FINITE ELEMENT MODEL OF HUMAN FINGERTIP

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1 Abstract

The fingertip deformation represents the basic mechanical action that shapes human haptic perception. Everyday, humans use their fingertips (and hands) to explore, manipulate and grasp the external environment for many tasks, ranging from simple object grasping towards complex palpation procedures used for medical diagnoses. Moreover, the investigation of fingertip sensing and mechanical properties has gained an increasing attention not only for modeling human behavior, but also in humanoid robotics, where the need for compliant robotic fingers endowed with tactile sensors has become crucial. In this work, we present an experimental set up to provide a characterization of human fingertip mechanical properties, in terms of **contact area**, **fingertip deformation** and **pressure distribution**. Such measures, obtained from experimental tests, are then correlated with the output of a 3D Finite Element (FE) Model of fingertip developed in order to validate the proposed study.

2 Experimental Tests

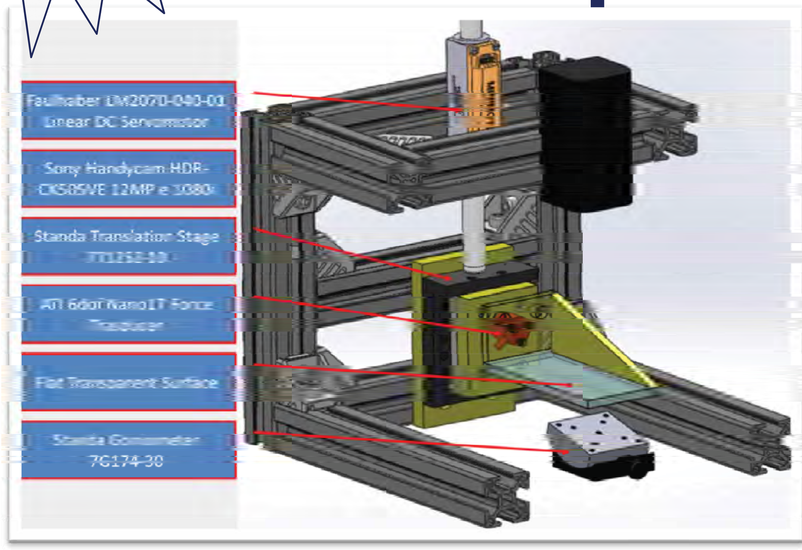

Fig.1 *Virtual test-rig*

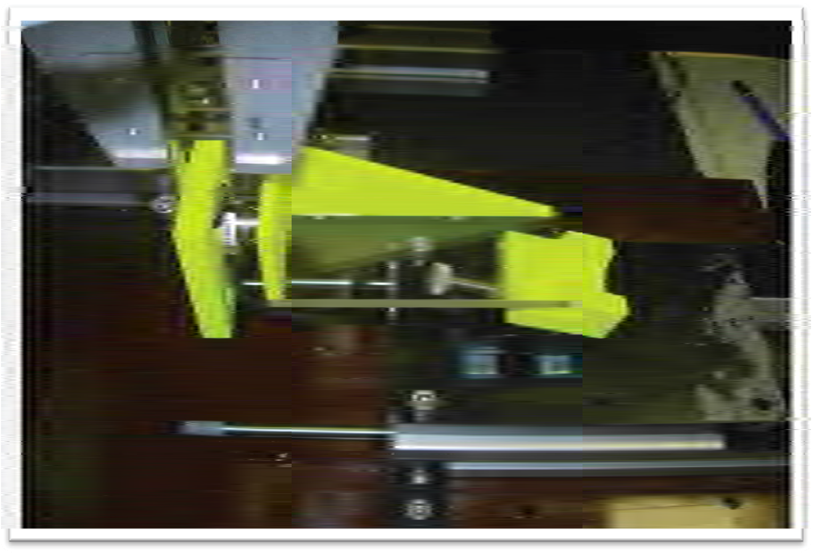

Fig.2 *Physical test-rig*

❖ The **displacement** is given by a linear DC actuator with 9.2 N of full scale.

❖ The **forces and torques** are recorded using a 6-DoF force/torque sensor (ATI 6-DoF Nano17).

❖ The **contact area** is acquired visually using a video camera, with 1500 x 1120.

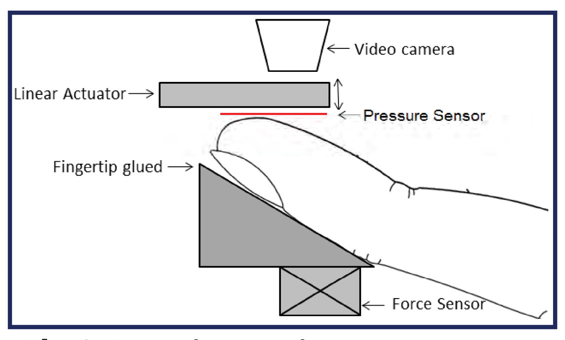

Fig.3 *Experimental test concept*

❖ Subject placed the finger pad on the finger-holder, and the indenter surface was moved toward the finger pad.

❖ The finger was fixed to the finger-holder on the top of the nail, and it was oriented at a 15 deg angle [1].

❖ **Displacement of indentation 3 mm**

❖ **Velocity of indentation 1 mm/s**

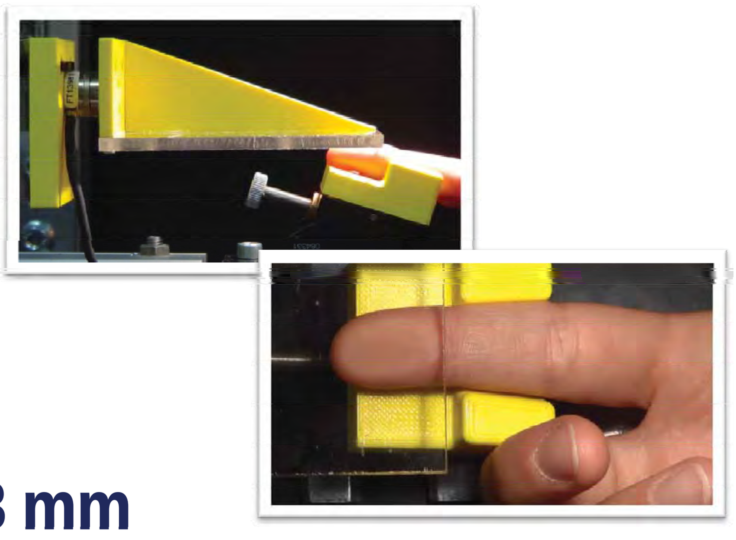

Fig.4 *Experimental test*

3 Numerical Model

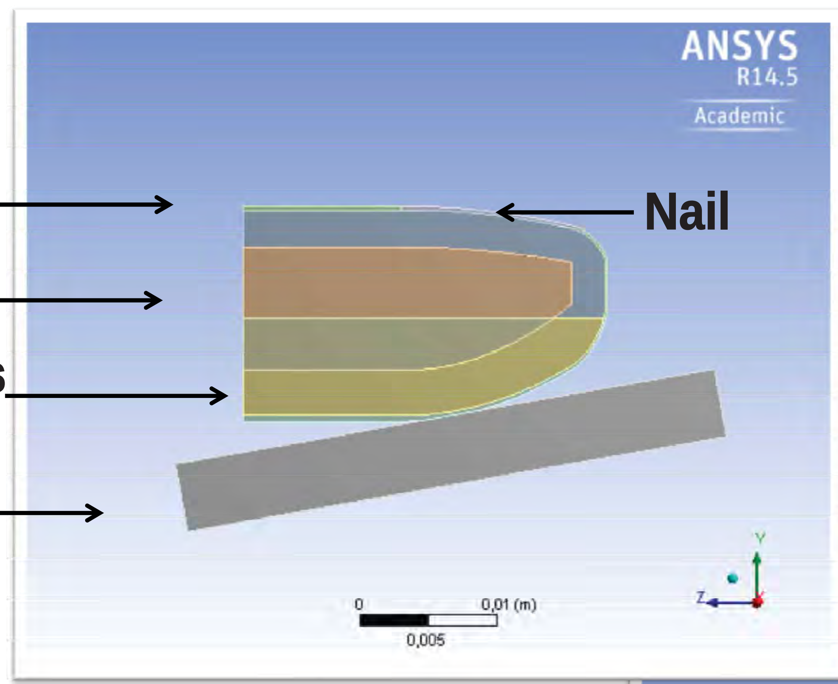

Fig.5 *Materials*

Component	Thickness [mm]
Dermis	0.41
Bone	6.35
Subcutaneous T.	2.5
Plate	5

Tab.1 *Geometrical properties*

❖ Dermis, bone, nail and plate have a **linear elastic behavior** that was modelled using the mechanical properties in Tab.2 .

Component	Young Modulus [Mpa]	Poisson's ratio [-]
Dermis	2.00	0.30
Bone	17.0	0.30
Nail	170	0.30
Plate	71300	0.17

Tab.2 *Linear-elatic mechanical properties*

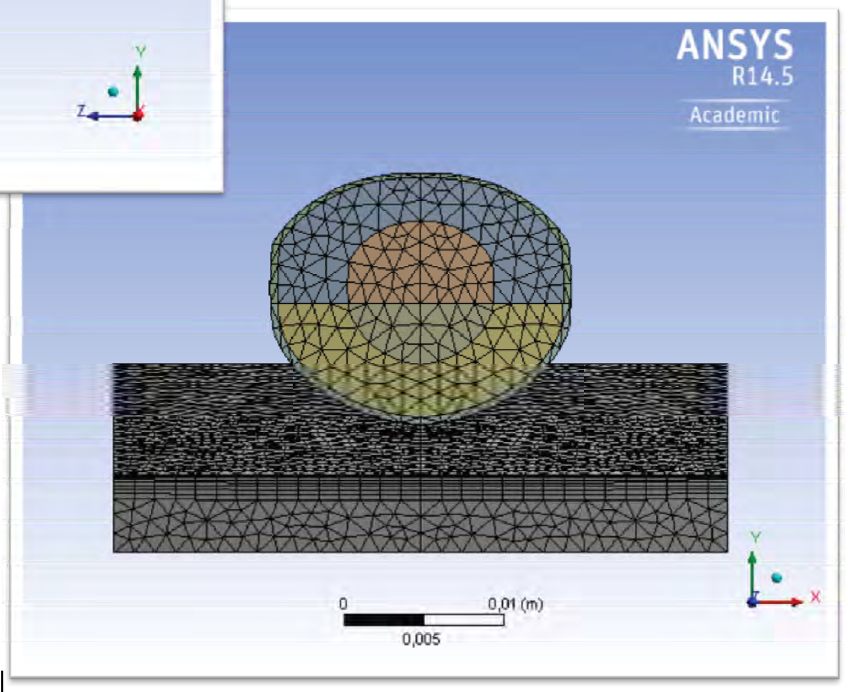

Fig.6 *Mesh*

❖ The solid was meshed by using a **3D tetrahedral element** that exhibit a quadratic displacement behavior.

❖ **31672** elements and **77829** DOF.

❖ In order to optimize the simulation time, the finger model was divided in two parts according to the **sagittal symmetrical plane**.

❖ The subcutaneous tissue was present an **hyperelastic behavior** and it was modelled by using a **Mooney-Rivlin model** [2].

Parameters	C_{10}	C_{01}	C_{20}	C_{11}	C_{02}	D_1
Subcutaneous T.	300	671	29800	32700	9330	106.5

Tab.3 *Hyperelastic mechanical properties*

Mooney-Rivlin formulation

$$W = C_{10}(\bar{I}_1-3) + C_{01}(\bar{I}_2-3) + C_{20}(\bar{I}_1-3)^2 + C_{11}(\bar{I}_1-3)(\bar{I}_2-3) + C_{02}(\bar{I}_2-3)^2 + 1/d\,(J-1)^2$$

$C_{10}, C_{01}, C_{20}, C_{11}, C_{02}$ d = material constants

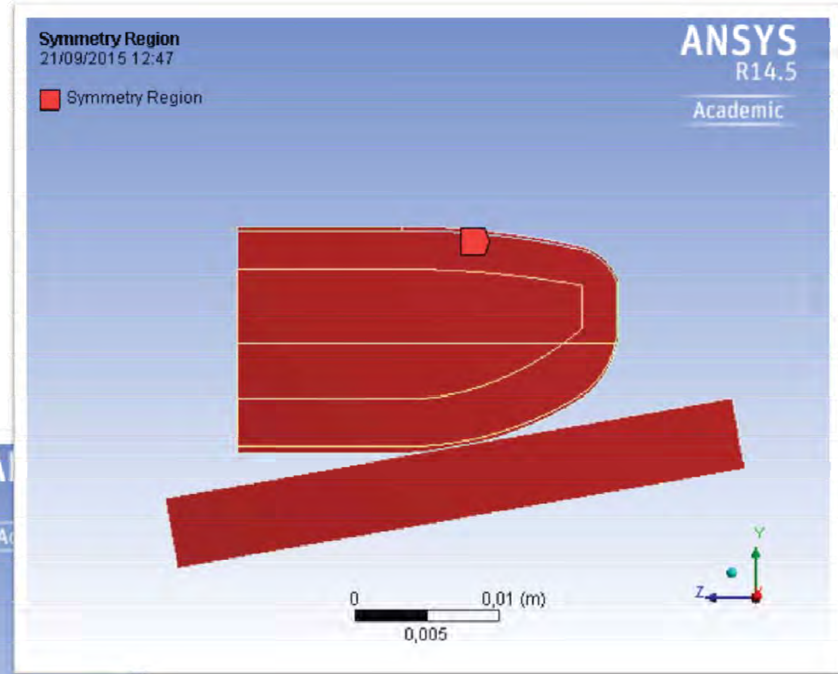

Fig.7 *Symmetric plane*

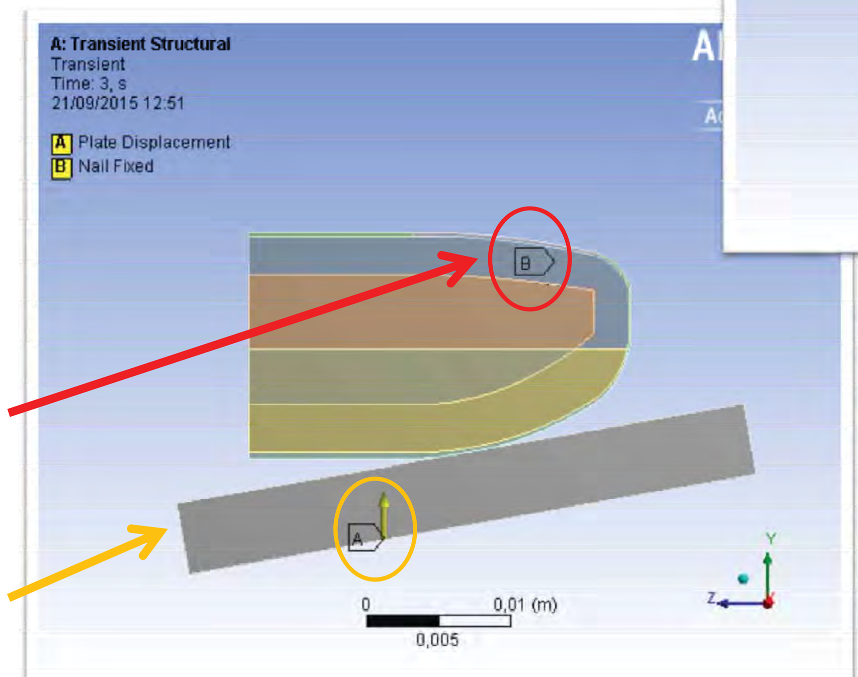

Fig.8 *Constraints and displacement*

❖ All contacts were modeled as **bonded contacts**, except the contact between the finger and the plate which was modeled as a **frictionless contact.**

❖ A **fixed support constraint** was applied on the nail and a **displacement of 0.1 mm/s** over **30 seconds (3 mm overall)** was imposed to the lower face of the plate.

4 Results

1. *Experimental Tests*

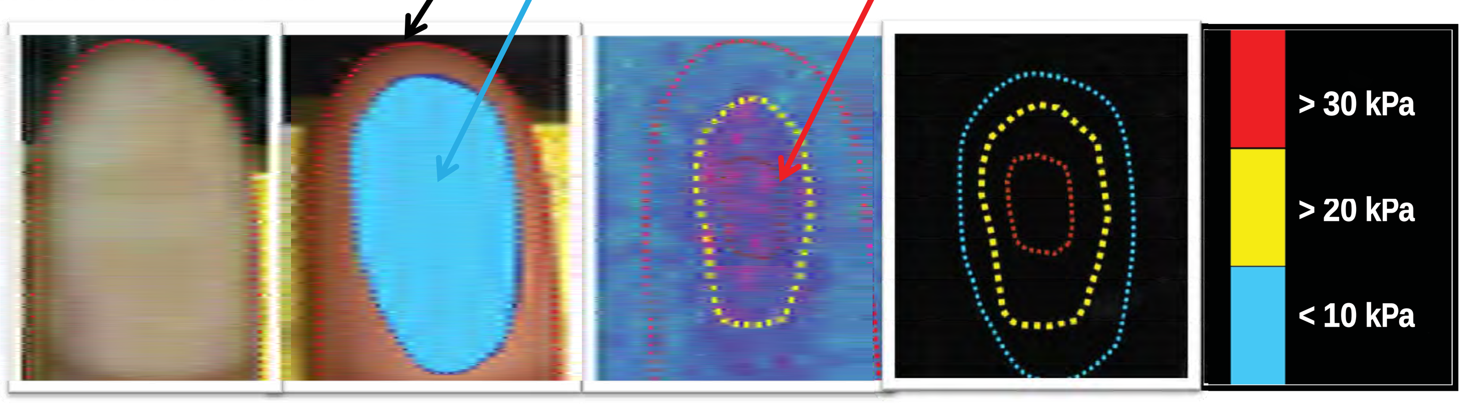

Fig.9 *Experimental test results*

2. *Numerical Simulations*

The numerical results were mainly two:

❖ **CONTACT AREA:** the one between the finger and the plate (blue one in Fig.10)

❖ **PRESSURE AREA:** the one corresponding to the maximum value of pressure [Pa] (red one in Fig. 10) [1].

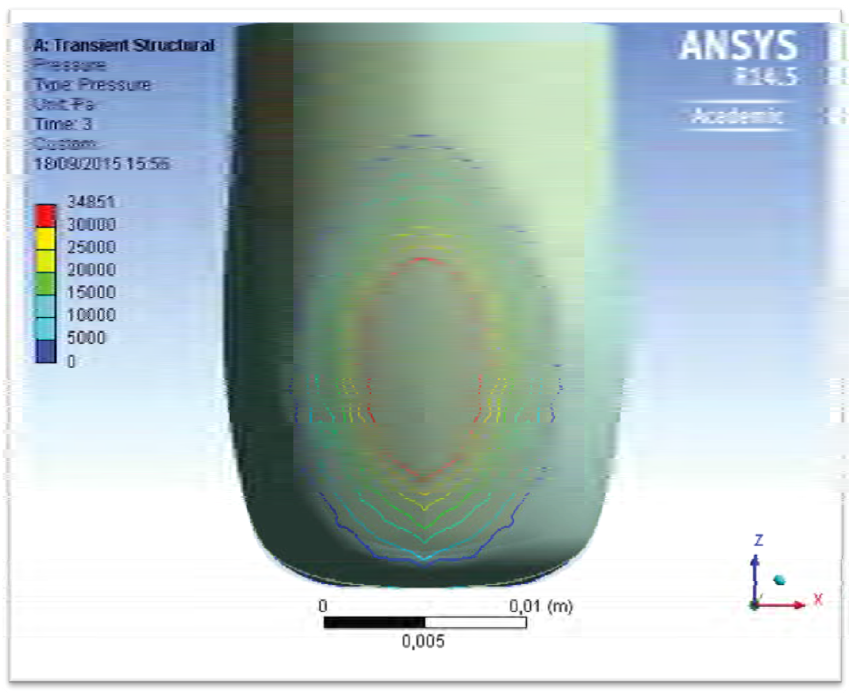

Fig.10 *Numerical results*

3. *Comparison and Validation*

Experimental and Numerical Values Comparison Contact Area [mm^2]	
Experimental Contact Area	133 ± 16.8
Numerical Contact Area	129
Accuracy [%]	12.1

Experimental and Numerical Values Comparison Force [N]	
Experimental Force	1.71 ± 0.06
Numerical Force	1.90
Accuracy [%]	11.1

Tab.3 *Comparison between Experimental and Numerical Values in terms of Contact Area and Force*

5 References

[1] **Maria Laura D'Angelo**, F. Cannella, M. Memeo, M.D'Imperio and M. Bianchi . "Preliminary Fingertip Pressure Area Distribution Via Experimental Test and Numerical Model" (2015 XXI IMEKO World Congress)

[2] **Gerling, G.J.**; Rivest, I.I.; Lesniak, D.R.; Scanlon, J.R.; Lingtian Wan. "Validating a Population Model of Tactile Mechanotransduction of Slowly Adapting Type I Afferents at Levels of Skin Mechanics, Single-Unit Response and Psychophysics," IEEE Transactions on haptics.