ENGINEERING MECHANICS 2004
NATIONAL CONFERENCE
with international participation
Svratka, Czech Republic, 10 - 13 May 2004

UNIAXIAL TENSION TEST OF HUMAN SKIN IN VIVO, NUMERICAL MODEL OF SKIN AND FINITE ELEMENT MODELING OF HUMAN SKIN WOUNDS CLOSURE

L. Čapek*, T. Hruš*

Summary: Healing of wounds in human skin is very important in the clinical treatment, but the mechanism and optimal shape of incisions *in vivo* is still uncertain. Large field and magnitudes of stresses around the wound closure produce complication during healing of the wounds. It is essential to analyse stresses around the wound closure. This paper gives a non-linear model for analyse by finite element method regions of high stresses in sutured wounds. Parameters for the model were obtained by *in vivo* uniaxial tests.

1. Introduction

Surgeons commonly suture wounds after surgical intervention. Even the shape of the wound might be simple, it is often associated with various problems. From the mechanical point of view, the field around the sutured wound should not contain large and high magnitudes of residual stresses; then the sutured wound can get extruded and healing of the wound can take more time. The stress field depends on material characteristics and boundary conditions. So the shape of the wound directly influences the residual stress area.

The study presented in this paper is close to the one realised by Lott-Crumper et al. [3]. We tried to use the similar wound closure but we used a material model developed by Arruda et al. The parameters were obtained from *in vivo* uniaxial test.

2. Methods and models

A description of the properties of the skin can be found in numerous textbooks on dermatology. However, the description of the mechanical properties of the skin still differs from author to author. The human skin is a stratified tissue, which consists of the epidermis at the outer surface and the dermis under it. As for the mechanical properties it is known that the skin is an anisotropic, non-linear, viscous and incompressible material.

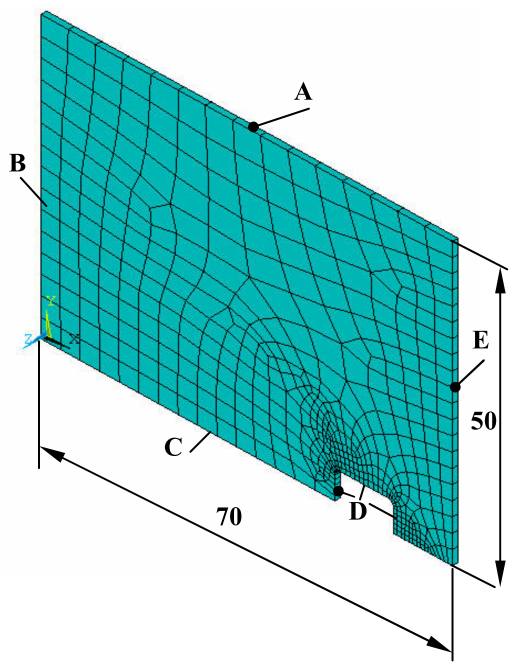
* Ing. Lukáš Čapek, Dr. Ing. Tomáš Hruš: Department of Engineering Mechanics, Faculty of Mechanical Engineering, Technical University of Liberec; Hálkova 6; 461 17 Liberec 1; tel.: +420 485 354 149, e-mail: lukas.capek@vslib.cz

Many tissues can undergo large deformation. The human skin belongs to this category and can be modelled as a non-linear elastic, or we can say hyperelastic material if long-term changes are supposed.

For determining the mechanical properties of the human skin *in vivo* was used an extensometer developed in Laboratory of Applied mechanics R. Chaléat (LMARC), Besançon, France. The extensometer is constructed for measuring on the right forearm. The machine is characterised by two tabs sticked to the skin and driven apart from each other with a constant stretching rate. The tabs on the instrument were for the experiment 10 mm long and 10 mm wide, initially spaced 20 mm apart with constant rate of deformation 0.5 mm/s. The uniaxial *in vivo* tests were performed on a healthy skin of the forearm.

The finite element simulations were performed using a finite element software ANSYS 6.1. The thickness of the skin (epidermis and dermis) we assumed it to be 1 mm [4]. Because of the existing symmetry of the problem, we took only a quarter of the plate. For meshing the geometry we used 495 eight - node elements (SOLID 185).

To approach the reality we assumed two different boundary conditions (Fig.1).



Model I:

- Surface A: Uz=0
- Surface B: Uz=0
- Surface C: Uy=0, Uz=0
- Surface D: Ux=-5, Uz=0, Uy=0
- Surface E: Ux=0, Uz=0

Model II:

- Surface A: Ux=0, Uy=0, Uz=0
- Surface B: Ux=0, Uy=0, Uz=0
- Surface C: Uy=0, Uz=0
- Surface D: Ux=-5, Uz=0, Uy=0
- Surface E: Ux=0, Uz=0

Fig.1**:** Geometry and deformation boundary conditions used for finite element model in [mm], where U means displacement in x,y,z directions also in [mm]

We used the two models that are already incorporated into ANSYS 6.1: linear isotropic described by Young's modulus and Poisson ratio and Arruda-Boyce model. The second model is hyperelastic, isotropic developed for rubber materials [1, 2]. Any elastic material may be represented by a strain energy function. The strain energy function of this model is given by the following formula [1, 2]:

$$W = nk\Theta\left[\frac{1}{2}(I_1 - 3) + \frac{1}{20N}(I_1^2 - 9) + \frac{11}{1050N^2}(I_1^3 - 27)\right] +$$
$$+ nk\Theta\left[\frac{19}{7000N^3}(I_1^4 - 81) + \frac{519}{673750N^4}(I_1^5 - 243)\right] \quad (1)$$

where n [1/m^3] is the network molecular chain density, k=1.3807 x 10^{-23} [Nm/K] is a Boltzman's constant, Θ=298 [K] is absolute temperature and I_1 is the first stretch invariant given by

$$I_1 = \lambda_1^2 + \lambda_2^2 + \lambda_3^2, \quad (2)$$

where λ_i are the principal stretches.

3. Results

The experimental data were obtained from *in vivo* uniaxial tests for a 21-year-old female and 27-year-old male. These tests were performed in the direction of fingers (Fig.2).

The simulation of the experiment for these two boundary conditions and two materials models was done only for the first experiment (female 21 year-old). As we can see, simulations do not differ very much from each other and they closely match the experimental data (Fig.3).

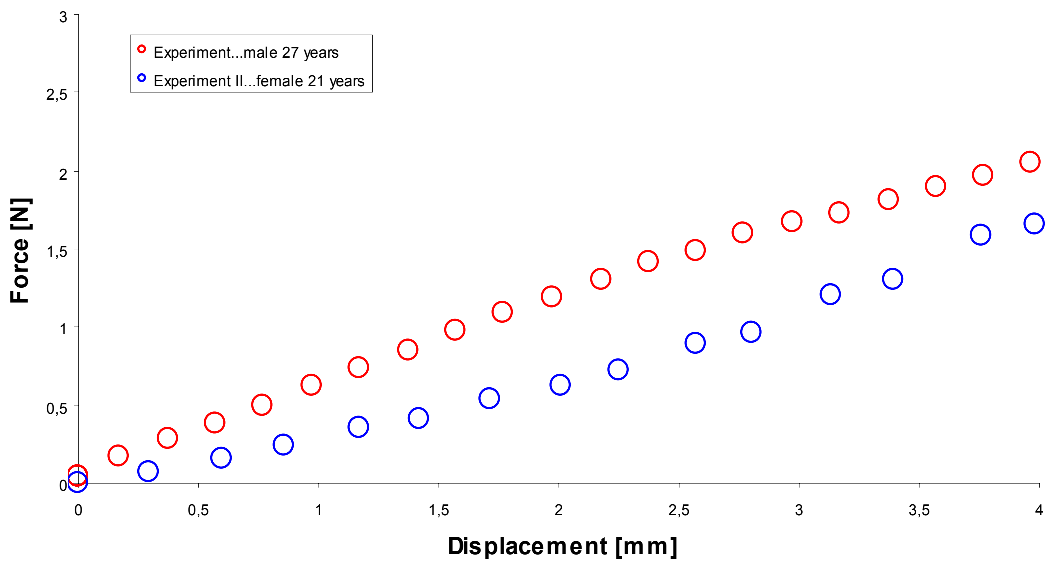


Fig.2: In vivo uniaxial tests data for a 21-year-old female and 27-year-old male

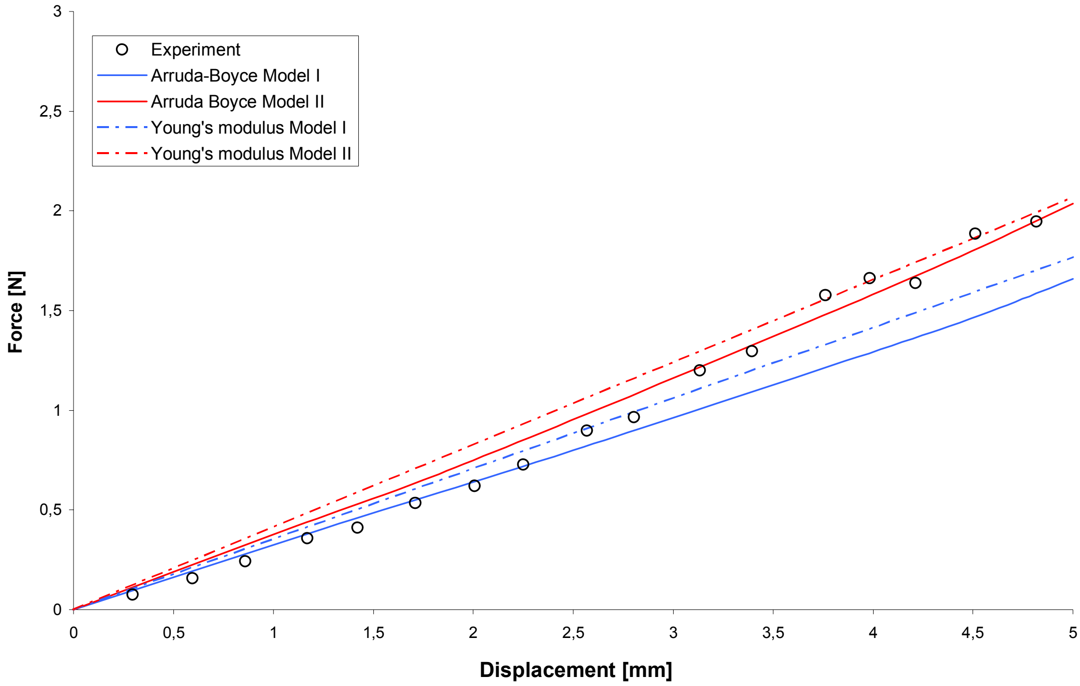


Fig.3: In vivo uniaxial test data for a 21-year-old female

The parameters used in simulations were N=1.05, n=7.169 10^{24} [1/m^3] for the model of Arruda-Boyce and E=0.35 [MPa], ν=0.3 [-] for the second material model.

4. Application of the model

Numbers of approaches have been used for modelling the wound closure but the amount of information about the field, magnitudes of stresses and about the optimal shape of incision is not still sufficient. The stress and shape of the incision are mechanical factors that play an important role in wound healing.

It is essential to find an optimal shape of the incision that produces the minimum of the maximal tension in the boundary of the suture wound and also the minimum of compressive stresses. If the field of residual stress contains an area of compressive stresses, we can suppose production of scars, because skin can't support negative stresses [4].

We have chosen two problems, which can appear in surgeon's experience. The first one is a diamond shape defect and the second one is a triangular wound (Fig.4). The sheet of the wounded skin is taken to be large enough that it doesn't influence the results. The dimensions of the sheet are being 100 x 100 mm.

Simulations were performed by software ANSYS 6.1. The thickness of the skin is taken 1 mm. Geometry was meshed by eight - node elements (SOLID 185).

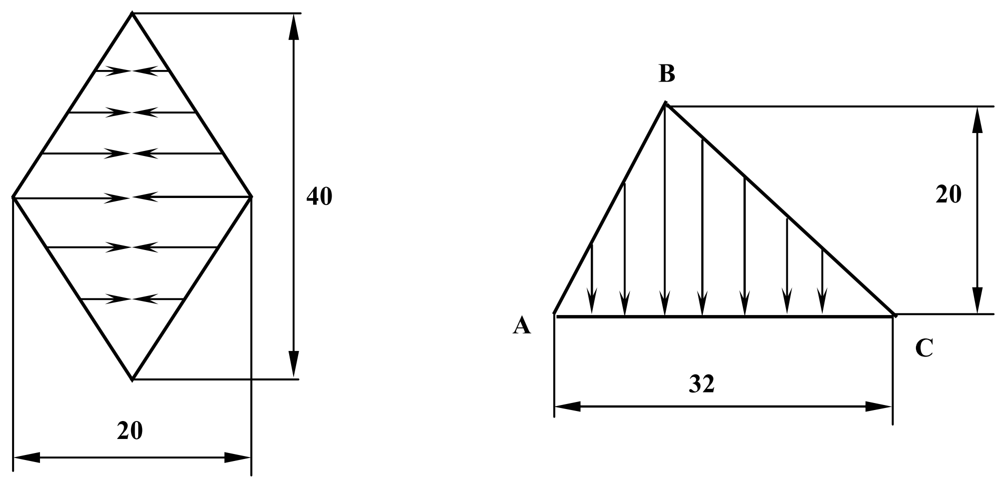


Fig.4: Geometry of the diamond shape wound and the triangular wound in [mm]

The first geometry will enable us to compare the results and to predict the mechanical behaviour of more complex shapes. In spite of this fact that the geometry of the simple shape has two planes of symmetry we do not take it into consideration.

The second case is a nonsymmetrical wound in the shape of triangle. This geometry resembles to those of Lott-Crumpler [3].

In the first case lateral edges of the wound are advanced horizontally towards each other. In the second case the upper edge of the wound is advance horizontally towards the base. The nodes of external boundaries were constrained (fixed in space) in both cases.

The results are shown as the first and the third principal stress.

In the first problem the maximum of the tensile stress appears in a small region of the centre of the sutured wound. The compressive area occurs in the tapered edge of the wound. (Fig.5, 6).

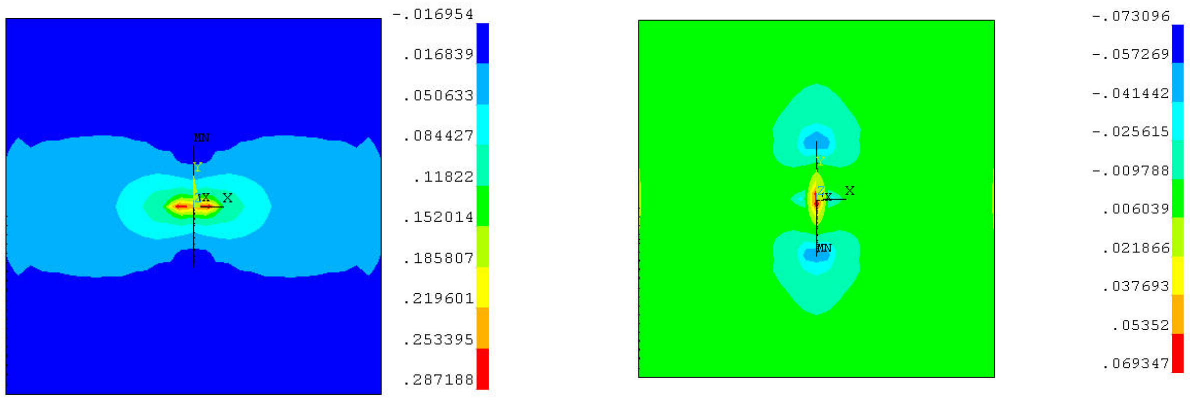
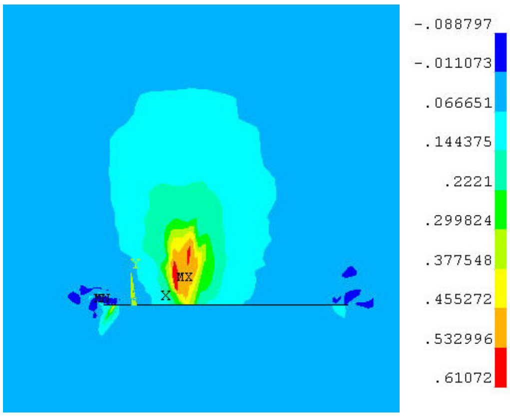


Fig.5: The first and the third principal stresses, wound closure, of a diamond shape wound in [MPa]

In the second case, the maximum of the tensile stress is in the area where the vertex point (B) of the triangular wound meets the opposite side of the wound. The compressed areas are to be found around the points A and C (Fig.6).



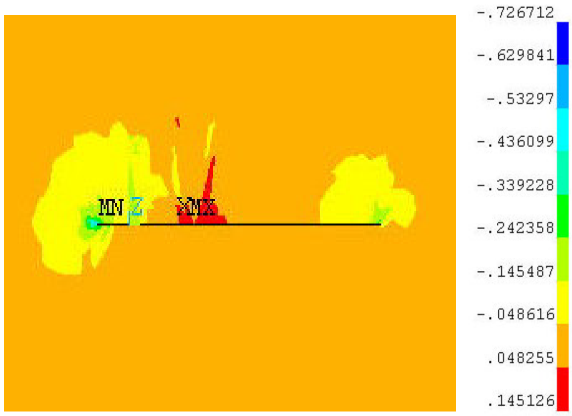


Fig.6: The first and the third principal stresses, wound closure, of a diamond shape wound in [MPa]

The non-linear model was used on very simple shapes of incisions on human skin. In the practice of plastic surgery surgeons use more complex incisions as Linberg incision (Fig.7) or Z plasty (Fig.8).

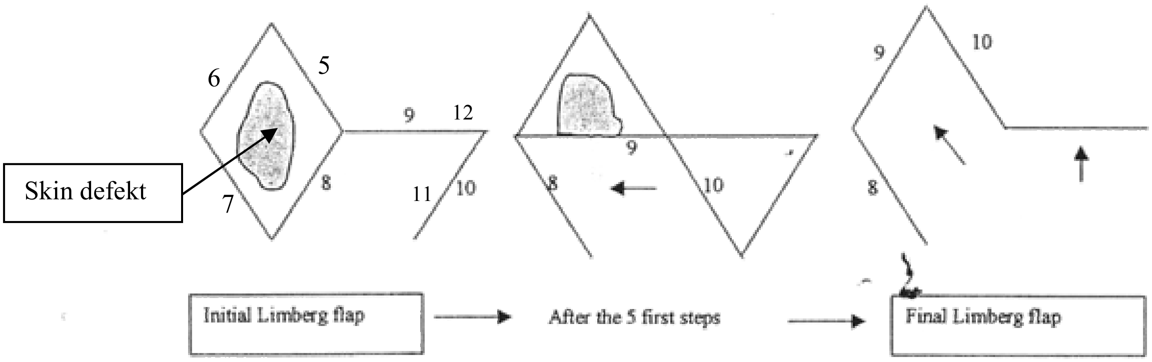


Fig.7: Geometry and Linberg flap during wound closure

The Linberg incision closure technique consists of moving the flap of skin defined by lines 8, 9 and 10 upon the hole defined by lines 7, 6 and 5 and then moving edges 11 to 12. Thanks to this technique we can cover large skin defects.

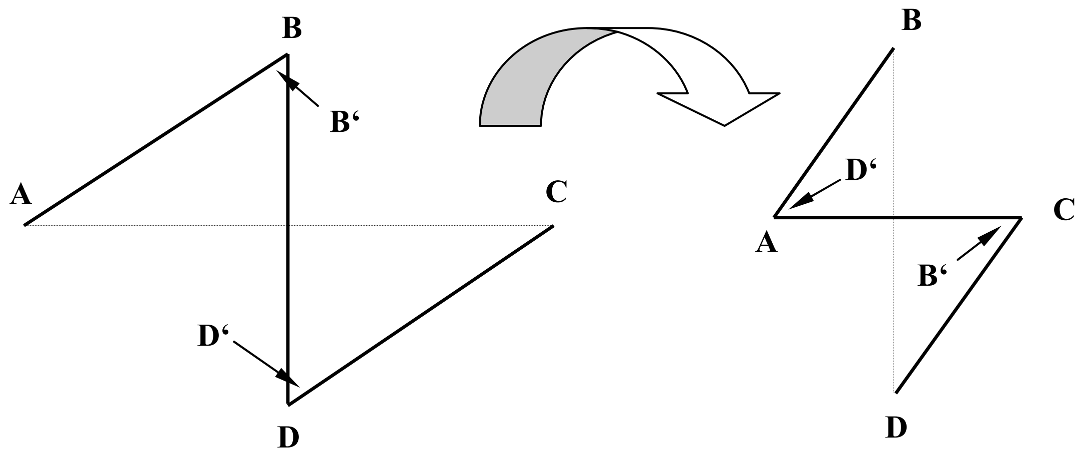


Fig.8: Geometry of Z plasty during wound closure

The Z plasty operation is one the most favourite method in the plastic surgery. The first reference dates to year 1837. It consists of moving the vertex B' to C and D' to A.

5. Conclusion

The purpose of this work was to find out parameters for a non-linear model and its application at the wound closure.

In spite of the fact that the non-linear model was developed for rubber materials, its two parameters, N and n posses physiological meaning (network of collagen). The parameters were fitted by a uniaxial *in vivo* test and they closely match to those found by Bischoff et al. The model does not respect the fact that the skin is anisotropic.

We have calculated distribution of stress in the region of two different wounds. The region of the maximal tensile stress and the compress stress is one of useful information for surgeons. They should avoid those shapes that produce high magnitudes of tensile stress and regions of compressive stresses.

The distribution of the stress confirms our presumptions and is close to those evaluated by Lott-Crumpler et al., small differences are due to the assumption of isotropy. Magnitudes of calculated stresses are much higher than those by Lott-Crumpler et al. and approach better to those calculated by Retel et al. They are supposed to be closer to reality.

This work is to be understood as a step in searching an optimal method and model for determining the wounds closure. However, the simulation could be improved by using a viscous model of the skin and mechanical anisotropy of the skin. In the future the simulation should be also compared with an experiment which should be also carried out.

6. Acknowledgement

This paper was done in collaboration with Laboratory of Applied Mechanics (LMARC), Besançon, France. I wish to thank M. Daniel Varchon and Paul Vescovo for their help.

7. References

1. Arruda, E.M., Boyce M.C., 1993. A three-dimensional model for the large stretch behaviour of rubber materials. *Journal of the Mechanics and Physics of Solids* (389)

2. Bischoff, J.E., Arruda E.M., Grosh, K., 1999. Finite element modelling of human skin using an isotropic, nonlinear elastic constitutive model. *Journal of Biomechanics 33* (647)

3. Lott-Crumpler, D.A., Chaudry, H.R., 2000. Optimal patterns for suturing wounds of complex shapes to foster healing. *Journal of Biomechanics 33* (51)

4. Retel et al., 2001. Nonlinear model of skin mechanical behaviour analysis with finite element method. *Skin research and technology 7* (152)

5. Yoshida et al., 2000. Three-dimensional finite element analysis of skin suture. *Medical Engineering and Physics 22* (481)

6. Wan Abas, W.A.B., Barbanel J.C., 1982. Uniaxial tension test of human skin in vivo. *Journal of biomedical engineering 4* (66)

7. Wayn F., Larrabee JR, 1986. A finite element model of skin deformation III. The finite element model. *Laryngoscope* (413)