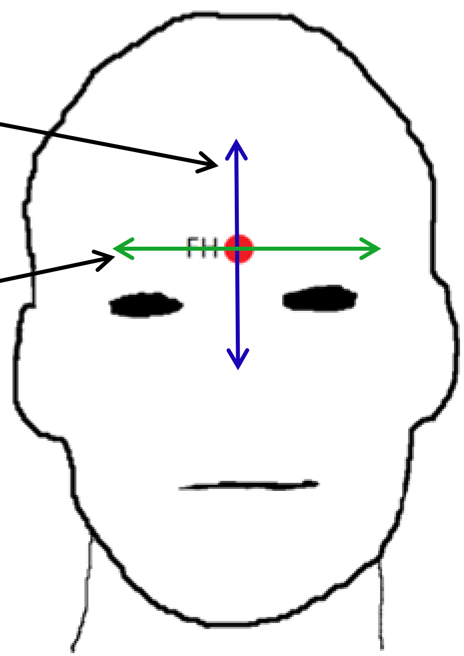
ANSYS Finite Element Model



Force-Displacement Response of Skin in Forehead Region



Directions of probe displacement



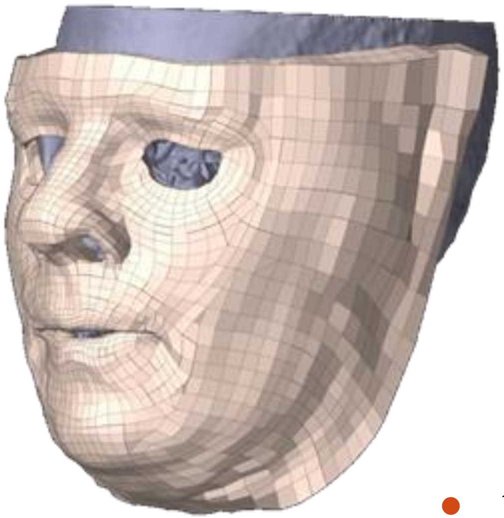
Flynn et al, 2013. Journal of the Mechanical Behavior of Biomedical Materials, 28, pp. 484-494

Facial Skin Experiment Conclusions

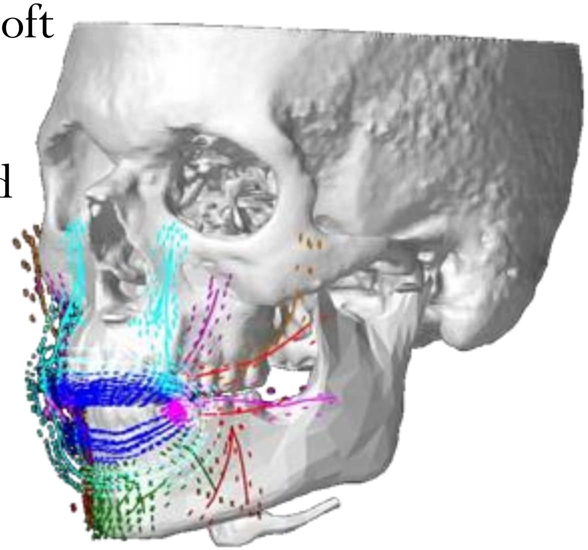
- Five volunteer-specific model parameter sets
  - Wide inter-volunteer variation
- In vivo tensions from 15 kPa to 90 kPa
  - First reporting of facial in vivo tensions
- Error ranges from 12% to 23%
  - Largest error in zygomatic area
- Facial experiments more challenging than arm
  - Uncomfortable!
  - Effect of underlying connections is greater

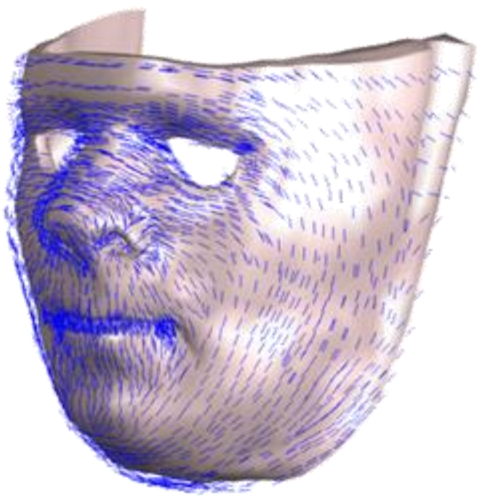
Flynn et al, 2013. Journal of the Mechanical Behavior of Biomedical Materials, 28, pp. 484-494

Applications – Face/Head Model UBC



- CT data of adult male (Bucki et al, 2010)
- Parameters from in vivo experiments input into face model
- Contact modelled between soft tissue and bony structures
- 10 orofacial muscles represented



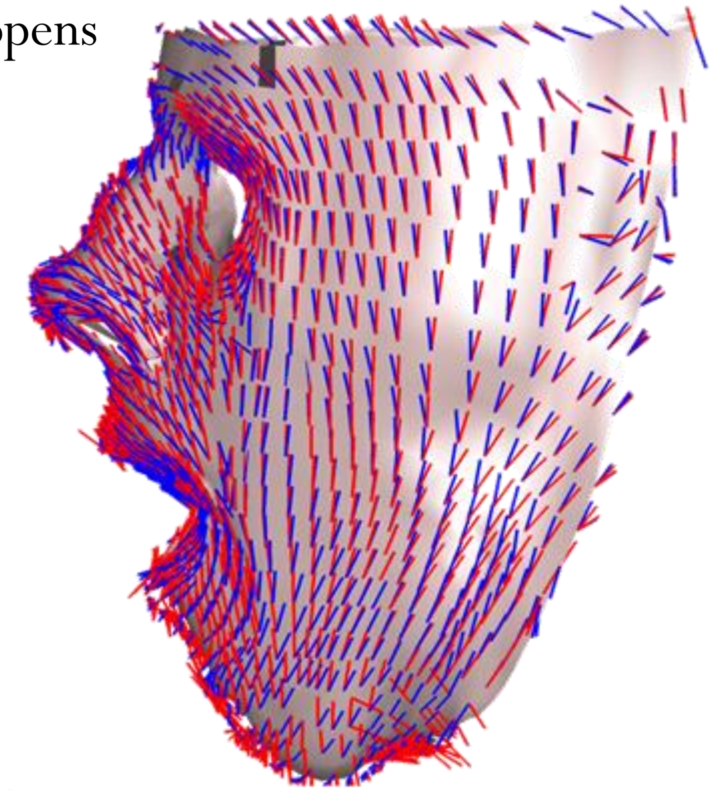


- Relaxed skin tension lines traced onto face model surface

www.Artisynth.org

Analysing the tension field

- Examine change in tension field when mouth opens



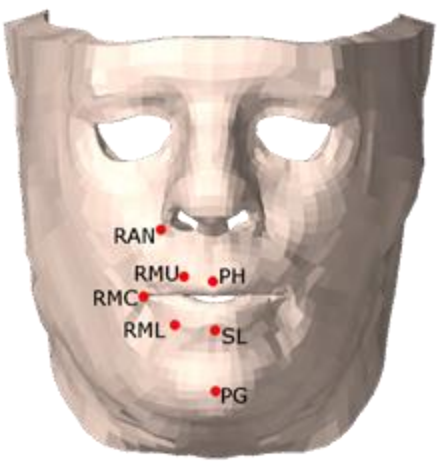
Directions of maximum tension when mouth closed (blue line)

Directions of maximum tension when mouth open (red line)

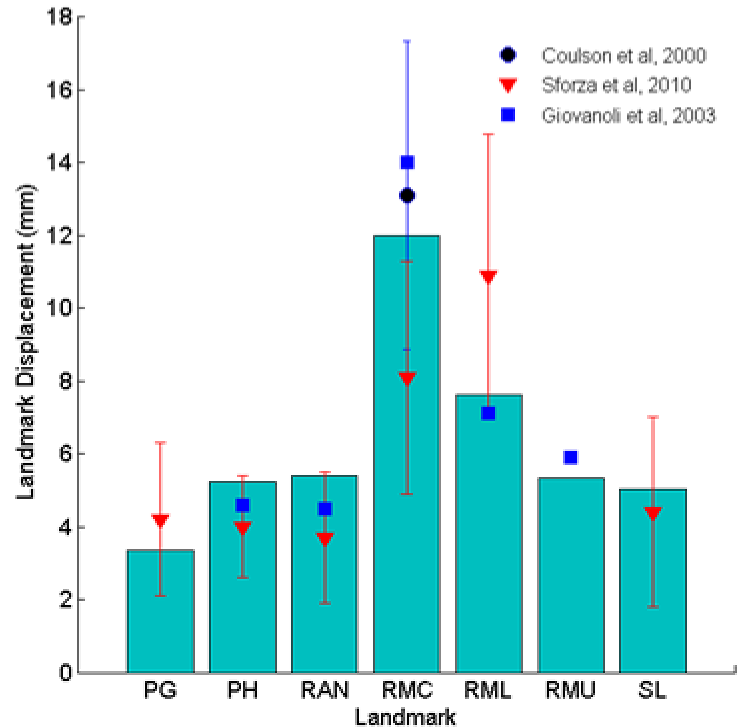
- Compare with experimental measurements (Bush et al, 2007)

Flynn et al, Computer Methods in Biomechanics and Biomedical Engineering (2015)

Modelling Facial Expressions



Facial landmarks



Calculate landmark displacements for expressions and compare to experimental data

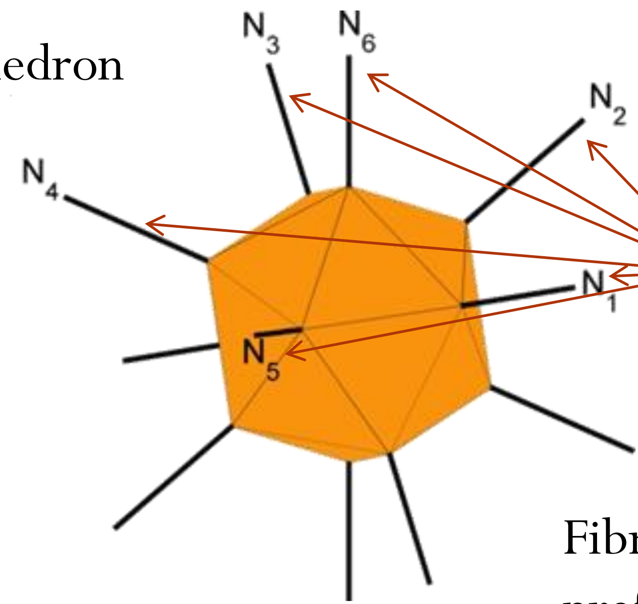
Flynn et al, Computer Methods in Biomechanics and Biomedical Engineering (In Press)

Face/Head Model Conclusions

- First face model to include anisotropy and in vivo tension in the skin layer
- Good comparison with experimental data
- Results dependent on material parameters and in vivo tension for given activations

Constitutive Equations of Skin

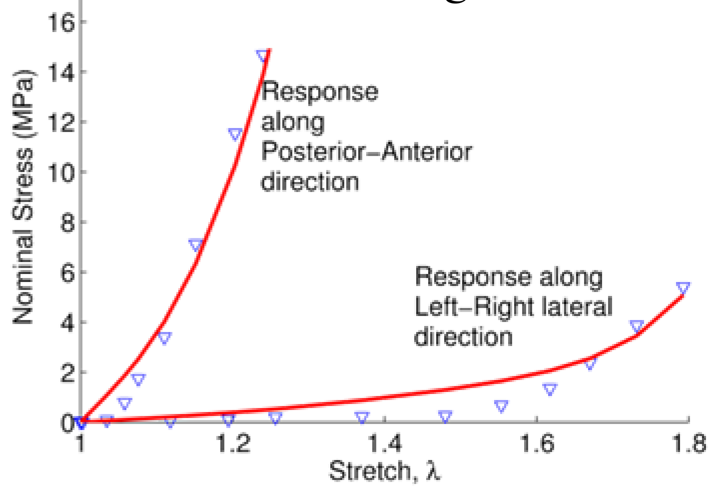
- Models based on six collagen fibre bundles

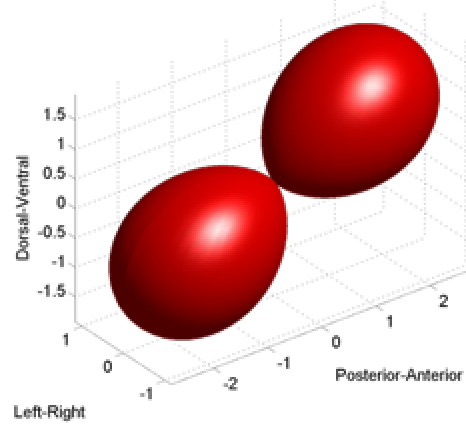


- Simple expressions to describe straightening of collagen fibres when skin is stretched

Constitutive Equations of Skin

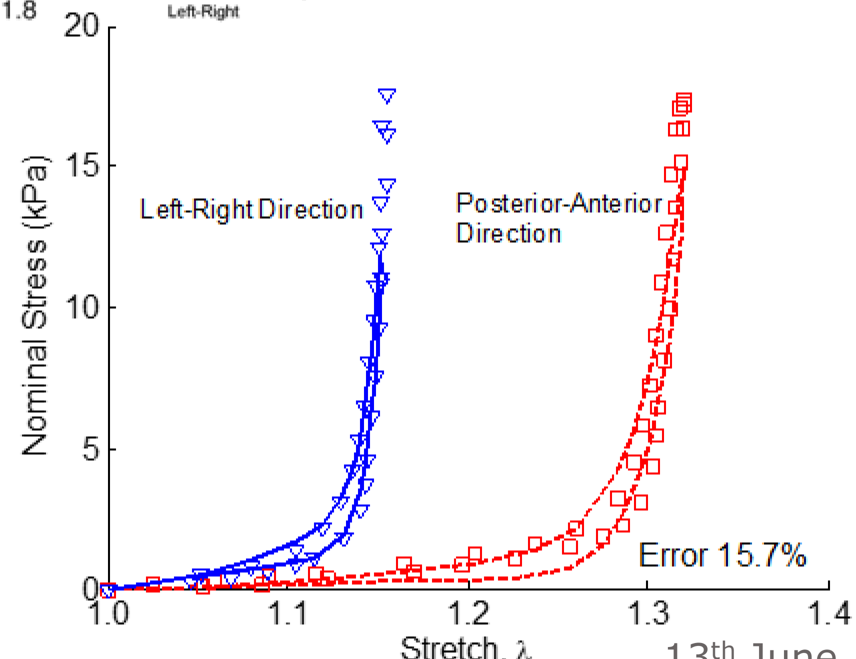
Simulating uniaxial stretching of pig-skin





Predicted Collagen fibre distribution

Simulating biaxial stretching of rabbit-skin including viscoelasticity



Flynn and Rubin, 2014. Mechanics of Materials, 68, pp. 217-22

The Next Step

- Enrich the data set further
  - Surface strain measurement
- Track sub-surface deformations
  - Ultrasound, OCT, or Confocal Microscopy
- Use physically-based constitutive models
  - Model parameters determined through imaging
- Development of hand-held probe
  - BET project