Experimental and numerical assessment of the mechanics of keloid-skin composites undergoing large deformations

Marco Sensale, Jérôme Chambert, Franz Chouly, Arnaud Lejeune, Sylvain Joly, El Khansa Rekik, Gwenaël Rolin, Thomas Lihoreau, Brice Chatelain, Patrick Sandoz, et al.

Experimental and numerical assessment of the mechanics of keloid-skin composites undergoing large deformations

M. Sensale[1,2,3], J. Chambert[1,2], F. Chouly[1,4], A. Lejeune[1,2], S. Joly[1,2], K. Rekik[1,2], G. Rolin[5,6], T. Lihoreau[6,7], B. Chatelain[8], P. Sandoz[1,2], S. Bordas[9], E. Jacquet[1,2]

(1) Univ. Bourgogne Franche-Comté,

(2) FEMTO-ST Institute, UFC/CNRS/ENSMM/UTBM, Department of Applied Mechanics, Besançon, France,

(3) Polytechnic University of Turin, Italy

(4) Laboratoire de Mathématiques de Besançon, France,

(5) Clinical Investigation Center (INSERM CICB 1431), Besançon University Hospital, France,

(6) INSERM UMR1098, University of Franche-Comt, Besançon, France

(7) Research and Studies Center on the Integument (CERT), Department of Dermatology, Clinical Investigation Center (CIC INSERM 1431), Besançon University Hospital

(8) Service de chirurgie maxillo-faciale, stomatologie et odontologie hospitalire, Centre Hospitalier Universitaire de Besançon

(9) University of Luxembourg, Institute of Computational Engineering, Luxembourg.

The aim of this paper is to evaluate the stress fields in cutaneous tissues with the long-term goal to prevent keloid development in patients. Keloids are non cancerous tumors [1] that expand continously on the skin for a number of reasons. These specific tumors affect 11 million more patients of all age, every year [2] and are particularly frequent in the asian and african populations. The evolution of keloids is related to genetic, biological, biophysical and biomechanical factors [3] and are considered "complex biological systems" [4]. Keloids develop due to the excessive proliferation of fibroblasts on several specific anatomical sites on the skin, that can be identified from the value of the retractability of the tissue [5].
Keloids grow like expansive scars on the skin surface. The relation between their development and the mechanical stress fields in and around the Keloid were studied in some papers [6, 7] but to our knowledge one of the few attempts at formulating a growth criterion is due to [8] who studied the influence of the local state of stress on the keloid propagation direction.
The paper presents a patient-specific methodology to identify the stress field. A keloid was observed on a patient using several imaging modalities, namely ultrasound and optical microscopy. A 3D image of the surface of the keloid was used to develop a 3D geometrical model of the keloid under consideration. The hyperelastic properties of the keloid and of the healthy skin were obtained through independent testing, on the same patient using an custom-made extensometer [9].
A three-dimensional numerical model of the keloid-skin composite was built in order to investigate the nature of the stress field in the vicinity of the keloid-skin interface. The validity of the simulation is determined by complementary data that have been recorded during the mechanical tests. The mechanical results obtained from the numerical model are compared to displacement fields identified by Digital Image Correlation.

The paper highlights the key steps of the study:

- The development of a realistic 3D model of the keloid.

corresponding author: corr.author@science.world

- The Finite Element simulation of a uniaxial non invasive traction test.
- The comparison between numerical results and experimental data to validate the numerical model.

The knowledge of the stress field in and around the keloid has the potential to improve the design of a specific device able to contain the growth of the keloid which is the topic of further investigations.

References

[1] Ogawa R, Orgill D, *Mechanobiology of Cutaneous Wound Healing and Scarring, in Bioengineering Research of Chronic Wounds*. Springer Berlin Heidelberg, 2009.

[2] Shih B., Garside E., McGrouther DA., Bayat A. *Wound Repair Regen* **18** :139-153, 2010

[3] Salles F., Thiery G., Lari N., Adam S. and Morand J. *Med Trop* **69**:221-227, 2009

[4] Ben Amar M. and Bianca M. *Phys Life Rev* **17**: 61-85, 2016

[5] Ogawa R., Okai K., Tokumura F., Mori K., Ohmori Y., Huang C., Hyakusoku H.and Akaishi S. *Wound Repair Regen* **20**:149-157, 2012.

[6] Akaishi S, Akimoto M, Ogawa R, Hyakusoku H. *Ann Plast Surg* **60**(4): 445-51, 2008

[7] Nagasao T, Aramaki-Hattori N, Shimizu Y, Yoshitatsu S, Takano N, Kishi K. *Med Hypotheses* **81**(1): 136-141, 2013

[8] Chambert J., Zhao L., Remache D., Jacquet E. (2012) *Comput Method Biomech Biomed Eng* **15** 23-24, 2012

[9] Jacquet E., Joly S., Chambert J., Rekik K.,Sandoz P. (2017) *Skin Res Techno* **in press** 2017