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Research Paper

On skin expansion

Djenane C. Pamplona[a,*], Raquel Q. Velloso[a], Henrique N. Radwanski[b]

[a]Laboratory of Membranes and Biomembranes, PUC-Rio, Rio de Janeiro, Brazil
[b]Ivo Pitanguy Institute of Plastic Surgery, Rio de Janeiro, Brazil

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ABSTRACT

This article discusses skin expansion without considering cellular growth of the skin. An *in vivo* analysis was carried out that involved expansion at three different sites on one patient, allowing for the observation of the relaxation process. Those measurements were used to characterize the human skin of the thorax during the surgical process of skin expansion. A comparison between the *in vivo* results and the numerical finite elements model of the expansion was used to identify the material elastic parameters of the skin of the thorax of that patient. Delfino's constitutive equation was chosen to model the *in vivo* results. The skin is considered to be an isotropic, homogeneous, hyperelastic, and incompressible membrane. When the skin is extended, such as with expanders, the collagen fibers are also extended and cause stiffening in the skin, which results in increasing resistance to expansion or further stretching. We observed this phenomenon as an increase in the parameters as subsequent expansions continued. The number and shape of the skin expanders used in expansions were also studied, both mathematically and experimentally. The choice of the site where the expansion should be performed is discussed to enlighten problems that can lead to frustrated skin expansions. These results are very encouraging and provide insight into our understanding of the behavior of stretched skin by expansion. To our knowledge, this study has provided results that considerably improve our understanding of the behavior of human skin under expansion.

1. Introduction

The present work intends to describe and raise considerations about the surgical procedure of skin expansion. Skin expansion is a physiological process based on the ability of human skin to increase its superficial area in response to a stress (Van Rappard et al., 1988). The surgical procedure is performed by implanting skin expanders under the subcutaneous tissue. Skin expanders are silicon bags of different shapes and sizes, which are infiltrated with a saline solution. The skin relaxes after a period of time, and if the imposed deformation is maintained, the resulting stress, and consequently the internal pressure, decreases. The physiology of skin expansion considers both the stretching of the skin and the relaxation process used to obtain an extra flap of skin that possesses the required characteristics. For example, skin expansions are used to reconstruct burned areas and breasts after mastectomy as well as to hide scars and defects. Several papers have been published on the behavior of the skin due to expansion. Beauchene et al. (1989) presented an animal experiment performed on 24 animals that expanded the skin of the peritoneal cavity for 32 days. The authors concluded that the skin tension increased dramatically

*Correspondence to: Laboratory of Membranes and Biomembranes/CTC, Marques de São Vicente 225, 22451-900 RJ, Brazil. Tel.: +55 212 511 1647.
E-mail addresses: djenane@djenane.com, djenane@puc-rio.br, djenane.pamplona@gmail.com (D.C. Pamplona).

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at the time of inflation but fell to almost the control values at the end of 32 days and the skin thickness, which initially decreased, returned to normal by the end of the experiment. Silver et al. (2003), in an overview on the mechanobiology underlying skin growth, affirm that the tension in the skin affects the skin biology and is responsible for the growth of the skin because tensile stresses applied to skin appear to stimulate cellular growth. Buganza Tepole et al. (2011) established a new computational model for stretch-induced skin growth during tissue expansion. To model skin growth, the authors adopted the multiplicative decomposition of the deformation gradient into an elastic and a growth portion. The growth was characterized as an irreversible, stretch-driven, transversely isotropic process parameterized in terms of a single scalar-valued growth multiplier, the in-plane area growth. The analysis was performed by numerically simulating the process of gradual tissue expander inflation. In particular, they compared the spatiotemporal evolution of the area growth, elastic strains, and residual stresses for four commonly available tissue expander geometries. Zollner et al. (2012) presented a continuum model for skin growth that summarizes the underlying mechanotransduction pathways collectively in a single phenomenological variable, the strain-driven area growth. To simulate the process of tissue expansion in an anatomically exact geometry, they created a finite element mesh from three-dimensional computer tomography images of a child. They only modeled the tissue expander implicitly by controlling the expander pressure. However, the interplay between the mechanics and the biology during tissue expansion remains unquantified. The authors maintain that, during expansion, the epidermis (0.06 to 1 mm) undergoes significant thickening and the dermis (1 to 4 mm) and subcutaneous tissue becomes significantly thinner. Although there is some tension transfer to the epidermis, the maximum tension occurs in the dermis, which explains why there is a significant thinning of the skin in some models, including Pamplona and Carvalho (2012). The highlighted studies indicate that skin growth and its thickness during the expansion process are controversial issues that require more research to clarify the process. In this research, the measured pressure inside the skin expander dropped dramatically in the first days and even in the first hours of expansion, due to the viscoelastic properties of the skin. This discontinuity in the stresses levels during the studied expansion process is the principal reason for not considering the growth of the skin in this model. We attributed this skin behavior to relaxation due to viscoelastic properties and not due to structural or molecular changes. In real tissue expansion, the external control parameter is the expander volume, not the internal pressure. Some simulations display creep under constant loading, but clinical tissue expansion may display relaxation under constant deformation instead; therefore, these models do not account for the fact that the tensile stress varies due to relaxation. In practice, it can be seen that if an expansion is frustrated in the initial steps, it stops before the expected number of expansions, and after the skin expander is removed, there is no extra flap of skin. The skin returns to its original size. When the skin expansion is completed, at the moment of the surgery, the skin immediately recovers part of the expanded surface area, given that, it is necessary to consider the need of 20–30% of extra tissue due to the dog ear, and mechanical recovery of the skin (Padam, 2009; Bhandari, 2009). It appears that only one to two months after the reconstruction, the skin gains its original thickness. The site of the expansion can be very important for attaining the extra flap of skin (Pamplona and Mota, 2012). The present article suggests the type, number and volume of skin expanders necessary to obtain the extra amount of skin to repair a certain medical problem and also proposes a constitutive equation to describe and predict the behavior of the expanded skin. We also show the importance of the site chosen for the expansion to assure that the whole procedure can be successfully accomplished.

2. Planning the skin expansion

Skin expansions are usually performed near the places where the skin is required to provide skin of the same color, texture, sensibility and structure as the skin to be removed, such as in the cases of scars, burns and so on. The question that is constantly raised during expansion is whether it will create enough skin; in other words, whether the achieved expansion is adequate to resurface the defect (Padam, 2009). These questions can be answered if one knows how much new tissue is required for the reconstruction in a given condition and if this required tissue (surface area) can be calculated in relation to the volume injected under of the expanded tissue. Additionally, the site of expansion can be very important to attain the extra flap of skin (Pamplona and Mota, 2012). Skin expanders are silicone bags of several shapes (circular, square, oval, croissant and rectangular) and internal volumes that are implanted under the subcutaneous tissue in different parts of the body. Through an incision, the surgeon inserts the skin expander and its valve under the skin. After the incision is closed, a saline solution, which should be equivalent to 10% of the nominal volume of the skin expander (Radwanski, 2012), V_n, is injected into the skin expander using a needle in the implanted valve. Some days after the surgery, the process of expansion begins, and in this way the process of cicatrization is guaranteed. During the skin expansion procedure, a certain volume of saline solution is injected into the expander every week. As the solution is injected, the skin expands due to the increase of pressure inside the expander producing stresses in the skin and, consequently pain in the patient. Because of the viscoelastic properties of the skin, the skin relaxes after some time, diminishing the pressure inside the expander and, the pain of the patient. After a week, there is no measurable pressure inside the expander. Fig. 1 shows a complete expansion in the stomach with a croissant skin expander.

Fig. 1 – Expansion in the stomach.