

OPTIMIZING BREAST RECONSTRUCTION WITH ADJUSTABLE IMPLANTS: A NUMERICAL ANALYSIS

Cristina de Abreu Alvim
Civil Engineering Department, Pontifícia Universidade Católica do Rio de Janeiro (PUC-Rio)
Rua Marquês de São Vicente, 225 CEP 22453-900 Rio de Janeiro RJ Brasil
crisalvi@civ.puc-rio.br

Djenane Pamplona
Civil Engineering Department, Pontifícia Universidade Católica do Rio de Janeiro (PUC-Rio)
Rua Marquês de São Vicente, 225 CEP 22453-900 Rio de Janeiro RJ Brasil
djenane@civ.puc-rio.br

Abstract. In the last few decades, breast reconstruction has evolved significantly due to the improvement of surgical techniques and development of new materials. Although most authors consider that breast reconstruction using autologous tissue offers the best aesthetic results, excellent outcomes have been obtained employing silicone implants. *A better understanding of the implications of using each type of adjustable implant on tissue dynamics and the influence on final breast shape is still lacking. The objective of this work is analyze the stresses and strains that occur in skin immediately after the breast reconstruction, to suggest the refinement of surgical techniques and the searching of new implant's models. This simulation is performed using the finite element package ABAQUS/Explicit.*

Keywords. Breast reconstruction, inflatable implants, ABAQUS

1. Introduction

In the last few decades, breast reconstruction has evolved significantly due to the refinement of surgical techniques and development of new materials. As a result, excellent aesthetic results may currently be achieved utilizing autologous tissue, prosthetic devices, or a combination of both. The social importance of these procedures is fundamental, since restoration of an aesthetic breast mound as a symbol of female identity enhances the quality of life of women previously submitted to mastectomy.

Although most authors consider that breast reconstruction using autologous tissue offers the best aesthetic results in terms of symmetry, excellent outcomes have been obtained employing prosthetic devices. The potential advantages of this reconstructive modality are its relative simplicity, employment of covering tissue with similar texture, color and sensation, avoidance of distant donor-site morbidity, less scarring, and reduced operative time and postoperative recovery (Spear et al, 2001).

Breast reconstruction can be performed in one or more stages and may be immediate (i.e. at the same stage as the mastectomy) or delayed (Malata et al, 2000; Ward et al, 1987 and Beasley, 1998). In fact, various different standard implants, adjustable implants and tissue expander are available to restore the breast's volume. Satisfactory results depend on adjusting the available options to the patient's anatomy, expectations and the surgeon's preference.

Potential candidates for reconstruction with adjustable implants are patients with small to moderate breasts (500g or less), minimal ptosis and a noticeable deficiency of tissue coverage.

The most important parameters that guide the choice between round and anatomically shaped implants are the breast's vase diameter, height and projection, all of which should be accurately measured before surgery. Implant volume may be estimated by weighing the mastectomy specimen during ablative procedure. In general, patients with flat, round breasts and without ptosis should receive a round implant, whereas anatomical implants tend to offer more satisfactory results in breasts presenting some fullness in the lower pole and minimal ptosis. Mastopexy or breast reductions may be necessary for matching symmetry in patients whose contralateral breast is large and/or ptotic (Spear et al, 2001).

The commonest way to reconstruct a breast using breast implants is divided in two steps. First, the surgeon draws the size and position of the implant in the skin, after making an incision he peels the marked area of skin layer and places the skin expander under the skin. The expander is enlarged by serial injections of saline solution over several weeks to stretch the skin and implant pocket in preparation for a permanent implant. Recently, a new expandable breast implant has been developed and approved for use in breast reconstruction (Wanzel et al, 2003). This implant is very similar to a tissue expander with an integrated port, as it is inserted in the same fashion and is then expanded slowly over the course of several weeks. However, the advantage of this device is the fact that after the implant is expanded to the desired size, it remains as a permanent breast implant. Therefore, the implant reconstruction becomes closer to a one-staged procedure, as the expander does not have to be replaced with a permanent implant. The injection port is removed through a minor secondary procedure. The main disadvantage is the increased cost of the device.

Nipple and areola reconstruction is performed at a time when the surgeon and patient are both happy with the final shape and size of the reconstructed breast.

In almost all cases, the surgeon uses the mastectomy's incision to introduce the empty implant or tissue expander. This incision uses to be horizontal or transversal:

Figure 1. Incision and scar after the mastectomy

Unfortunately, some of the long-term outcomes of breast reconstruction using prosthetic devices have been frustrating due to capsular contracture, infection and deflation (Maxwell, 1992). Even though the use of textured implants reduced these complications, a better understanding of the implications of using each type of adjustable implant on tissue dynamics and the influence on final breast shape is still lacking, and is the purpose of this research.

2. Objective

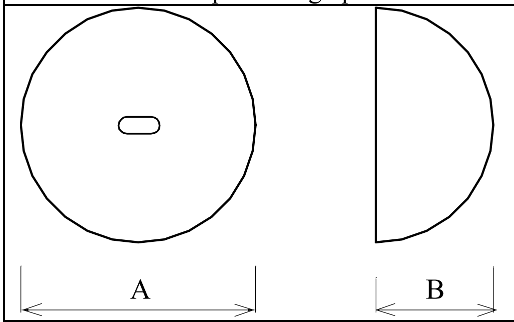
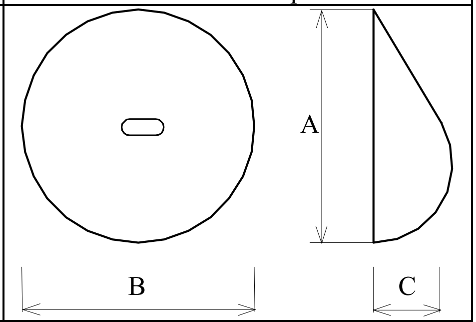
The final objective of this work is to analyze numerically the stresses and strains that occur in skin immediately after the breast reconstruction, to suggest the refinement of surgical techniques and the searching of new implant's models. The common mastectomy site (used for the insertion of the implant and/or the tissue expander) is verified to be stretched or compressed. If in this region occurs the highest stresses, it is interesting to analyze if the suture is "strong" enough or if it is better to avoid an incision and suture in this site. Furthermore, the patient is in the horizontal position during breast reconstruction and the nipple reconstruction. So, it is interesting to visualize the final aspect of reconstructed breast when the patient is upstanding to be sure about the position of the reconstructed nipple.

In this stage, two models of implants are compared: a round shaped implant with high profile and an anatomical implant, both with internal volume equal to 200 cm^3 (Fig (2) and Tab. (1)). Both implants are inflatable, so they remain in the reconstruction's place after the desired volume and shape are reached.

(a) (b)

Figure 2. Inflatable mammary implants: (a) round shape and (b) anatomic shape

Table 1 – Mammary Implants – Dimensions

Round implant - high profile	Anatomical implant
	
Volume (cm³): 200 A: 10.1 cm B: 4.4 cm	Volume (cm³): 200 A: 11.3 cm B: 10.3 cm C: 4.5 cm

The tissue to be expanded (chest skin) and the implant are, at this stage, considered isotropic, homogeneous and hyperelastic materials. The strain energy function, proposed by Ogden and shown in Eq. (1), is used:

$$W = \sum_{i=1}^{N} \frac{2\mu_i}{\alpha^2}\left(\lambda_1^{\alpha_i} + \lambda_2^{\alpha_i} + \lambda_2^{\alpha_i} - 3\right), \tag{1}$$

where μ_i and α_i are material parameters.

Additionally, the effects of gravity and implant's weight are verified.

3. Methodology

The simulation of a breast reconstruction is performed using the finite element package ABAQUS/Explicit (pre and post processor). Skin is modeled as a hyperelastic membrane; initially plane, subjected to an indentation imposed by the completely filled implant. The square shape (width = 20 cm) and the boundary conditions of skin model were idealized to analyze the stresses in the neighborhood of reconstructed breast and to simulate the peeled skin, free for transversal movement, as shown in Fig.3.

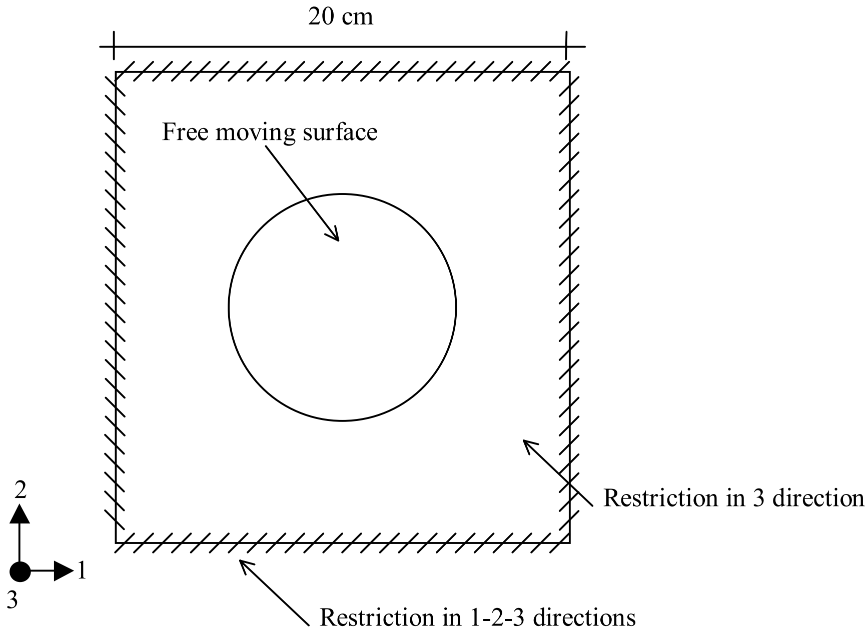
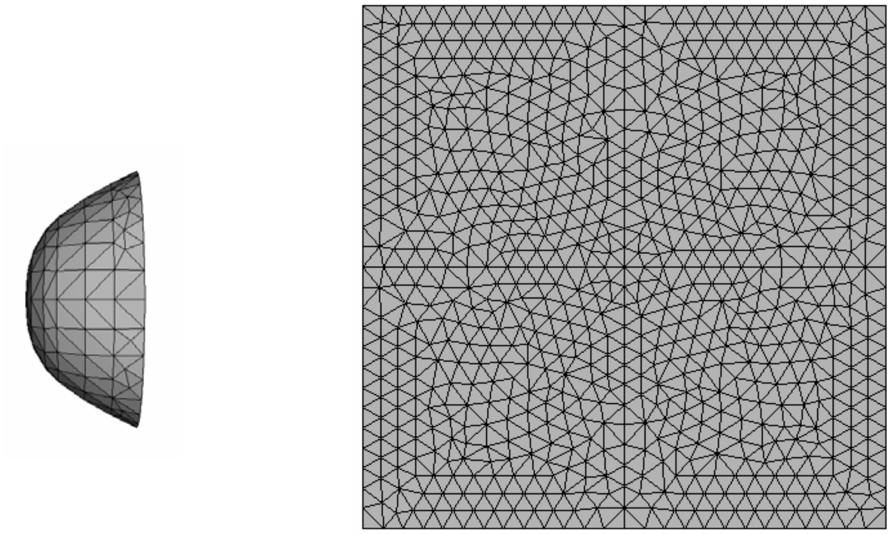


Figure 3. Scheme of boundary conditions.

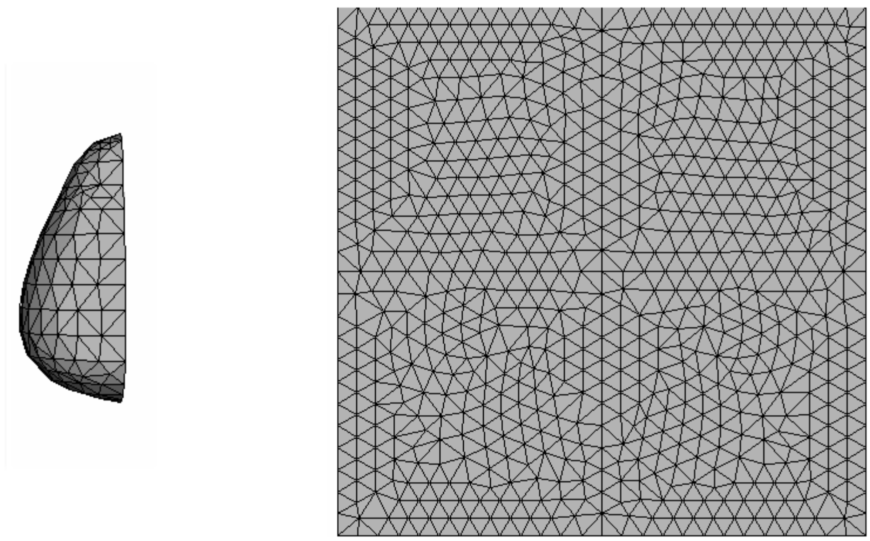
The material parameters of the skin were previously obtained from the tissue expansion in an animal model (Pamplona et al, 1999). In this research it was possible to model the pig's skin with two terms of the Ogden's function: μ_1= 2950 Pa, μ_2= 5900 Pa, α_1= 2 e α_2= 4. Although the implant is a silicone bag filled by a fluid, it is modeled here as a hyperelastic solid. Its material constants were first evaluated modeling the effects of gravity in a totally filled expander.

This parameters are still in development, but to a comparative simulation, one term of the Ogden's function for implant is used: μ_1= 2350 Pa, α_1=-4,7. The discretized models of membrane and implants can be seen in Figs. 4 and 5:



(a) (b)

Figure 4. Finite Element Models of: (a) round implant and (b) plane membrane



(a) (b)

Figure 5. Finite Element Models of: (a) anatomic implant and (b) plane membrane

The analysis is performed in two steps: in the first one (indentation step), the implant is displaced in the membrane's direction. After a total penetration, we consider that the implant is completely filled. In the next step (gravity step), the gravity effect is considered. The final volume of the implant is known, whereas the density of the fluid (in this case, water). So, the weight of the reconstructed breast is considered, simulating the upstanding position.

4. Results

The automatic discretization of complex models is an important advantage of pre-processor ABAQUS/CAE. Numerous simulations can be performed using this tool. However, as it is described in Abaqus Manual (2002), the symmetry of the discretization is not guaranteed in very complex models, as an example, the anatomic implant and its respective membrane are shown in fig. (5).

The regions with highest stresses in round and anatomical implant procedures, before and after the gravity step, are compared:

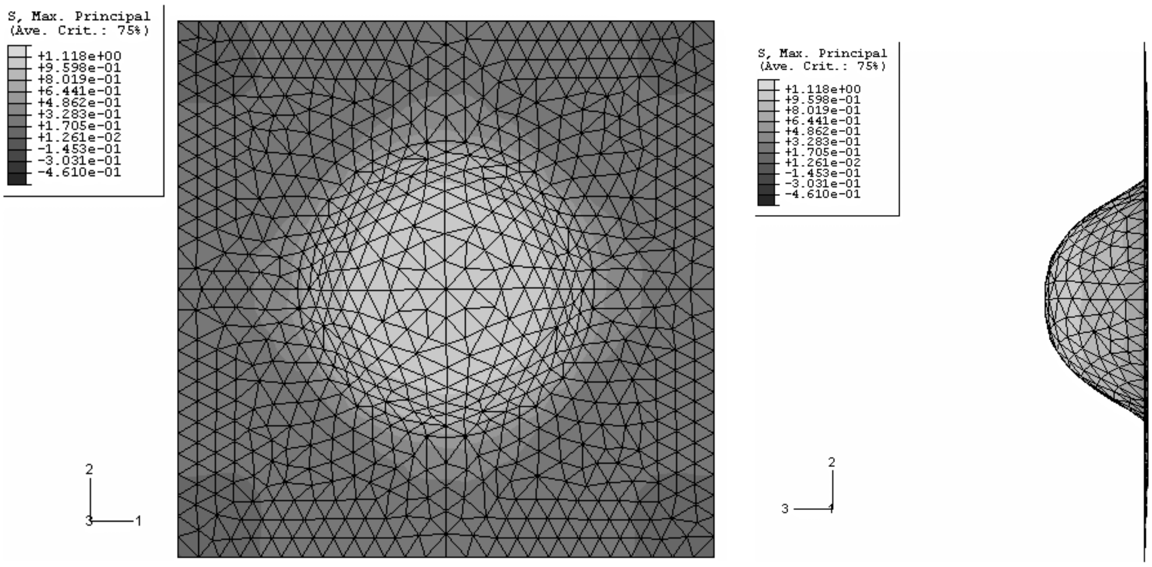


Figure 6.Stresses using round implant, after indentation step: frontal view and profile (Obs.: stresses in N/cm^2 in all the following figures)

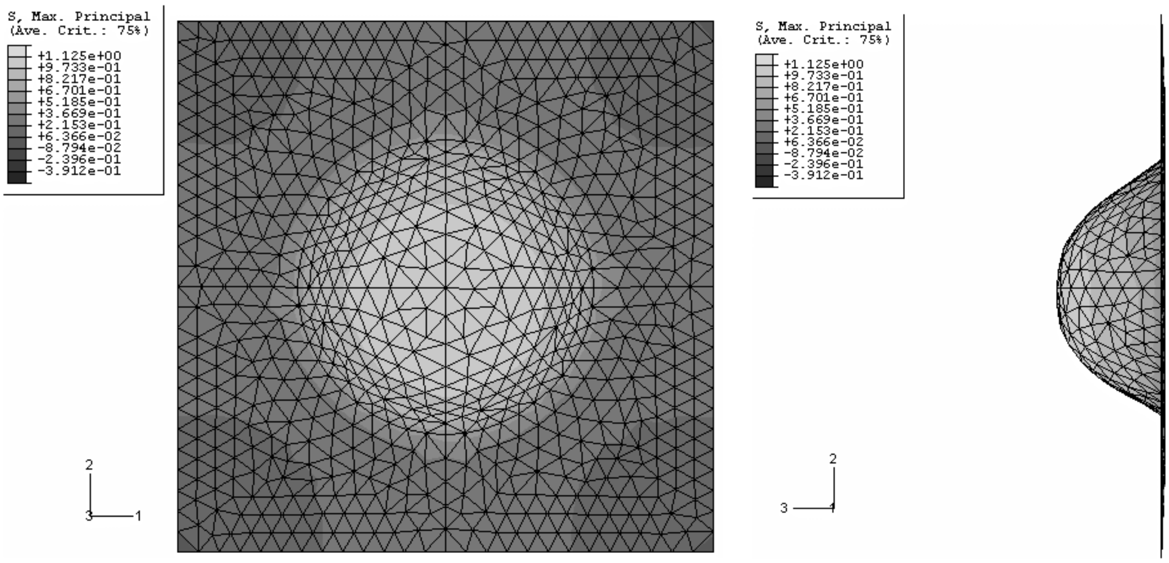


Figure 7. Stresses using round implant, after gravity step: frontal view and profile

In the round implants, the stresses are symmetrically distributed. The skin over the implant and the entire adjacent region are completely under traction. The regions of higher max. principal stresses are located in the center of reconstructed breast. After the indentation, the stresses vary from 9.59 to 11.18 kPa. After the gravity step, stresses vary from 9.73 to 11.25 kPa. In the neighborhood, 5 cm far from the implant border, the stresses are lower, comparing to the lower part of the reconstructed breast (0 a 2.583 kPa).

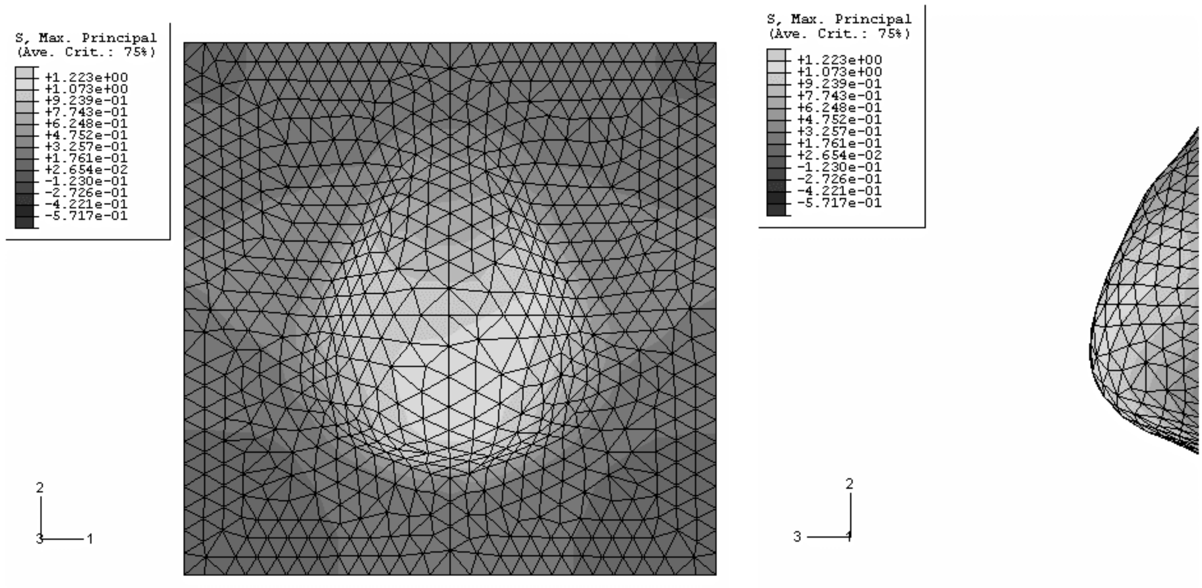


Figure 8. Stresses using anatomic implant, after indentation step: frontal view and profile

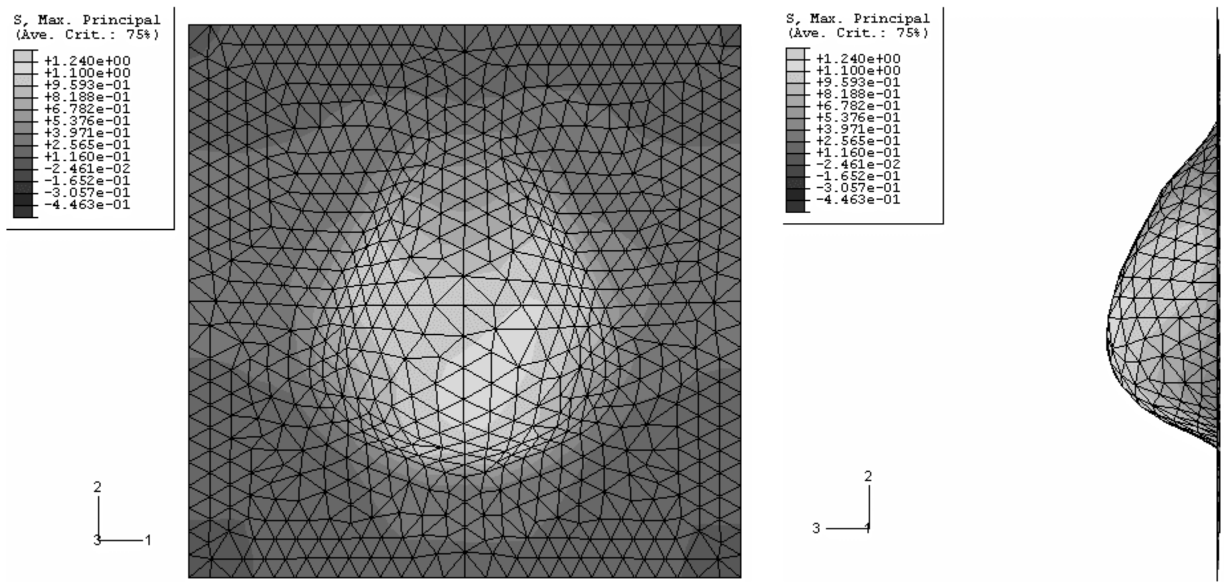


Figure 9. Stresses using anatomic implant, after gravity step: frontal view and profile

The skin that covers the implant and the entire adjacent region are also under traction. The regions of max. principal stresses are located in the lower pole. After the indentation, the stresses vary from 10.73 to 12.23 kPa. After the gravity step, stresses vary from 11 to 12.4 kPa. In the neighborhood, the stresses also are lower (0 a 1.16 kPa).

5. Conclusions and Suggestions

Incision and scars after the mastectomy use to be in a horizontal or transversal position. To choose the type of implant it is necessary to analyze the mastectomy procedure. If the scar is located near the lower pole, it would be better to use a round implant, to avoid the high stresses that the anatomic implant could cause. On the other side, the anatomic implant could be the best choice if the scar is located in the central region of the new breast.

The ideal situation would be a scar near the inframammary fold. In this region, the stresses are relatively low, in both implants, round or anatomic. The final scar could be hidden by the natural profile of the breast.

This article is a first stage of a complete research involving the study of breast reconstruction and finite element analysis. The following steps are: use human skin's parameters to be able to compare our results with the stresses obtained in the numerical simulation of skin suture (Yoshida et al, 2001 and Chretien-Marquet et al, 1999).

The material parameters of the implant, modeled as a solid, can be more accurately determined, using more terms in the Ogden's function. Other constitutive laws can also be tested.

The adjacent skin has presented very low stresses. So, it could be interesting to optimize the neighborhood region and analyze two breasts together.

The viscoelastic properties of skin were ignored here, to simplify the analysis, although it has been shown that they are important to model skin in one of our previous investigations. Considering the relaxation of stresses as function of time, a conventional procedure of breast reconstruction, using tissue expanders and permanent implants, will be developed.

It could be seen that the stresses and strains, before and after considering gravity, do not increase too much. But, in the future analysis, considering the viscoelastic properties, the strains in a reconstructed breast can be evaluated after weeks, months and years.

6. Acknowledgement

We are grateful to the Brazilian National Council for Research (CNPq) for their financial support for this project. We are also thankful to the plastic surgeons from Santa Casa de Misericórdia do Rio de Janeiro and Dr. Ivo Pitanguy's staff, for their technical support.

A special thank to Claudio Ribeiro Carvalho, Msc, for technical support in ABAQUS.

7. References

ABAQUS/Explicit User´s Manual (ver.6.3), 2002, Hibbit, Karlsson & Sorensen, Inc., USA

Beasley, M.E., 1998, "Two stage expander/implant reconstruction: Delayed", In SL Spear (Ed.), Surgery of the Breast: Principles and Art, 1st Ed. Philadelphia: Lippincott-Raven

Chretien-Marquet, B., Caillou, V.Brasny, D.H., Bennaceur, S., Buisson, T., 1999, "Description of coetaneous excision and suture using a mathematical model", ", Plast Reconstr Surg 103:145-150

Malata, C.M., McIntosh, A.S., Purushotham, A.D., 2000 "Immediate breast reconstruction after mastectomy for cancer", Br J Surg, 87(11), 1455-72

Maxwell, G.P., and Falcone, P.A., 1992, "Eighty-four consecutive breast reconstructions using a textured silicone tissue expander", Plast Reconstr Surg 89: 1022

Pamplona, D., Alvim, C.A., Carvalho, C.R., 1999, "Axially Symmetric Analysis of Tissue Expansion Using the Theory of Elasticity and Finite Element Analysis", In: IV International Symposium in Computer Methods in Biomechanis and Biomedical Engineering, Lisboa, Portugal.

Wanzel, K.R., Brown, M.H., 2003, "Reconstructive Breast Surgery Website", http://www.breastreconstruction.ca

Spear, S.L., and Majidian, A., 1998, "Immediate breast reconstruction in two stages using textured, integrated-valve tissue expanders and breast implants: A retrospective review of 171 consecutive breast reconstructions from 1989 to 1996", Plast Reconstr Surg 101:53

Spear, S.L., Spittler, C.J, 2001 "Breast reconstruction with implants and expanders" Plast Reconstr Surg 107(1), 177-187

Ward, J., Cohen, I.K., Knaysi, G.A., Brown, P.W, 1987, "Immediate breast reconstruction with tissue expansion", Plast Reconstr Surg, 80(4), 559-66

Yoshida, H., Tsutsumi, S., Mizunuma, M., Yanai, A., 2001,"A surgical simulation system of skin sutures using a three-dimensional finite element method", Clin, Biomech 16: 621-626