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Application of FEM to Improve the Accuracy of Skin Viscoelasticity Quantitative Evaluation Techniques

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Introduction

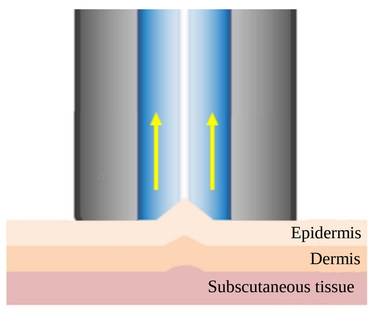
Aging and diseases such as diabetes and pressure ulcers change the material properties of the skin. In addition, they occur throughout the body. In clinical practice, skin diagnosis is often performed based on the physician's experience with palpation. If the physician's senses could be quantified, it would be easier to monitor the progress of the treatment and manage the risk of disease outbreaks.

Therefore, it is necessary to quantitatively evaluate the material properties of skin throughout the body.

Cutometer

Problems when using cutometer measures *in vivo*

Skin measurements have *in vivo* limitations.
In vivo skin elasticity meter (cutometer) measures the properties of the entire skin from the epidermal layer to a certain depth on average, and is not able to measure the mechanical properties of each skin layer independently



Cutometer suction method

The purpose of this study

In this study, We aim to independently evaluate the mechanical properties of each layer of the skin using FEM.

FEM on dummy skin

Materials

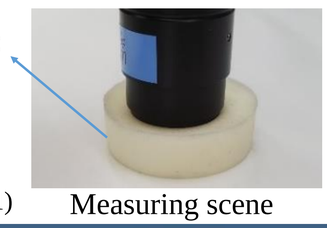
Probe model

Size [mm]	Φ30（boreΦ2）x 12
Young's modulus[MPa]	21000（default）
Poisson's ratio	0.30（default）
Rigidity's ratio [MPa]	8079.2（default）

Human skin gel model (3 types)

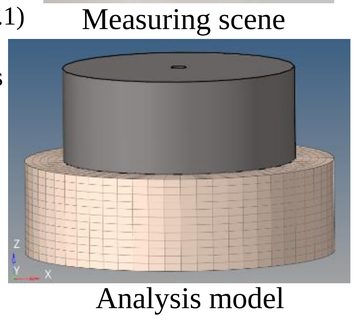
Size[mm]	Φ40 x 12		
Young's modulus[MPa]	0.102※1	0.33※2	0.51※2
Poisson's ratio	0.48	0.48	0.48
Rigidity ratio[MPa]	0.036	0.11	0.17

Human skin gel:
Urethane resin that simulates skin


Measuring scene

※1 Young's modulus (Ref.1)

※2 Compressive modulus (Manufacturer)


Analysis model

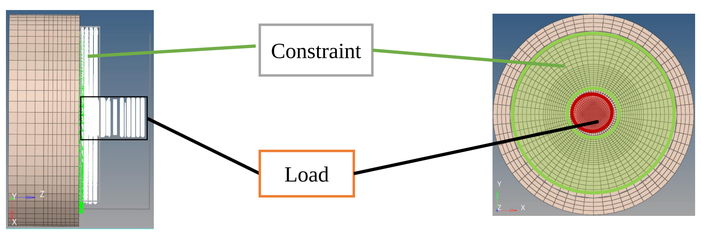
Methods

Analysis conditions

Software	Hypermesh
Version	2021
Maker	Altair
Solver	Optistruct
Unit	N、mm、MPa（N/mm²）
Method	Static
deformation	Large
Number of nodes	gel 29340 / human 80736
Mesh size	0.01~0.5

Boundary conditions

Constraint	Contact with probe	Others
	Z-axis direction	Free
Load	Suction on human skin gel surface inside probe diameter	
Suction pressure	0.02MPa(200mbar)	



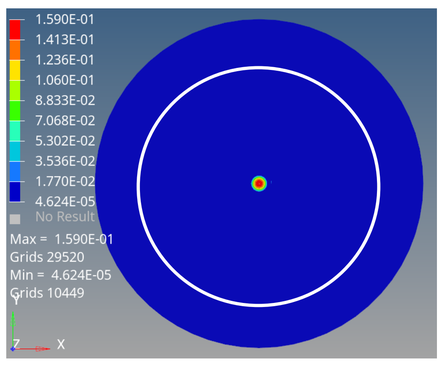
Results

Analysis Results

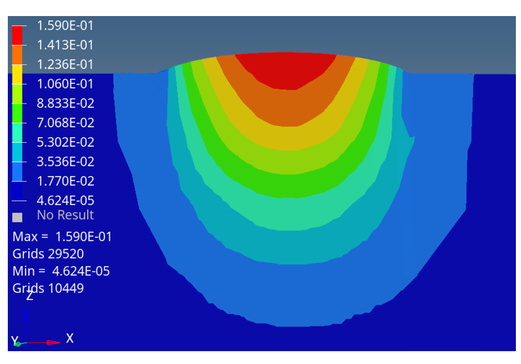
Young's modulus[MPa]	0.102	0.33	0.51
Poisson's ratio	0.48	0.48	0.48
Rigidity ratio[MPa]	0.034	0.11	0.17
Max deformation[mm]	0.159	0.064	0.042

Measured by Cutometer

Probe diameter [mm]	2
Human skin gel hardness	15
Suction presssure[mbar]	200
RO（Max deformation）[mm]	0.159



Deformation of Contours(0.102)



Partial cross-sectional view(0.102)

- For Young's modulus of 0.102mm, the maximum deformation (0.159 mm) is similar to the experimental value

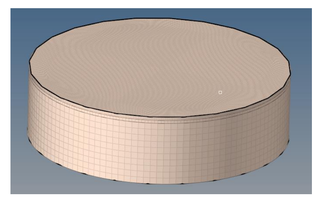
FEM on human skin

Materials

Human Skin Model 1 (with Stratum corneum)

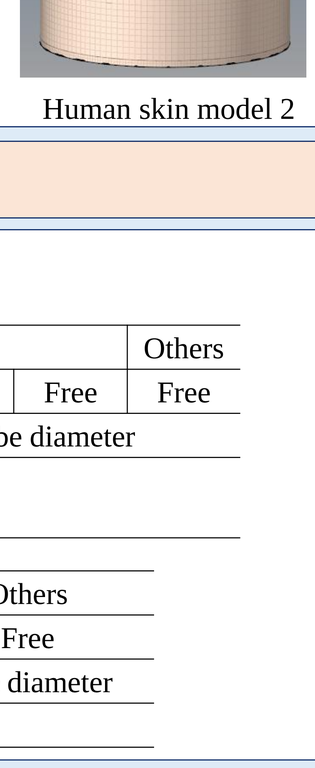
Probe size[mm]: Φ4（boreΦ2）x 2

Size[mm]	Φ4 x 1.1Φ		
Layer	Stratum corneum	Epidermis	Dermis
Thickness [mm]	0.025	0.075	1
Young's modulus[MPa]	2.02	0.136	0.074
Poisson's ratio	0.48	0.48	0.48
Rigidity ratio[MPa]	1.04	0.045	0.138


Human skin model 1

Human Skin Model 2 (with Subscutaneous)

t	Φ4 x 4.1		
Layer	Epidermis	Dermis	Subscutaneous
Thickness [mm]	0.1	1	3
Young's modulus[MPa]	0.136	0.074	0.035
Poisson's ratio	0.48	0.48	0.48
Rigidity ratio[MPa]	0.046	0.025	0.012


Human skin model 2

Methods

Boundary conditions (model 1)

Constraint	Contact with probe	bottom				Others
	Z-axis direction	X、Y、Z	X、Y	Z	Free	Free
Load	Suction on human skin gel surface inside probe diameter					
Suction pressure	0.02MPa (200mbar)					

Boundary conditions (model 2)

Constraint	Contact with probe	Others
	Z-axis direction	Free
Load	Suction on human skin gel surface inside probe diameter	
Suction pressure	0.02MPa(200mbar)	

Results

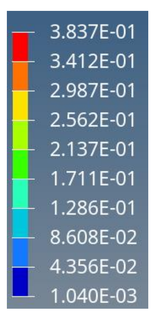
Experimental results

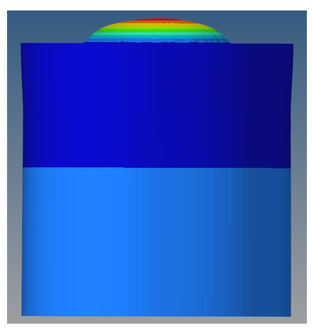
R0 (Max deformation) [mm]	0.265～0.392

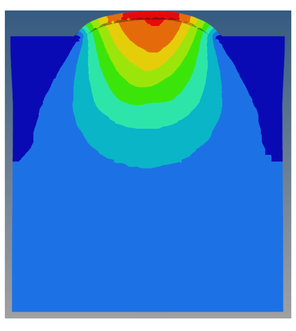
Subjects:
6 males in their 20s
Determined part:
back of hand, forearm, upper wrist

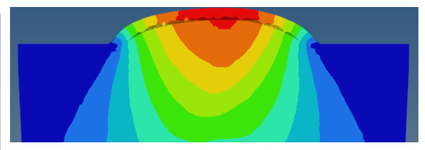
Analysis Results

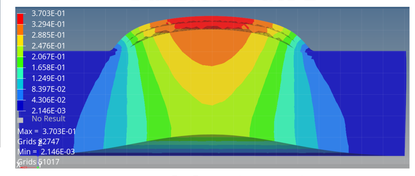
Model	1				2
Bottom Constraint	X、Y、Z	X、Y	Z	Free	Free
Max deformation[mm]	0.192	0.370	0.256	0.446	0.383




Model 2


Model 2


Partial Model 2



Model 1 (X、Y)

- The results of model 2 are in the interval of the experimental results
- The results of simulating skin base constraint with subcutaneous (model2) are similar to condition of base X and Y axis constraint with Stratum corneum (model1)

Conclusions

- The analysis for the human skin gel reproduced the suction behavior of the experiment with the cutometer, and the maximum deformation also showed the same values.
- The constraint condition at the base of the dermis is more inclined to X, Y-axis constraint.
- For human skin, the deformation range extends to the bottom of the model, so the model thickness must be increased.
- Individual differences in experimental results may be due to the thickness of each skin layer.

References

(1) Yuwei Suga: Presentation of a sensation of hardness and softness by fusion of electrical stimulation of the skin and force sensation
(2) Osamu MAKIO: Development of a method for measuring Young's modulus of epidermis of human skin
(3) Pembe Oltulu : Measurement of Epidermis, Dermis, and Total Skin Thicknesses from Six Different Body Regions with a new Ethical Histometric Technique