Medical Engineering and Physics 37 (2015) 987–994

Contents lists available at ScienceDirect

Medical Engineering and Physics

journal homepage: www.elsevier.com/locate/medengphy

Numerical analysis of the V-Y shaped advancement flap

D. Remache [a,b,c,1,2], J. Chambert [a,b,c,*], J. Pauchot [a,d,e], E. Jacquet [a,b,c]

[a] University of Franche-Comté, 1 rue Claude Goudimel, Besançon Cedex 25030, France
[b] Department of Applied Mechanics, FEMTO-ST Institute, CNRS UMR 6174, 24 rue de l'Épitaphe, Besançon 25000, France
[c] University Bourgogne Franche-Comté (UBFC), France
[d] Orthopedic, Traumatology, Aesthetic, Plastic, Reconstructive and Hand Surgery Unit, University Hospital of Besançon, 3 bd Alexandre Fleming, Besançon 25030, France
[e] Research Unit, EA 4268 I4S IFR 133 INSERM, Besançon 25030, France

ARTICLE INFO

Article history:
Received 16 December 2014
Revised 8 July 2015
Accepted 1 August 2015

Keywords:
Human skin
V-Y advancement flap
Finite element method
Hyperelasticity

ABSTRACT

The V-Y advancement flap is a usual technique for the closure of skin defects. A triangular flap is incised adjacent to a skin defect of rectangular shape. As the flap is advanced to close the initial defect, two smaller defects in the shape of a parallelogram are formed with respect to a reflection symmetry. The height of the defects depends on the apex angle of the flap and the closure efforts are related to the defects height. Andrades et al. 2005 have performed a geometrical analysis of the V-Y flap technique in order to reach a compromise between the flap size and the defects width. However, the geometrical approach does not consider the mechanical properties of the skin. The present analysis based on the finite element method is proposed as a complement to the geometrical one. This analysis aims to highlight the major role of the skin elasticity for a full analysis of the V-Y advancement flap. Furthermore, the study of this technique shows that closing at the flap apex seems mechanically the most interesting step. Thus different strategies of defect closure at the flap apex stemming from surgeon's know-how have been tested by numerical simulations.

1. Introduction

Complex flaps such as the Limberg skin flap [2] or Z-plasty flap [3,4] have been largely discussed in the literature on the contrast of the V-Y advancement flap for which only few theoretical studies have been proposed [1,5]. However this technique is generally used when a wound with a lack of substance needs to be covered.

A previous study [5] has been recently proposed to highlight the relation between the geometric parameters of the V-Y flap. In this previous paper, the skin has been considered as a rigid membrane and the technique has consisted in lessening the distance to suture through the three edges of the flap instead of concentrating on the initial lack of substance. Nevertheless the effective closure of skin defects is mainly obtained thanks to the elasticity of the tissue.

In the present paper, a more realistic approach is proposed by taking skin extensibility into account in order to quantify the sensitivity of several parameters for the V-Y advancement flap:

- The dimensions of the flap;
- The elastic properties of the skin;
- The natural tension within the tissue;
- The way to close and suture the wound.

The numerical analysis concerns the simulation of the suture and the prediction of the forces induced to close the wound. For each simulation, the skin flap is qualified by evaluating the closure effort at the most critical stitch point, also named the corner stitch. The critical stitch point is the one which requires the highest closure force and coincides with the flap apex when reaching the opposite edges of the wound. It is shown that a compromise between the size of the flap and the level of the closure effort value has to be found. The sensitivity to the mechanical parameters shows that the closure effort at the corner stitch is not only dependent on the size to be covered. At the end, the surgeon's technique is analysed: first by modifying the way of suturing the corner stitch and then by stretching the flap before suturing the wound.

* Corresponding author at: Department of Applied Mechanics, FEMTO-ST Institute, CNRS UMR 6174, 24 rue de l'Épitaphe, 25000 Besançon, France. Tel.: +33 3 81 66 60 25; fax: +33 3 81 66 67 00.
E-mail addresses: dj.remache@gmail.com (D. Remache), jerome.chambert@univ-fcomte.fr (J. Chambert), julien.pauchot@gmail.com (J. Pauchot), emmanuelle.jacquet@univ-fcomte.fr (E. Jacquet).
[1] Unité INSERM UMR 930 – Imagerie et Cerveau, Université François Rabelais, Équipe 5 – Imagerie et Ultrasons, 2 Bd Tonnellé, 37044 Tours Cedex 9, France.
[2] Laboratoire de Mécanique et Rhéologie, INSA Centre Val de Loire, Université François Rabelais Tours, 3 rue de la Chocolaterie CS 23410, 41034 Blois cedex, France.

http://dx.doi.org/10.1016/j.medengphy.2015.08.005
1350-4533/

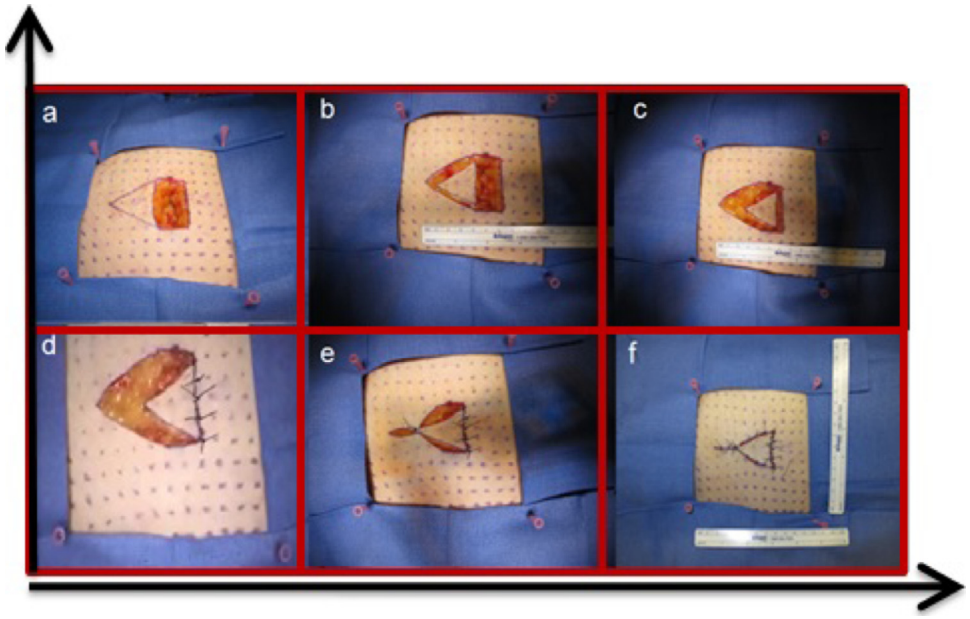

Fig. 1. Successive steps of a V-Y advancement flap: (a) design of a triangular flap adjacent to a rectangular defect. (b) incision of the triangular flap. (c) translation of the flap. (d) three first stitches to fix the flap on the intact skin. (e) corner stitch at the flap apex. (f) final closure.

2. Clinical practice of the V-Y advancement flap

2.1. Description of the V-Y advancement flap

In some clinical cases, it is necessary that the surgeon performs a chirurgical excision of cutaneous lesions such as tumours or nodules by cutting a large strip of skin. The V-Y advancement flap is commonly used in practice to cover skin defect as illustrated in Fig. 1. The main interest of the V-Y advancement flap lies in substituting the rectangular defect (Fig. 1a) adjacent to the base of the triangular flap by two smaller defects in the shape of parallelogram (Fig. 1d), which are adjacent to each side of the triangular flap. The main steps of this surgical technique are described as follows:

- First, the surgeon draws a rectangular pattern around the cutaneous lesion and an isosceles triangle adjacent to the largest dimension of rectangle. The dimensions of the triangle are defined by assessing the skin extensibility.
- Second, the surgeon excises the rectangular pattern, which takes the shape of a barrel (Fig. 1a) due to the natural tension of the skin. Indeed, the width of the rectangle in Fig. 1a is aligned with Langer's lines [6], which are parallel to the horizontal x-axis. Langer's lines define the direction within the human skin along which the skin exhibits minimum extensibility and maximum principal pre-stress. So, the skin natural tension is characterized by the orthogonal biaxial pre-stress state σ_x and σ_y. By the way, the rectangular defect is stretched along the horizontal and vertical directions. The Langer's lines direction is of great interest for surgical operations in particular to obtain a better wound healing process.
- Third, the surgeon performs an complete incision of the isosceles triangle (Fig. 1b), which becomes a triangular flap submitted to skin contraction as a result of the skin pre-tension. The flap remains attached to the body and is always kept by a vascular supply.
- Fourth, in order to cover the defect, the flap (Fig. 1b) is submitted to an horizontal translation to reach the distal border (Fig. 1c).
- Fifth, the flap is sutured to the surrounding skin for the closure of the wound firstly at the distal border: three first stitches shown on Fig. 1d.

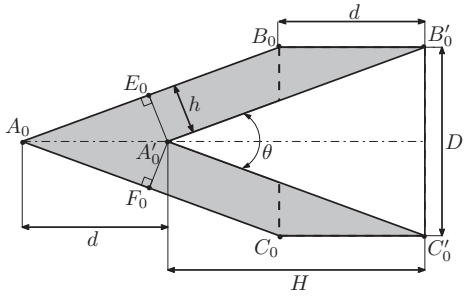

Fig. 2. Geometrical description of the V-Y advancement flap.

- Sixth, the flap is sutured at the flap apex (Fig. 1e). The fourth stitch, also called the corner stitch, is the most highly constrained.
- Finally, the whole flap is entirely sutured (Fig. 1f).

In current practice, the surgeon not only considers that the height of the flap remains unchanged before and after excising the triangular flap, but also performs a corner stitch with the nearest points on the opposite sides of the wound. Andrades et al. [1] have shown that once the dimensions of the defect are fixed, the angle at the flap apex and the flap height are the most important parameters of the flap geometry. These parameters depend on the location of the defect, the elasticity of the surrounding tissues and the cause of the surgery.

2.2. Geometrical analysis of the V-Y advancement flap

As in the preliminary analysis [5], the lack of substance considered as rectangle ($B_0B'_0C'_0C_0$) shown in Fig. 2 is covered by a triangular flap ($A_0B_0C_0$) incised from the largest dimension of the rectangle and translated through the defect ($A'_0B'_0C'_0$).

As described in Fig. 2, the dimensions of the lack of substance are $d \times D$. The angle at the flap apex is named θ. The height of the flap is H. In the V-Y technique, the initial rectangular lack of substance is replaced by two parallelograms ($A_0A'_0B'_0B_0$) and ($A_0A'_0C'_0C_0$) of height h which are formed by reflection symmetry (Fig. 2). The height of each parallelogram is smaller than the length of the initial rectangular one. The two following relations highlight the link between on the one