Title: **Finite element analysis of the V-Y advancement flap**

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Abstract: In surgery, the local flap is used for closing round or rectangular skin defects. The fundamentals of the V-Y advancement flap consist in replacing the initial defect with two smaller defects by a translational movement of an isosceles triangular flap (V-shape). After suturing, the V-shape flap, which is adjacent to the initial defect, becomes a Y-shape scar.
From a clinical case in vivo, the aim of this study is to carry out some finite element simulations of the V-Y advancement flap in order to determine the prestress and the evolution of the stress field within the human skin. The V-Y flap is modelled by 2D plane stress finite elements, and the skin is considered as an isotropic hyperelastic material.

Keywords: V-Y advancement flap, Human skin; Finite element method; prestress

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Introduction

In surgery, a local flap is a skin tissue in which the blood supply is retained by leaving the tissue permanently attached to its site of origin. Contrary to skin grafting, the local flap is advanced to cover skin defects by using the elastic properties of the skin subcutaneous tissues.
In the V-Y advancement flap technique, a triangular flap is incised adjacent to the skin defect. As the flap is advanced to close the initial defect, two smaller defects in the form of parallelogram are formed and sutured. Some geometric analysis of the V-Y advancement flap by considering the skin as rigid body have been performed (Pauchot et al 2010). The finite element method is an interesting tool to simulate complex flaps such as the Limberg skin flap (Retel et al. 2001) or the V-Y advancement flap by taking into account of the skin stretching capacity.
From a clinical case in vivo, the aim of this study is to carry out some finite element simulations of the V-Y advancement flap in order to determine the prestress (Chaudhry et al. 1998) and the evolution of the stress field within the human skin. The V-Y flap is modelled by 2D plane stress finite elements, and the skin is considered as an isotropic hyperelastic material.

Materials and methods

Experiment

For our purposes a movie of V-Y flap of a real patient 41 years old on human skin and numerical analysis were performed. The movie needed for our experiments was performed at the Plastic Surgery Department of University hospital in Besancon, France. This type of experiment was ruled by ethical regulations of the University hospital. V-Y plasty technique is common in plastic surgical practice. In this technique, an incision is made as V pattern and the V patterned skin is approached to cover the defected area as Y shape. The V-Y flap consists in these steps (see figure 1.): a) The triangular flap pattern and the future rectangular defect are drawn on the skin. b) The defect is cut off in the rectangular shape c) For two corners of this rectangle two incisions that forms a triangle are made. This incision is made only through the thickness of dermis d) such triangular flap is translated up to the further side rectangular defect and sutured (usually in three points) e) In next step one of the Y vertex (point M) is sutured together with the vertex of the triangle (point N) f) the left part of the flap is sutured.

A rectangular mesh was drawn on the surface of the human skin before incision, the dimension of one rectangular is 14x14 mm. When the V-Y skin flap is in characteristic positions, snap pictures are taken. And the displacement field is obtained by the comparison between two following pictures.

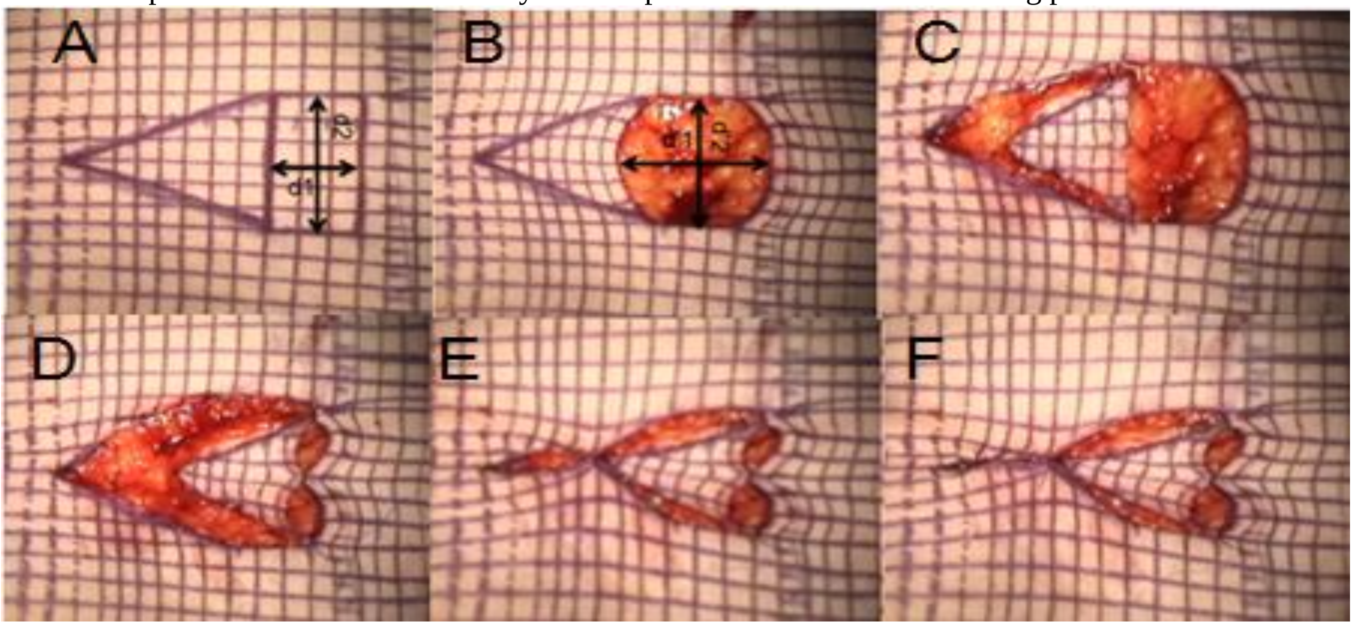

Figure 1 : Picture of 6 steps (A to F) from the suture of a V-Y flap

Numerical analysis

In this study the planar non-linear finite element models (FEM) of V-Y flap was used. The software ANSYS v.12 was used for these numerical analyses. The non-linear material model was used thanks to the fact that deformation in this model overcame 20% (Fung 1993). Moreover the mechanical behaviour of human skin is nonlinear hyperelastic. For numerical purposes the following assumptions were taken:

- The plane stress hypothesis was supposed for all elements.
- The thickness of the human skin was set to be 1 mm.
- The material properties of the human skin with the six-noded planar elements were set to non-linear Arruda-Boyce eight-chain model (Arruda and Boyce 1993) with parameters N=1.2 and n= 9,6e23 [1/m^3] taken from (Bischoff et al. 2000). N represents the free length of the collagen fibers and n is the collagen fiber density.
- The wound is considered to be small compared to the size of the skin sheet (560 x 406 mm).
- Prescribed zero displacement is set to left (x direction) and bottom (y direction) edge's nodes, fig 2b.
- The generated mesh was manually refined in locations were needed (PLANE 183)

The analyses were done in several steps corresponding to those from fig 1.

- In the first analysis step A, the rectangular defect (42mm x 82mm) was loaded by a biaxial prestress and compared to data gained from experiment (step B). This load was applied to skin sheet edges in x and y directions. (figure 2.a)
- In the next analysis, the geometry of step D was simplified. The incision is considered to be symmetric along the X axis and consists of straight lined, (figure 2.b). The model is loaded by a prestress gained from previous analysis and the node M is moved to node N (step E).

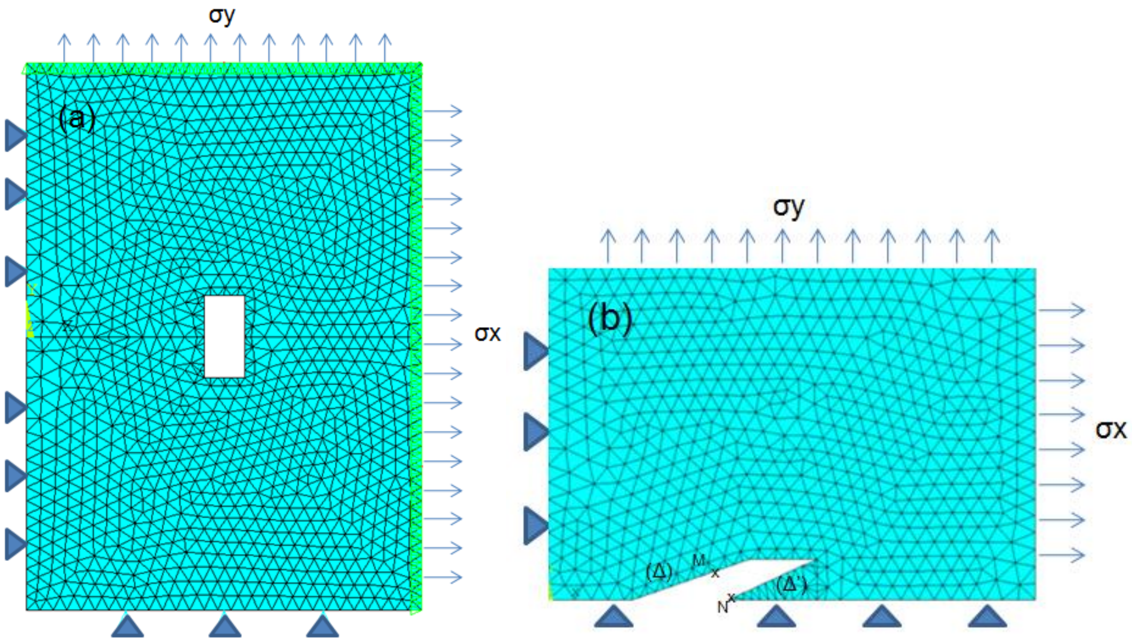

Figure 2 : 2.a geometric model, meshing and boundary conditions of the domain with rectangular hole
2.b geometric model, meshing and boundary conditions of the V-Y flap.

Experimental and numerical results

The final aim of research is to find out the stress distribution after suturing of V-Y flap. In this study, we would like to present only results from the step B and E.

The natural stress of the tissue from the step B was identified by inverse methodology. It was reached by biaxial loading of the model according to deformation geometry carried out from the in vivo experiment. In figure 3.a the rectangular defect of the skin deformed itself after incision from initial dimensions d1=42mm and d2=82mm to deformed ones d1'=84mm and d2'=76mm. From finite element analyses using the nonlinear material model the prestress was found to be σ_x=6.4kPa σ_y=0.3kPa.

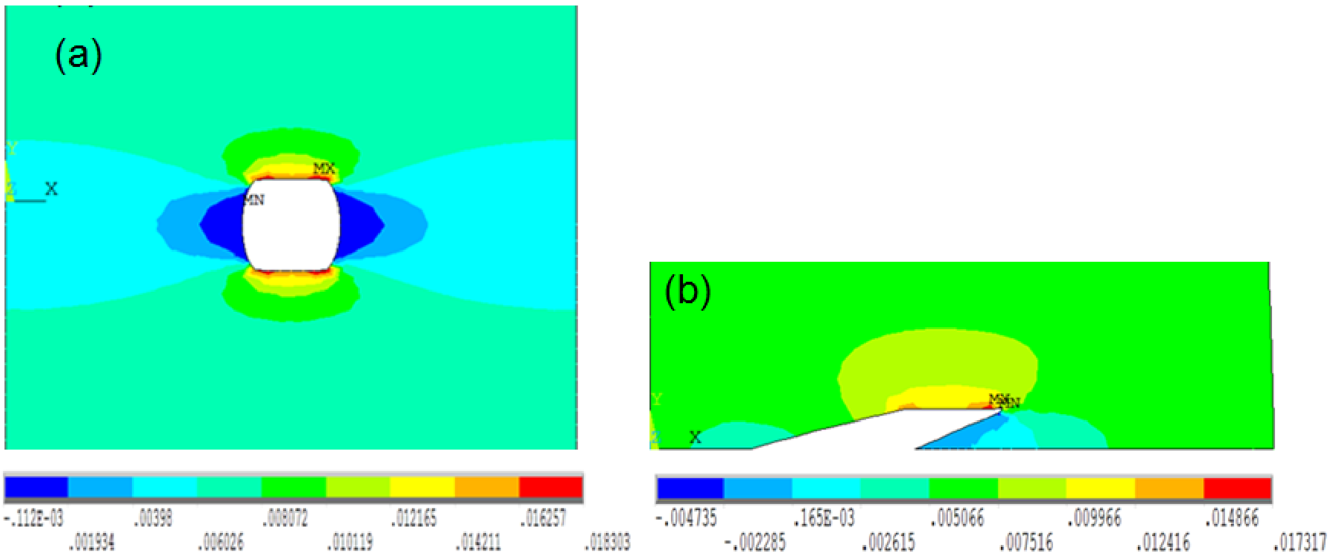

figure 3 3.a. stress field σ_x from the step B

3.b. Stress field σ_x in the V-Y flap with applied biaxial prestress.

After reaching the natural tension of the skin from the step B it was used in the step E for biaxial loading of the numerical model (figure 3.b). The maximal stress (figure 4) was found to be σx=45.3kPa σy=93.4kPa.

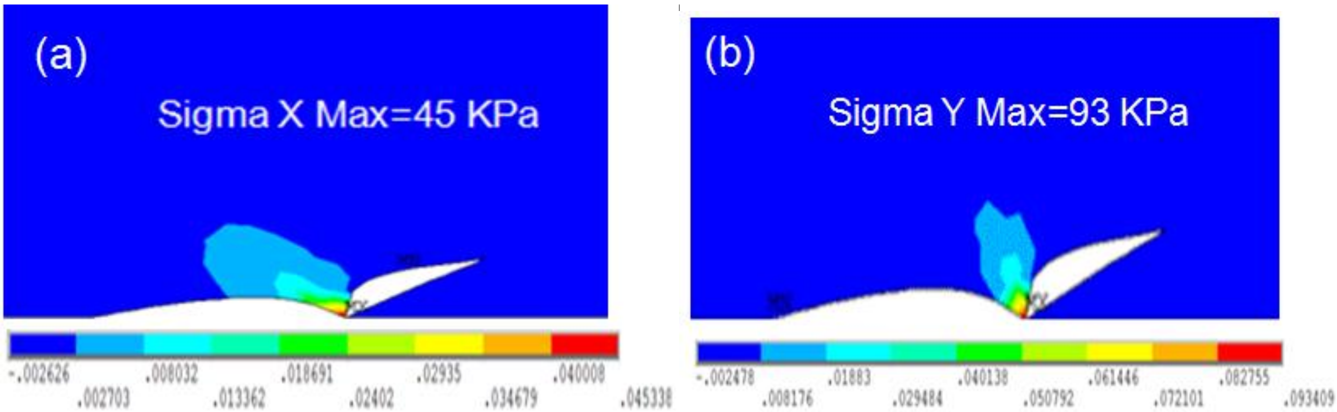

Figure 4 : Stress fields σx and σy from the step E

Discussion :

Proposed analyses allowed us to define the stress regions through the suturing process of the V-Y flap. The results reached in this study showed natural tension for our V-Y case to be biaxial, with σx=6.4kPa and σy=0.3kPa. The natural tension in vertical direction is inferior to that from horizontal direction, it corresponds well to literature. The value of σx approaches the value presented by Dahan (Dahan et al. 2004). It was shown that the step E, when suturing point M and N, is the most crucial during suturing. The surgeon must change the suture wire to thicker one providing the step E. In prospect, the analysis of the stress fields in V-Y flap simulation should allows us to predict the appearance of necrosis, which is sometimes clinically observed next to the most loaded suture points.

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