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DEVELOPMENT OF AN APP TO ASSIST DOCTORS ON CHOOSING SKIN EXPANDERS

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Abstract. *Skin expansion is a physiological process that is defined as the ability of the human skin to increase its superficial area in response to stress or to a given deformation. Skin expanders are silicon bags that are implanted underneath the skin. Because the skin presents creep or relaxation, the resulting stress decreases after a specific amount of time due to the imposed deformation. For example, skin expansions are used to reconstruct burned areas and breasts after a mastectomy or to hide scars. This technique is usually performed near areas where skin is required, to provide skin of the same color, texture, sensibility and structure as that to be removed, such as in cases of scars and burns. However, a question that constantly arises during skin expansion is whether it creates a sufficient amount of skin or, in other words, whether the achieved expansion is sufficient to resurface the defect. These questions may be answered with information about how much new tissue is required to achieve the reconstruction in a given context and if this required tissue (surface area) might be calculated in relationship to the volume infiltrated. The goal of the present study is to calculate the number and shape of skin expanders required to ensure that an extra area of skin is present to achieve the reconstruction. Thus, this study provides information to determine the type, number and volume of skin expanders necessary to obtain an extra amount of skin to repair a specific medical condition and to determine the amount of skin obtained even in cases when the expansion does not come to term. Round, as well as rectangular and crescent skin expanders are discussed.*

Keywords: *skin expansion, reconstruction surgery, skin, expander*

1. INTRODUCTION

Skin expansion is a physiological process that is defined as the ability of human skin to increase its superficial area in response to stress or to a given deformation. Skin expanders are silicon bags of different shapes and sizes that are implanted underneath the skin. Because the skin presents creep or relaxation, the resulting stress decreases after a specific amount of time due to the imposed deformation. The physiology of skin expansion not only consists of the stretching of the skin, but it also includes the relaxation process involved to obtain an extra flap of skin with specific characteristics. For example, skin expansions are used to reconstruct burned areas and breasts after a mastectomy or to hide scars. This technique is usually performed near areas where the skin is required to provide skin of the same color, texture, sensibility and structure as that to be removed, such as in cases of scars and burns. Since the study conducted by (Austad and Rose, 1982 Schmidt and Logan, 1991) have attempted to improve the expansion process. Several authors have also examined the concepts and complications involved in the surgical process. Indeed, there have been numerous studies and findings on skin expansion obtained from a medical perspective. However, few studies have investigated the bioengineering process.

The question that constantly arises during skin expansion is whether this method results in sufficient skin, that is, whether the achieved expansion is sufficient to resurface the defect. These questions can be answered if information about how much new tissue is required to achieve the reconstruction in a given situation is known and if the required tissue (surface area) can be calculated in relationship to the volume of the expanded tissue.

Several attempts have been made to calculate the desired dimensions of the expander using computer programs and mathematical calculations. Raposio (Raposio and Santi, 1997) determined that the base dimensions of a rectangular tissue expander should be equal to the dimensions of the defect. They multiplied the surface requirement by 3/2, a "correcting factor" which accounted for tissue loss during the tissue transfer. Patel (Patel 1986)) contradicted Shively (Shively, 1986) and presented a mathematical calculation to predict the desired volume and height of a spherical expander without the aid of a computer. He suggested that when an analytical calculation is possible, then there was no need for a computer to perform these simple calculations. Furthermore, Duits and colleagues (Duits, Mollenar and

Rappart, 1989) presented mathematical calculations for rectangular and crescent-shaped expanders. Bhandari (Bhandari and Padam, 2009) presented a more simplified version for the mathematical calculation of the volume of a spherical expander by providing several examples of different types of defects. He considered the need to add 20-30% extra tissue for rotation, dog-ear and mechanical creep, resulting in a "stretch back". He also emphasized that the calculations should account for the inward displacement of the underlying tissue due to the pressure effect of the tissue expander. Finally it is proposed a mathematical calculation to predict the extra amount of skin needed for a round tissue expander. The total surface area required to resurface the defect could be calculated as the surface area of the defect added to the surface area of the donor site plus 20% of the defect and donor site surface areas. But, the surface area gained in vivo was significantly less compared to that determined by the mathematical calculation. Van Rappard (Van Rappard *et al*,1988) found that using spherical or semi-spherical expanders, the surface area gained was only 25% of the mathematical calculation, while it was 38% and 32% using the rectangular and crescent-shaped expanders, respectively. This resulted valid for expanders of any size. They concluded that the mathematical calculations proposed could only be used to guide in the selection of the expander. Furthermore, selection of the shape and size of the expander required a sound clinical judgment.

2. OBJECTIVE

The goal of the present study is to calculate the number and shape of skin expanders that will ensure the presence of an extra flap of skin for reconstruction, developing an application for i-Phone and Android to aid doctors in their choices. Round, rectangular and crescent skin expanders are considered.

Skin expanders are silicone bags of several shapes (circular, square, oval, crescent, rectangular), and internal volumes that are implanted underneath the skin in different parts of the body. During the skin expansion procedure, a specific volume of saline solution is administered inside the expander every week. The volume is dependent on the size of the expander and mostly on the discomfort of the patient. As the solution is administered, the skin expands due to the increase in pressure inside the expander, resulting in pain in the patient.

The surface area gained using tissue expanders is still debatable. In an *in vivo* model, the surface area gained from the use of tissue expanders was completely different from the predictions obtained using the mathematical and computer models developed until now.

First, the amount of skin required to resurface the defect, S_d, should be measured. Using Bhandari, the total surface area required to resurface the defect = surface area of the defect, S_d, + surface area of the donor site, S_{ds},+ 20% of the sum of the surfaces of the defect and donor site. This results in 20% more tissue due to skin retraction, which occurs after the removal of the skin expander. This also accounts for the retraction of the skin itself. This superficial area has to be equal or smaller than the flap of skin obtained by expansion using the formulas and tables developed in this study. Importantly, the extra flap of skin, $S_f^{i\,**}$, is the corrected superficial area of the expanded skin, $S_f^{i\,*}$, minus the area of the base of the expander, S_{ds}, because this region has to be re-covered using the gained skin.

For the rectangular skin expander with dimensions, *a* and *b* for the basis and *c* for the height, the relation between the internal volume V_i^r and superficial area S_f^r is straight forward.

$$S_f^r = c \times 2 \times (a+b) + (a \times b). \tag{1}$$

$$V_i^r = a \times b \times c. \tag{2}$$

A spherical cap, which represents the shape of a circular expander, is shown in Fig. 1. Dimension *a* represents the radius of the base and *h* is the height of the skin expander.

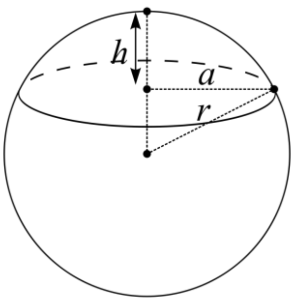


Figure 1. Spherical cap representing a circular expander.

The internal volume V_i^c of a spherical cap with radius *a* and height *h* and its surface area are given by the following equations:

$$V_i^c = \frac{\pi}{6}\left(3a^2 \times h + h^3\right) \quad (3)$$

$$S_f^c = \pi \ (a^2 + h^2) \quad (4)$$

For a crescent-shaped skin expander, it was not possible to accomplish a formula to determine the surface area (Fig. 2); thus, all calculations used to determine the relationship between the surface area and internal volume were performed using Finite Elements with Abaqus vi. Tridimensional Membrane finite elements with 4 nodes (M3D4), including the material, hyperelastic, similar to Mooney –Rivlin with the following parameters: C1 = 82.4 Pa and C2 = 99.2 Pa.

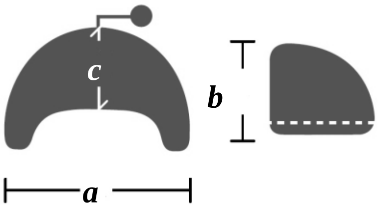


Figure 2. Crescent-shaped skin expander.

3. EXPERIMENTAL ANALYSIS

Formulas for the extra flap of skin were obtained mathematically or numerically; thus, it was necessary to verify if the results obtained were consistent with those obtained in reality. To achieve this, two experimental apparatuses were developed with a rigid acrylic base where four skin expanders were attached. One of them round (V_n^c of 200 ml), with radius *a*= 4.8 cm, and height *h*= 4.1 cm, another rectangular (V_n^r of 250 ml) with base *a*= 9.6 cm, *b*= 5.9 cm, and height *c*= 5.0 cm, Fig. 3. Another acrylic basis was constructed for two crescent-shaped skin expanders (V_n^{cresc} of 150 ml and 300 ml) (Fig. 4). A latex membrane was used to cover the skin expanders to simulate the skin.

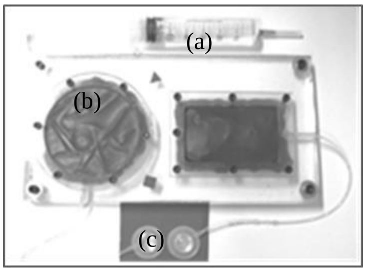


Figure 3. Experimental apparatus used for the round V_n^c = 200 ml and rectangular V_n^r =250 ml skin expanders, (a) syringe and needle, (b) skin expander valve.

Figure 4. Two crescent-shaped skin expanders (V_n^{cresc} of 150 ml and 300 ml).

Using Rhinoceros 4 software program, the internal volume and superficial area were determined. The scanned surfaces are shown in Fig. 5(a, b, c).

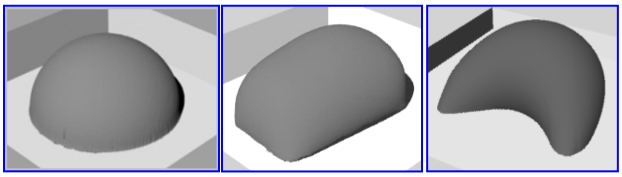


Figure 5. The scanned surface of expanders: (a) circular 200 ml, (b) rectangular 240 ml and (c) crescent 300 ml.

The following results revealed differences between the results obtained using a mathematical formula or Finite Elements and the results obtained in a more realistic manner using a 3D scanner. A comparison between the superficial area measured using the scanner, and a superficial area obtained using the formulas or finite elements, made possible to define correction factors to be used in the results obtained by formulas or finite elements. Those are 1.03 and 1.07 for the round and crescent, i.e. almost no correction, but 0.83 to the calculated superficial are of the rectangular skin expander. Differences in the results were clearly observed for the rectangular expander because the corners of its shape, when confined, become rounded and not sharp, and resemble a parallelepiped, resulting in a smaller superficial area.

4. THE ALGORYTHM

Although for the rectangular and round skin expanders it can be easy to relate the superficial area to the internal volume using Eqs 1-4, the correction factor has to be considered. For the crescent skin expanders the results of the finite element analysis can be seen in Tab. 1. Those results are for the most used geometry.

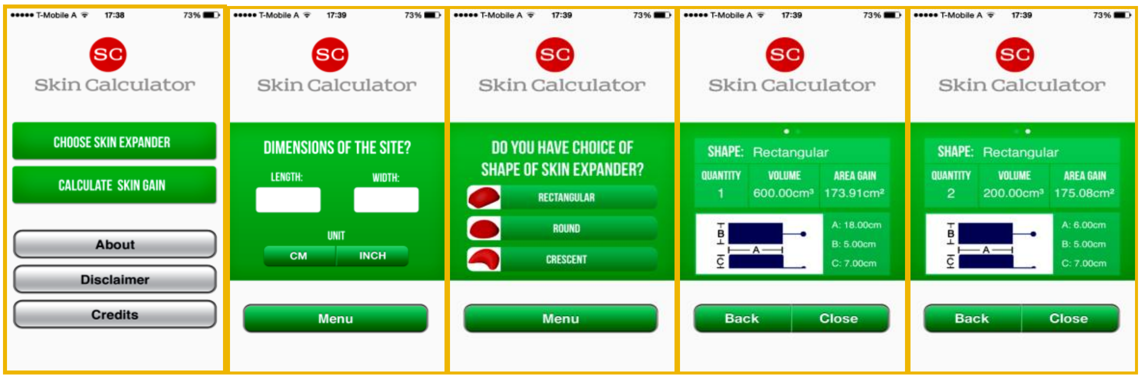
Table 1: Results for the superficial area obtained S_f^{cresc} using crescent-shaped expanders filled with the nominal volume V_n^{cresc} and the extra flap of skin $S_f^{cresc^*}$.

V_n^{cresc} *(ml)*	*a(cm)*	*b(cm)*	*c(cm)*	$S_f^{cresc}(cm^2)$	$S_f^{cresc}(cm^2)$
12	5.1	2.1	2.1	23.17	7.54
25	6.0	2.7	2.6	36.75	13.90
50	6.8	3.5	3.3	56.51	24.24
100	8.1	4.3	3.5	93.14	46.36
150	8.7	4.6	4.1	117.85	58.98
200	9.3	4.9	4.7	143.69	74.71
300	10.1	5.6	5.8	185.00	97.58
400	11.4	6.2	6.5	224.18	114.79
700	13.4	7.8	8.8	314.53	152.02

The extra flap of skin obtained, for the three skin expanders considered, crescent, S_f^{cresc*}, round S_f^{c*} and rectangular, S_f^{r*} is obtained using 80% of the calculated area, since 20% is lost due to the retraction of skin, minus the area of the site where the skin expander is implanted, that has also to be covered.

5. THE APLLICATION “SKIN CAL” FOR IPHONE AND ANDROID

The application aims to guide the plastic surgeon in choosing the number, shape and volume of skin expanders needed to obtain a given area of skin flap to be used in a plastic reconstructive surgery. The information provided is the area of retail, where the retraction of the skin and dog ear (20%) was already subtracted and also the skin required to cover the site where the expander was implanted. The results obtained are for an expansion over rigid or very firm tissue. The results over soft tissue as adipose tissue are not be reliable, but can give you an estimative of what to expect, Pamplona e Mota (2012).The application has two functions *CHOOSE SKIN EXPANDER* e *CALCULATE SKIN GAIN*.

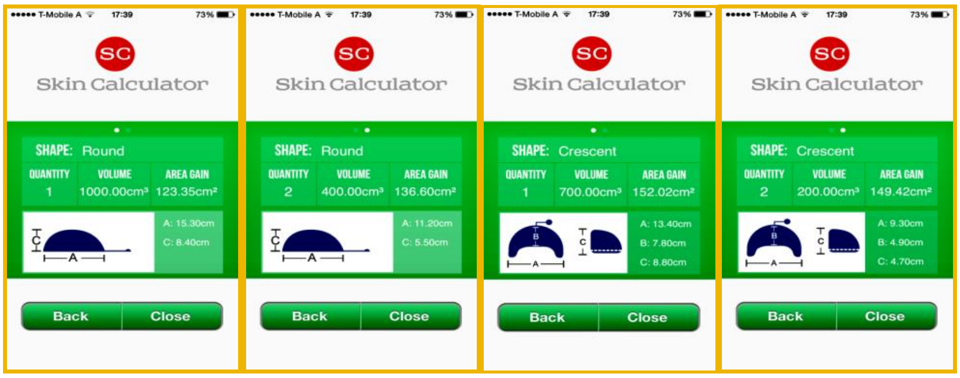


(a) (b) (c) (d) (e)

Figure 6. Screens for "*SKIN CALC*": (a) opens; (b) asks for the size of the defect; (c) asks for the type to be used; (d) returns the information if one rectangular skin expander is used; (e) for the option of two skin expanders

Tapping on *CHOOSE SKIN EXPANDER*, Fig. 6(a), one gets Fig. 6(b) asking for the size of the defect to be reconstructed (in centimetres or inches), and returns, Fig. 6(c), to the user the different choices of skin expanders, (number, type and nominal volume) that will allow the reconstruction safely. As an example for a site that has 10x12 cm, i.e., 120 cm^2 (Fig. 6(b)), and choosing an rectangular expander, Fig. 6(c), there will be two possibilities: one, Fig. 6(d) of a skin expander of 600 ml, with its dimensions offering a skin flap to be used of 173,91 cm^2, or, Fig. 6(e), two skin expanders of 200 ml with its dimensions offering a skin flap to be used of 175,08 cm^2.

The option *BACK* turns possible to choose another geometry, IF the choice is round it gives back two possibilities; one skin expander of 1000 ml, Fig. 7(a), with its dimensions offering a skin flap to be used of 136,3 cm^2 , or two skin expanders of 400 ml, with its dimensions offering a skin flap to be used o136,6 cm^2, Fig. 7(b). If the users chooses the crescent skin expander, it gives back two possibilities: one skin expander of 700 ml, Fig. 7(c), with its dimensions offering a skin flap to be used of 152,02 cm^2 , or two skin expanders of 200 ml, with its dimensions offering a skin flap to be used 149,42 cm^2, Fig. 7(d). The round geometry is by far the worst choice.

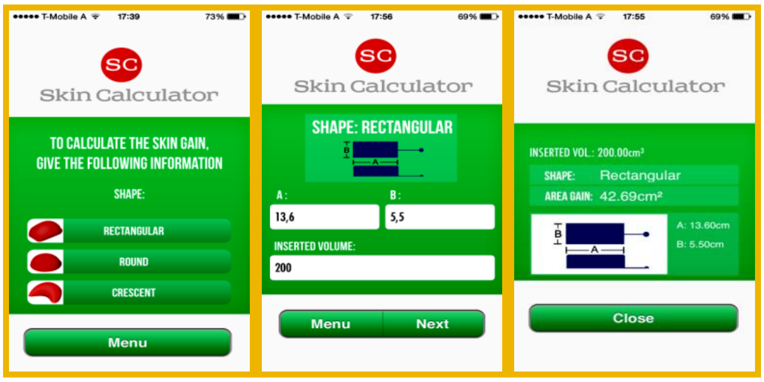


(a) (b) (c) (d)

Figure 7. Screens for "*SKIN CALC*": (a) returns option for the use of one round skin expander (b) returns option for two round skin expanders; (c) returns option for the use of one crescent skin expander; (d) returns option for two crescent skin expanders.

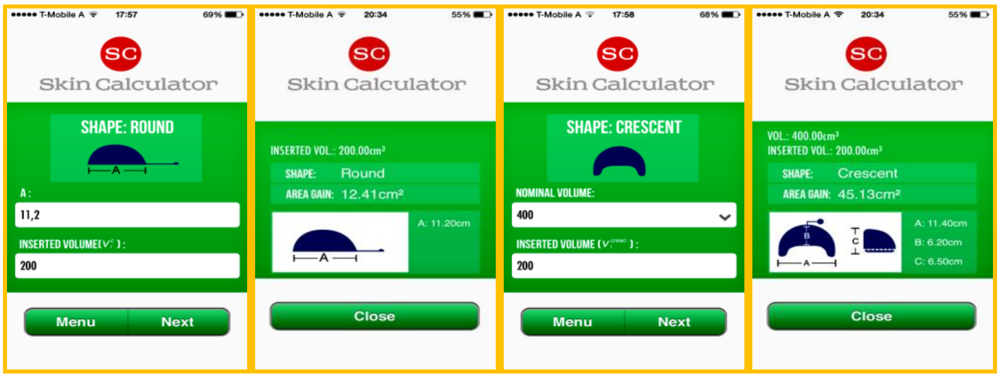
The function *CALCULATE SKIN GAIN* allows the user to know the amount of skin gain using a certain skin expander given the infiltrated volume. It asks for the geometry of the skin expander, Fig. 8(a), in this case rectangular, asks for the dimensions of the basis and infiltrated volume, Fig. 8(b) and returns the size of the flap of skin gain to be used Fig. 8(c), 42,69 cm^2.

If the skin expander in question is round, it asks for the diameter of the basis and the infiltrated volume, Fig. 9(a), and returns the size of the flap of skin gain to be used 12,41 cm^2, Fig. 9(b). In the case of the crescent skin expander the screen asks for the nominal volume of the expander and the infiltrated volume, Fig. 9 (c) and returns the size of the flap of skin gain to be used 45,13 cm^2, Fig. 9(d). Again the round skin expander with 400 ml of nominal volume, equal in the tree cases, infiltrating the same volume, offers the smallest skin flap.



(a) (b) (c)

Figure 8. Screens for "*SKIN CALC*": (a) asks for the geometry; (b) asks for the dimensions of the basis and infiltrated volume; (c) returns the size of the flap of skin gain to be used.



(a) (b) (c) (d)

Figure 9. Screens for "*SKIN CALC*": (a) asks for the diameter of the basis and the infiltrated volume; (b) returns the size of the flap of skin gain; (c) asks for the nominal volume of the expander and the infiltrated volume; (d) returns the size of the flap of skin gain.

6. CONCLUSIONS

The app has shown to be quite helpful, being considered as a fantastic improvement by plastic surgeons. It was verified that some of the expander geometries, in spite of having greater nominal volumes result in a lower skin gain. The main questioning is about the efficiency of the round expander. In future works, considerations on expansions done over soft tissue will be better explored and quantified, so that it may be included in the app.

7. ACKNOWLEDGEMENTS

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