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Numerical Modelling of Skin Suturing

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Abstract: Prediction of results in reconstructive surgery, e.g. suturing has not been numerically solved yet. In spite of the fact that suturing belongs to common surgery procedure, numerous aesthetical results indicate that this procedure cannot be overlooked. The aim of this contribution is to demonstrate a new approach in numerical modelling of skin suturing.

Keywords: Human Skin; Suturing; Biomechanics; FEM.

1 Introduction

Nowadays, numerical modeling of human tissues during physiological loading belongs to basic skills in the field of biomechanics. However, prediction of results in reconstructive surgery, e.g. suturing has not been numerically solved yet. In spite of the fact that suturing belongs to surgery routine, numerous aesthetical results indicate that this procedure cannot be overlooked.

There are several studies evaluating forces needed for skin suturing. Melis performed experiments with piglets, making rectangular wounds sized 9 $\times$ 9 cm on their skin [1]. Frick et al. determined the axial load applied to the wound edges of a piece of sheep skin and a tendon [2]. Cacou et al. tried to find the force required for closing elliptically-shaped wounds [3, 4]. Capek et al. evaluated forces needed for the suturing of elliptical skin wounds as a dependency of pre-stress by FEM and in vivo experiments [5].

All the authors mentioned above used nodal displacement boundary conditions at the edge of the wound for its closing. The aim of this contribution is to demonstrate a new approach in numerical modelling of skin suturing.

2 Materials and Methods

The elliptical excision model was chosen because it represents the standard shaped wound which surgeon closes after making a linear incision or after removing a lesion. The elliptical wound is defined by its major axis 30 mm and minor axis 10 mm. In this study, two standardized 3D skin defects were analyzed using the finite element method. The material data were gained from the literature [6]. The large strain isotropic-elastic model was used to represent the human skin. The Ogden model is one of various strain energy functions and very often used for describing soft tissues [7, 8]. The strain energy function is written in terms of the principal stretches as

$$W = \sum_{n=1}^{N} \frac{\mu_n}{\alpha_n} \left[J^{\frac{-\alpha_n}{3}} \left(\lambda_1^{\alpha_n} + \lambda_2^{\alpha_n} + \lambda_3^{\alpha_n} \right) - 3 \right] \tag{1}$$

where μ_n and α_n are material constants, K is the initial bulk modulus and λ_i is the principal stretch.

The material constants are summarized in the Tab. 1, and they correspond to those mentioned in the literature [9].

The MSC.Marc software (MSC.Software Ltd., the Czech Republic) was used for these numerical analyses. The following assumptions were taken into consideration for numerical purposes: the prestress was assumed in both directions of the model (σ_x=20 kPa, σ_y=20 kPa).

Two approaches for suture closure were used and analyzed:

a) suturing was provided by displacement of edge nodes,

b) suturing was provided by trust elements (with a negative coefficient of thermal expansion) that were put instead of stitches. The suturing was carried out by thermal loading of the whole model.

Tab. 1: Material constants for Ogden model.

μ_1[MPa]	α_1[-]	μ_2[MPa]	α_2[-]
3.15×10^{-4}	26.64	3.74	4.72×10^{-3}

3 Results

Results of numerical analyses are presented in Fig. 1. and Fig. 2. Maximal tensions occur in the middle of the elliptical wound in all cases. The difference between two chosen approaches of suturing is 43.2 %. The movement of nodes produces higher forces in the stitches. The distribution of stress is the same instead of values. The maximal tension occurs in the middle, the maximal compression is located at the end of the wound.

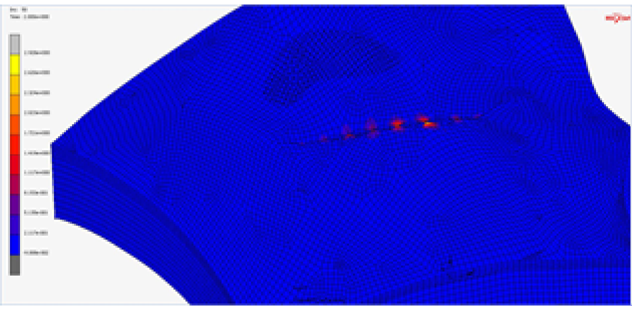


Fig. 1: Suturing by displacement of edge nodes.

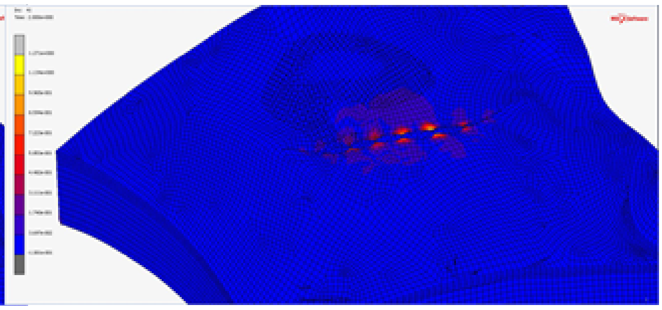
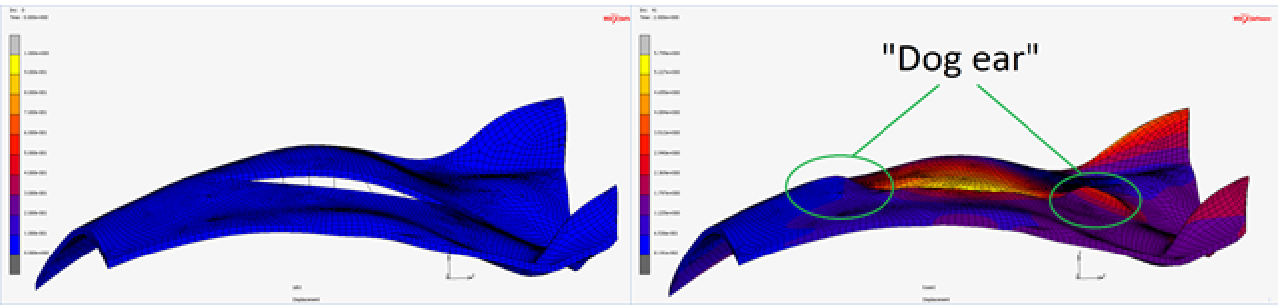


Fig. 2: Suturing by truss elements.

The compressive stress at the ends of the scar resulted in bulge out of the skin. The bulge out which is usually called "dog ear" is shown in Fig. 3b. If the "dog ear" is significantly large, it must be removed by further surgery. This effect depends on the opening angle of scar. It can be stated that increasing scar opening angle causes higher possibility of "dog ear" effect.



(a) without suturing

(b) with suturing

Fig. 3: Dog ear effect.

4 Conclusion

It was shown that it is worth to analyze different approaches used for modelling of skin suturing. The difference between the two chosen approaches of suturing might reach up to 43.2 %. Numerical analyses show that the maximum tension was in the middle of the wound. Generally, this corresponds with experience of surgeons. That is why surgeons start suturing at the end of the wound. In this way, they can make the tension lower. Although the authors of the present study formulate particular conclusions, they are aware of some limits of their study, such as anisotropy of the skin. Our next clinical study will deal with evaluation of the tension in different layers of the wound.

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