Simulating External Compressions of the Breast with the Surface Evolver

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Talk

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DEDICATION

THE 2nd AUTHOR

DEDICATES THIS WORK

TO HIS WIFE,

THE WOMAN THAT CONCEDED

HER MEASUREMENTS

FOR OUR RESEARCH.

1. Introduction

1.1. Breast Cancer

- The 2nd main cause of obits among women in the globe. At the 1st place: lung cancer. For details, browse on the web for *Cancer Fact Sheets - World Health Organization*.

- In Brazil, the *Cancer National Institute* predicted 53,000 cases of breast tumours in 2012, with an estimate risk of 52 cases per 100,000 women. In our country, the population has ca. 100 million women. Some statistics show these cases have been increasing.

1. Introduction

1.2. Mammography

- To date, this technique still has the best cost-benefit. It's largely applied in *developing countries*. Other techniques: resonance and ultrasonography.
- But all of them have a common disadvantage: the breast shape deforms drastically.
- For the surgery, tumour location is highly uncertain. A great portion of the breast has to be removed.

2. Surface Evolver

2.1. Brief History

- It was created by Prof Ken Brakke (nowadays at Susquehanna University - USA). First release: 1989.
- *Evolver* allows to simulate physical experiments in a virtual environment.
- Its source code is open. See `http://www.susqu.edu/brakke` for details.

3. Our Research

3.1. Aims

- In the long-term: a full and detailed reproduction of the mammography procedure with *Evolver*.
- By starting with the mammographies that show tumour nodules, we rewind the virtual procedure. Nodule position is located with precision for the surgery.

3.2. Purpose

- Remove tumour nodules through a small incision. The whole breast is preserved upon slight corrections by plastic surgery.

3. Our Research

3.3. Remarks

- The Purpose is not new. Many softwares have been developed to model the breast anatomy and its deformations by mammography procedures. For instance, [1,2,4].
- Some are aesthetically impressive, like [1]. However, its functionality wasn't tested yet, and too many components can lead to excessive computational complexity.
- Others stick to the essential, like the ITK-software (see [7]). Breast components are treated as global masses (fat, glands, etc.) But ITK works with meshes and produces a "Lego-effect" that penalises smoothness.

3.4. Why to Use the Surface Evolver?

- It works with *surface layers*, which can be refined to three-dimensional meshes if necessary.
- We can control the triangulation of each surface layer, at any step of the simulation and plainly. We can make triangles uniform, refine and remove them, either locally or globally, in order to avoid lack and excess of graphical data.
- Evolver optimises declared quantities given by integrals, and we can track values any step of the simulation (pressure, area, volume, etc.)
- With *Evolver* we can vary the complexity of our model. Components are added and removed at will, as well as their individual properties.

3. Our Research

Figure 1: Side view of the breast(*).

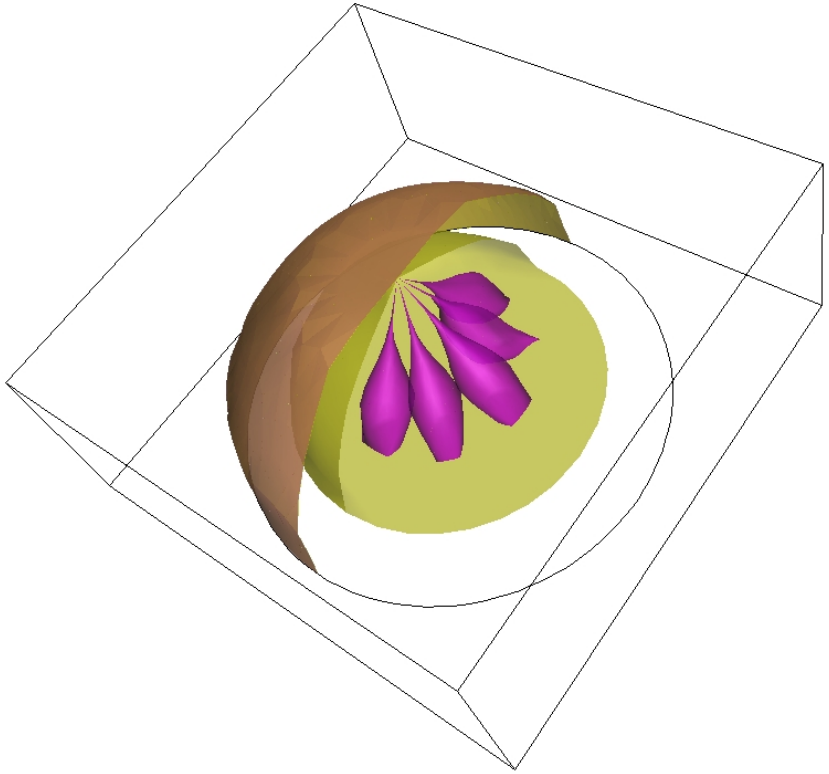

Figure 2: Surgery position with visible components.

(*) Taken from http://en.wikipedia.org/wiki/Portal:Medicine/Selected_picture/26

3. Our Research

3.5. Some Care at Using Evolver

- It's a powerful tool largely applied in several Areas of Knowledge, like Biology, Physics, Chemistry and Mathematics (see [4,5,6]).
- However, Evolver works with *surfaces*. Even when simulating volume, mass, gravity, etc., the inside of surfaces are meant to be either *ideal gases* or *liquids*. Namely, it was not programmed for three dimensional elasticities, but for superficial elasticities.
- For the time being, our work is devoted to simulations of external compressions of the breast. In order to track tumour nodules, we shall either consider the complexity of internal parts, or equate their trajectory by performing experiments with transparent breast phantoms.
- Hence, instead of working with too many components, we can take numerical trajectories and predefine them in our Evolver model.

3. Our Research

Figure 3: Stereotactic Needle Biopsy(*).

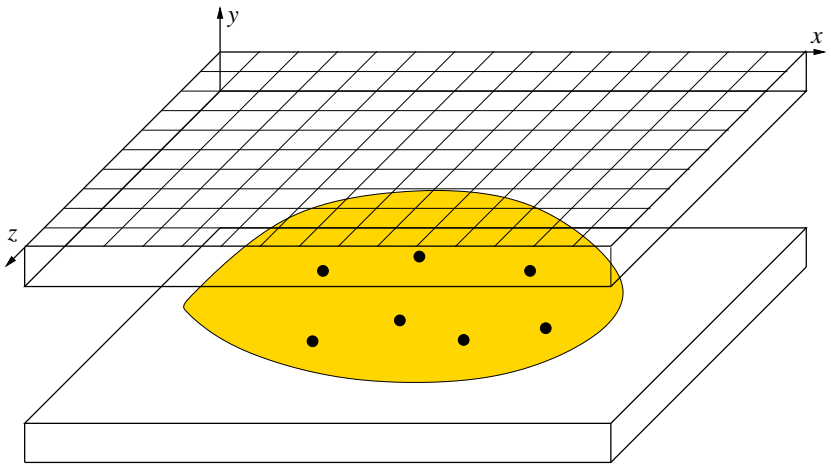

Figure 4: Performing CC/MLO compressions with the phantom.

(*) Taken from http://www.imagingsol.net/product/1724/Stereotactic-Needle-Biopsy-Training-Phantom.html

4. Our Programme

4.1. Preliminaries

- Before running the programme, the user should take strategic measurements.
- Together with a Virtual Tape-Measure, they'll help tweak the virtual breast towards the patient's.
- We use the term *breast base*, which is fixed to the woman's thorax. It's easily recognised when the woman is lain down. When she stands up, you can use the jugular notch to locate it again.
- The whole process depends upon 6 main steps for each breast: SRG (surgery), STU (stand-up), LAT (lay-on-table), CRC (cranio-caudal), LET (lean-on-table) and MLO (medio-lateral-oblique).
- Of course, the mass of the breast remains constant as the shape changes.

4. Our Programme

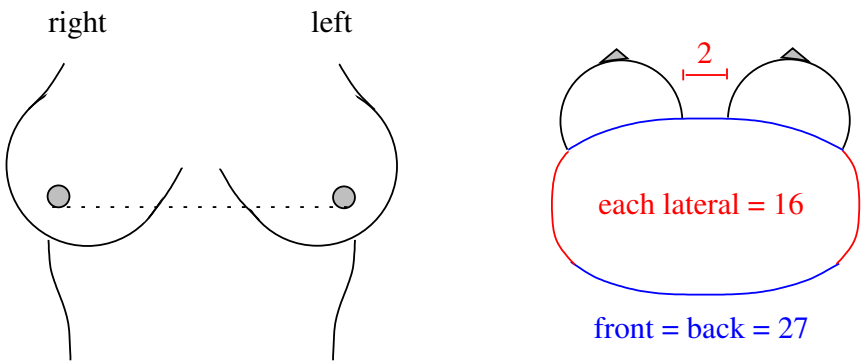

Figure 5: Strategic stretches of the thorax.

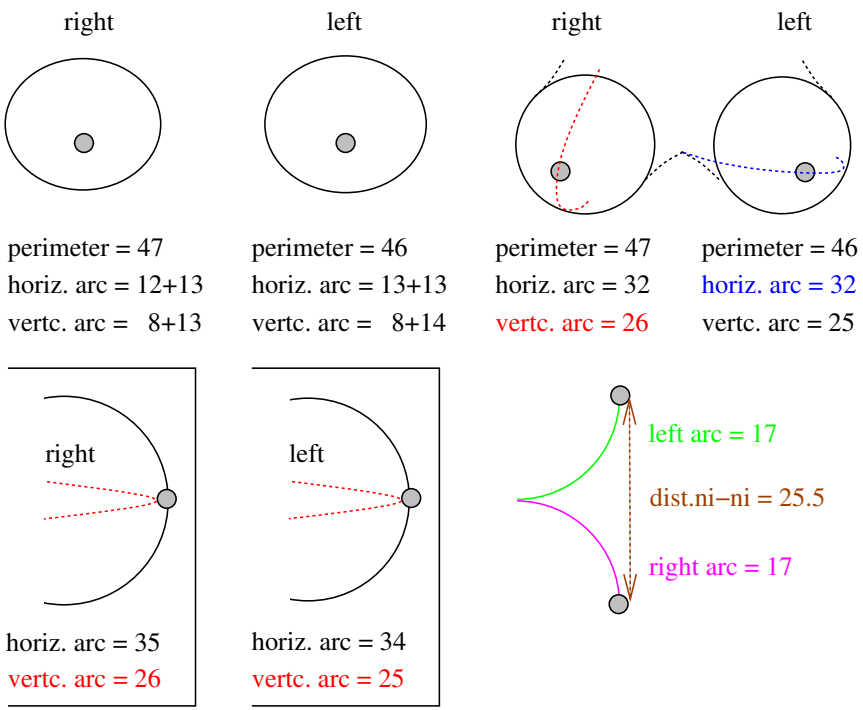

Figure 6: Measurements of SRG, LAT and STU (in colours).

4. Our Programme

4.2. Getting Started

- We recommend the Operating System Linux Ubuntu ≥ 11.10, Evolver 2.50 and Geomview 1.9.4.
- For the time being, we have implemented SRG, STU and LAT, all of them for the left breast only.
- You can run it in our Virtual Machine. Details: Link *Softwares* at
  http://www.facom.ufu.br/~nascimento
- Type **evolver lbs** and start a simulation with **qq**. A pyramid will appear. The command **pvars** displays the volunteer's measurements for SRG. You can change them at will.
- Now **srg** will make the pyramid evolve to the virtual breast, of which half is kept transparent for internal visualisation; **clean_bbase** and **nipple** will finally result in Figure 7.

4. Our Programme

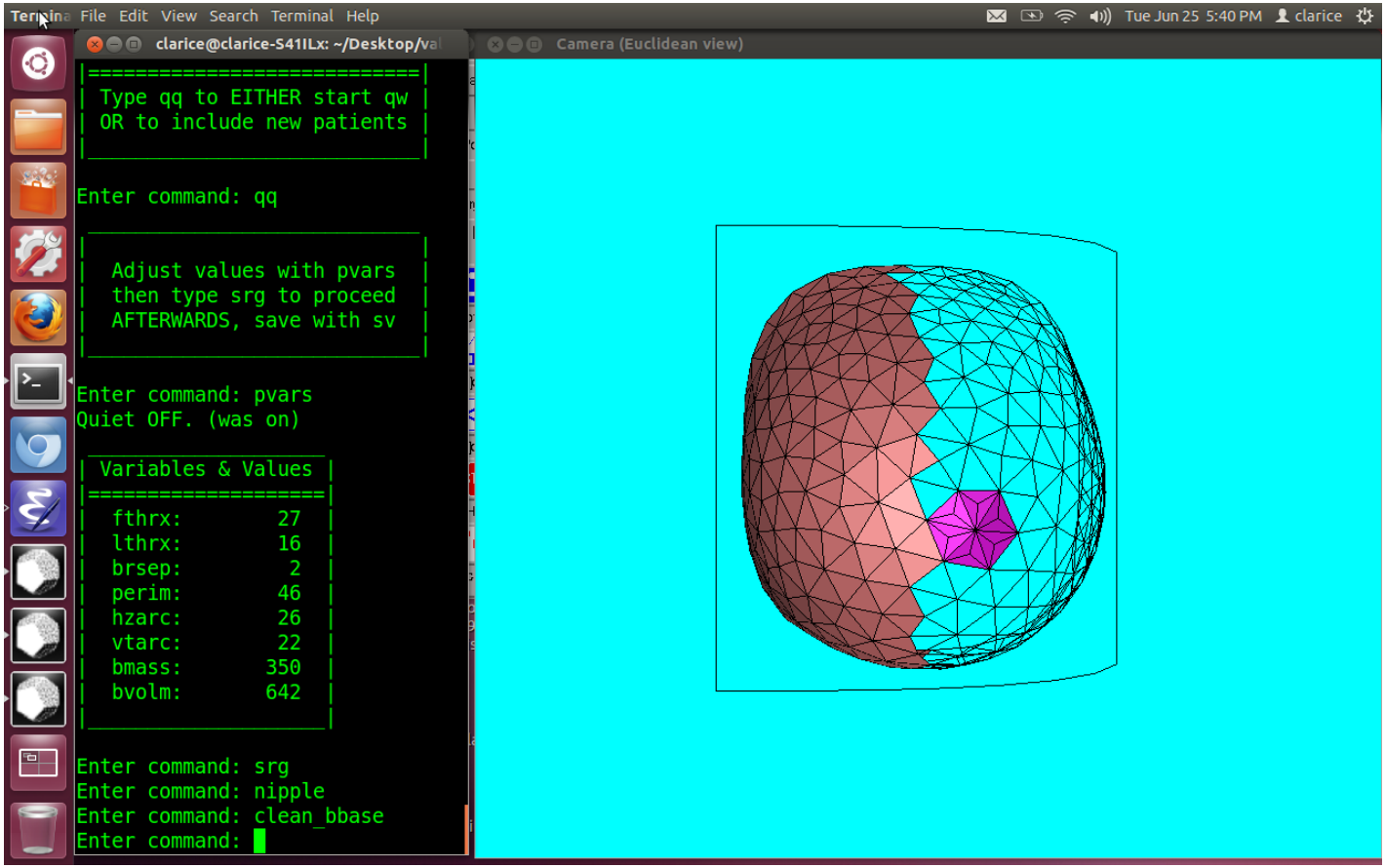

Figure 7: Virtual left breast with nipple.

4. Our Programme

4.3. Remarks

- Our simulation always start with SRG, because it is the most symmetric position.
- In practice, not only a surgical drape holds the base of the breast, but also an auxiliary surgeon and an extra support fitted under the woman's armpit.
- Thus, measurements in Figure 6 must be taken with this extra support, which can be a wrapped hand towel.
- You can rotate the image in space with the mouse. In order to restore the initial position type **rt** (see Figure 8).

4. Our Programme

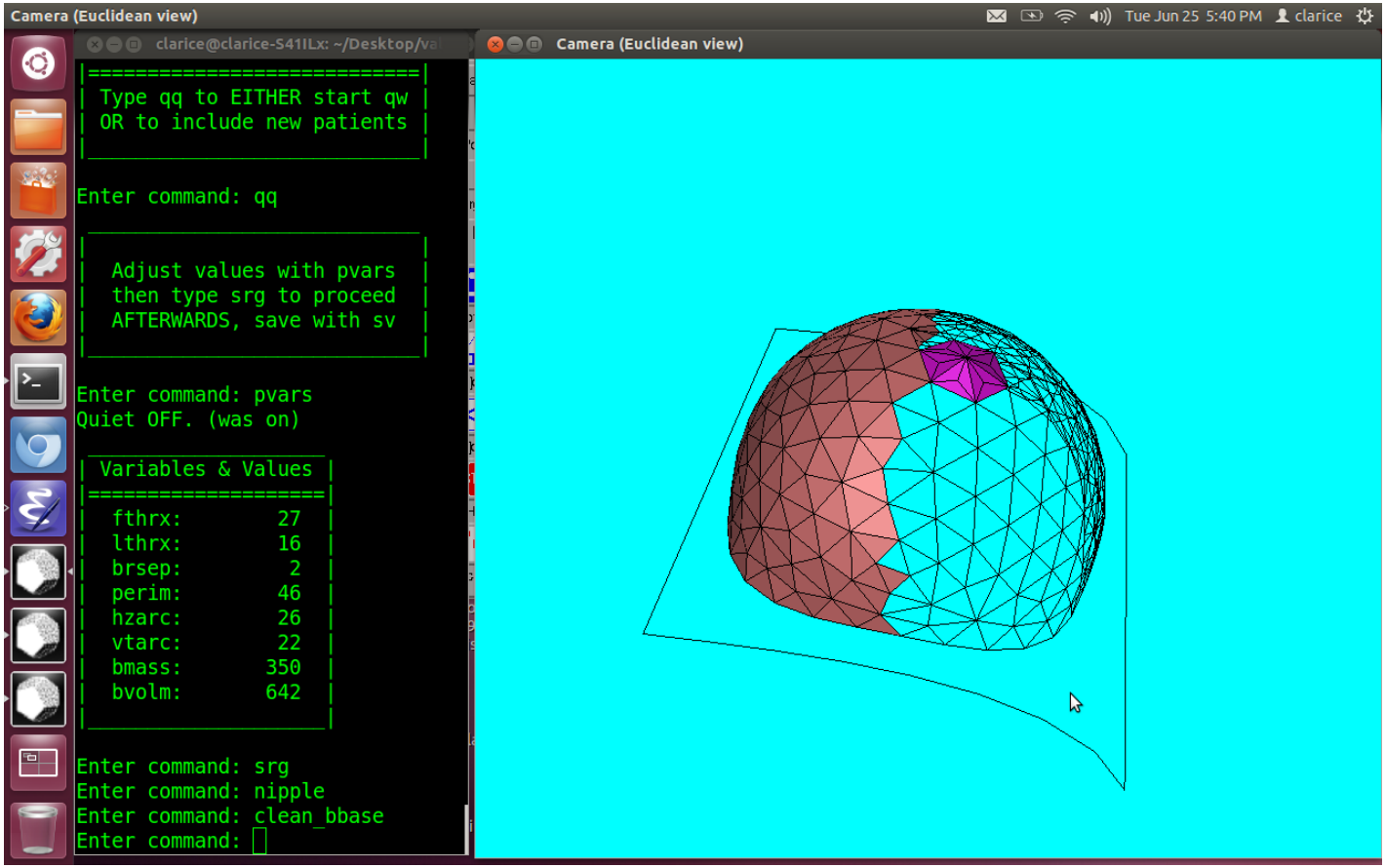

Figure 8: Rotating the image in space with the mouse.

4. Our Programme

4.3. Checking Measurements

- You can call our Virtual Tape-Measure with **tmr**, as many times as needed.
- We work with a shooting method in order to attribute an initial value to **bvolm** (breast volume). This initial value consider the breast to be the upper hemisphere of an ellipsoid. This is obviously not the case.
- You have to call **pvars** and guess some increase or decrease in **bvolm**. Then type **tmr** to check the changes. Repeat these three commands until you're close to the real measurements. See Figures 9 and 10.

4. Our Programme

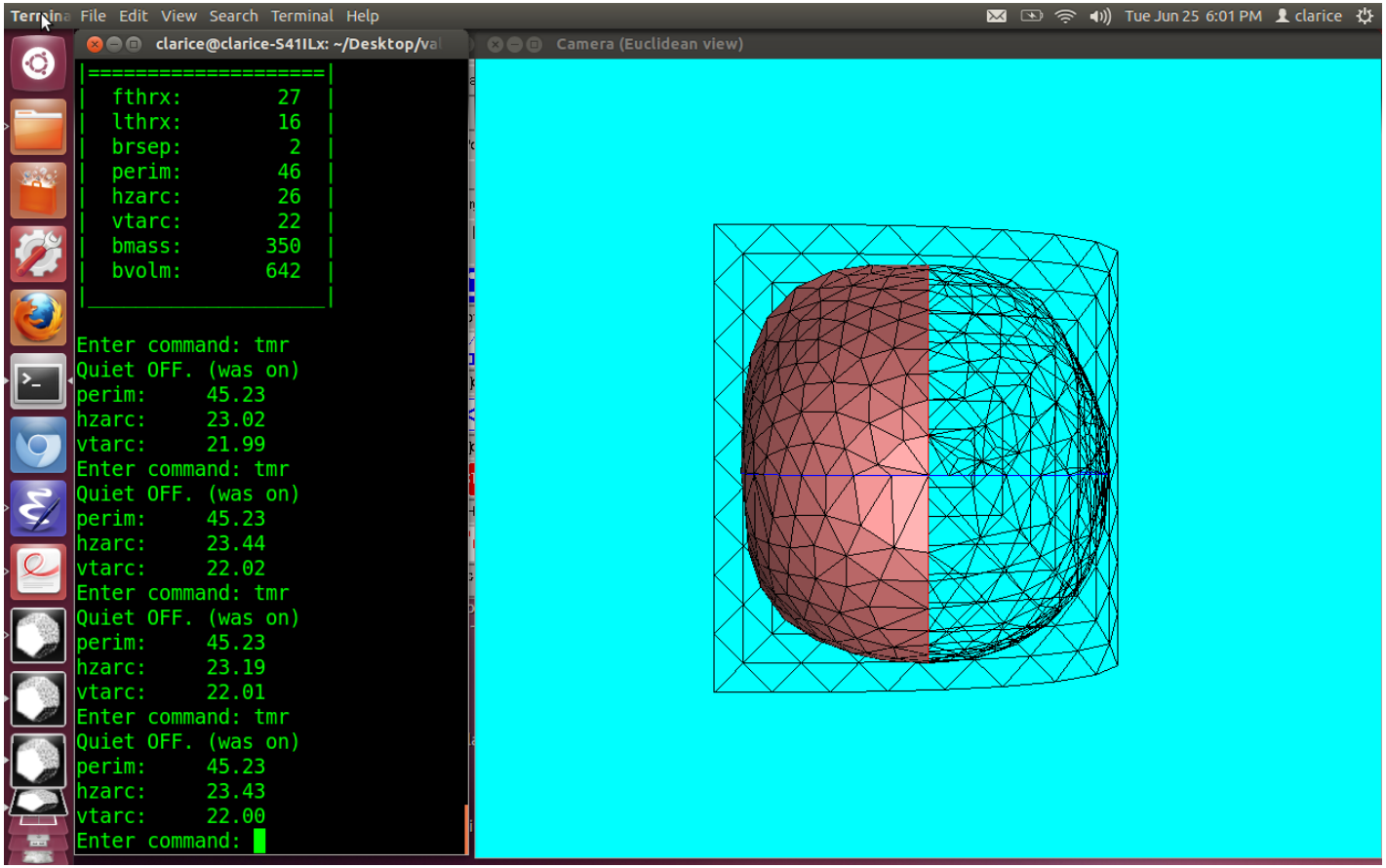

Figure 9: The command `tmr` - Virtual Tape-Measure.

4. Our Programme

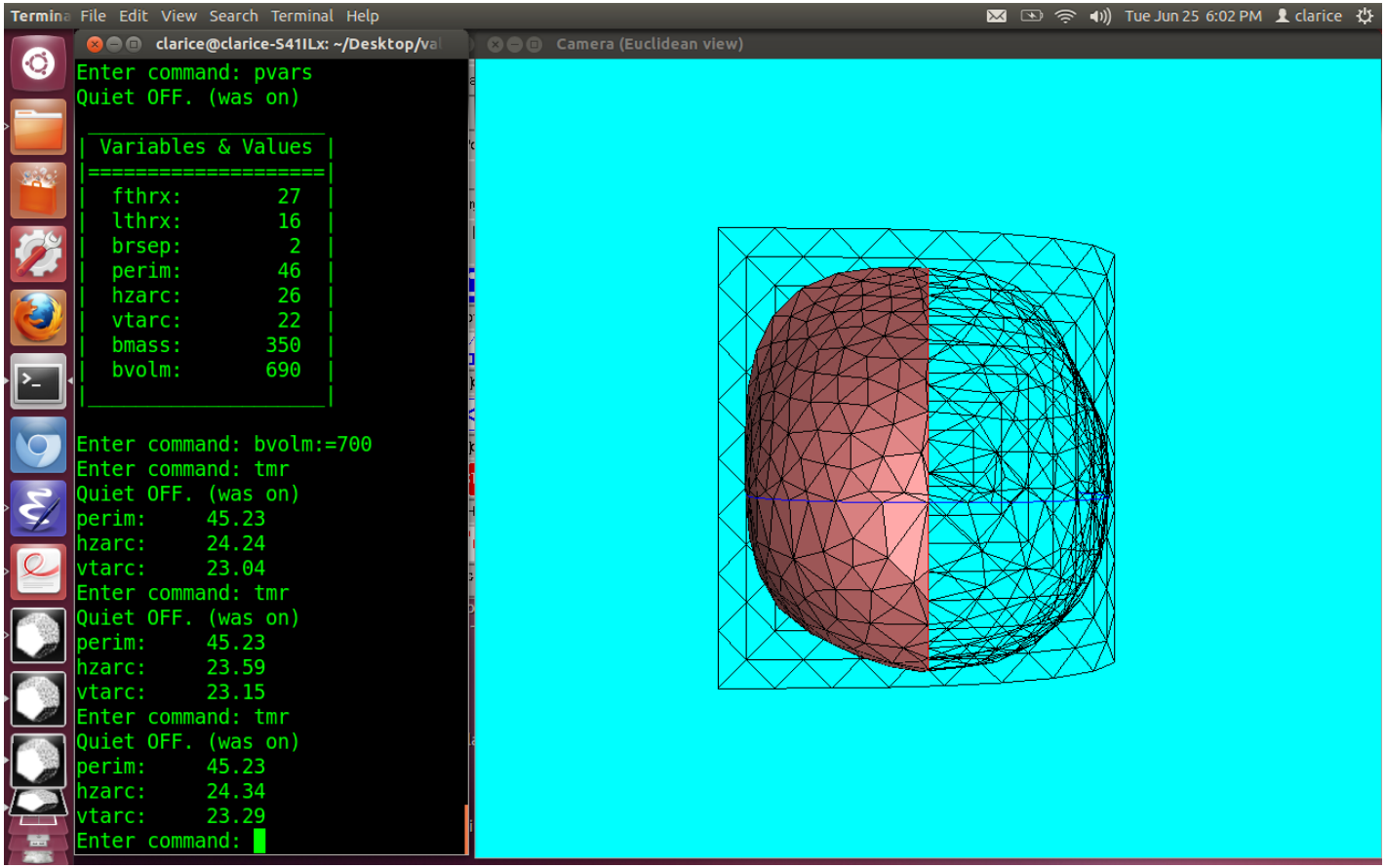

Figure 10: Tweaking towards the real measurements.

4. Our Programme

4.4. The Standing-up Position

- Before simulating STU, you should **save** the SRG-data with **sv**.
- This will not work before you **q**uote **w**ho your patient is. In our example, we took **qw:=1** (see Figure 11).
- The command **stu** will then perform the new position. A table with Variables&Values will be prompted in the terminal for you to enter the **new data** from Figure 6. The nipple is located as before.
- You **don't** have to update these data, unless you want to tweak the virtual measurements towards the real ones (as in the previous case).
- Once again, **tmr** performs this task (see Figure 12).

4. Our Programme

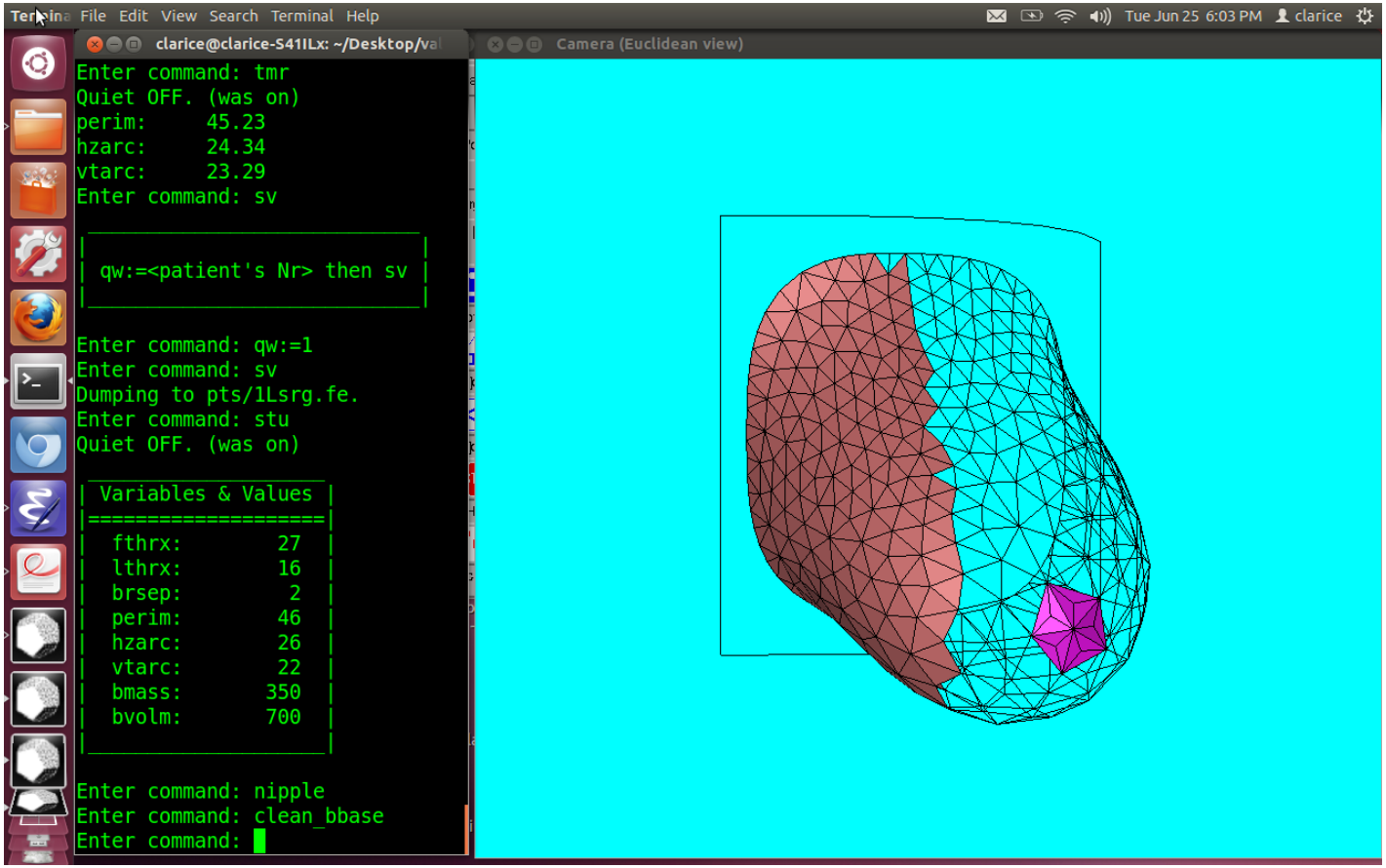

Figure 11: The Standing-up Position.

4. Our Programme

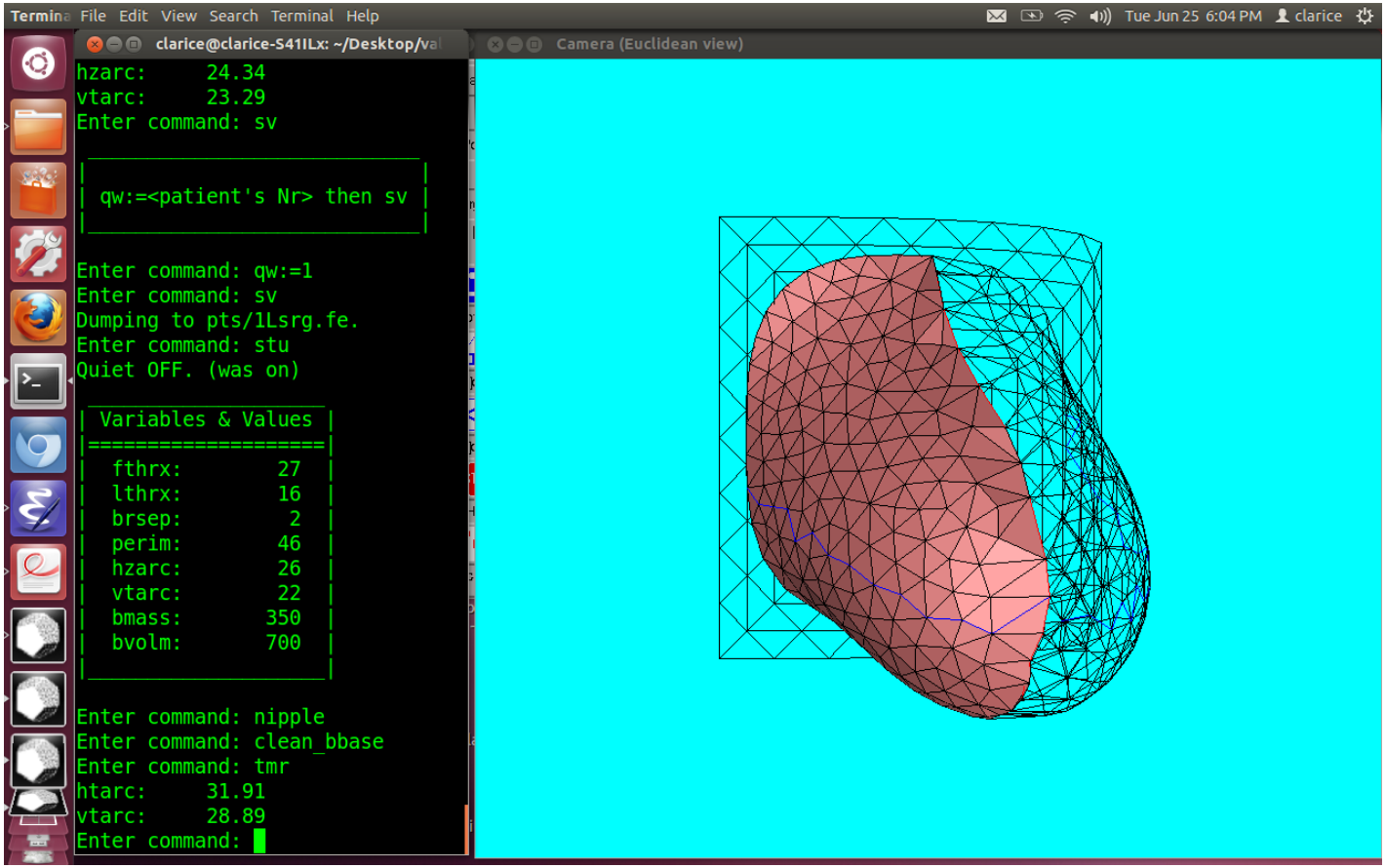

Figure 12: Taking measurements at STU.

4. Our Programme

4.5. The Laying-On-Table Position

- You don't have to perform all simulations at once. The programme will restart from the last **saved** data when called again.
- This can be done even on another computer with either Unix, Linux or MacOSX. Note: there is **no** proper Geomview for Windows. See details at

  http://www.geomview.org/windows

- Invoke **evolver lbs**, quote the patient and then type **qq**. In our example, **qw:=1** will give you back Figure 12. Now **lat** performs the laying-on-table simulation (see Figure 13).
- Finally, Figure 14 shows the virtual tape-measure for this last implemented case.
- Note: **simulations are as most realistic as possible**. The breast *is* asymmetric at LAT, and the nipple *does* point sideways.

4. Our Programme

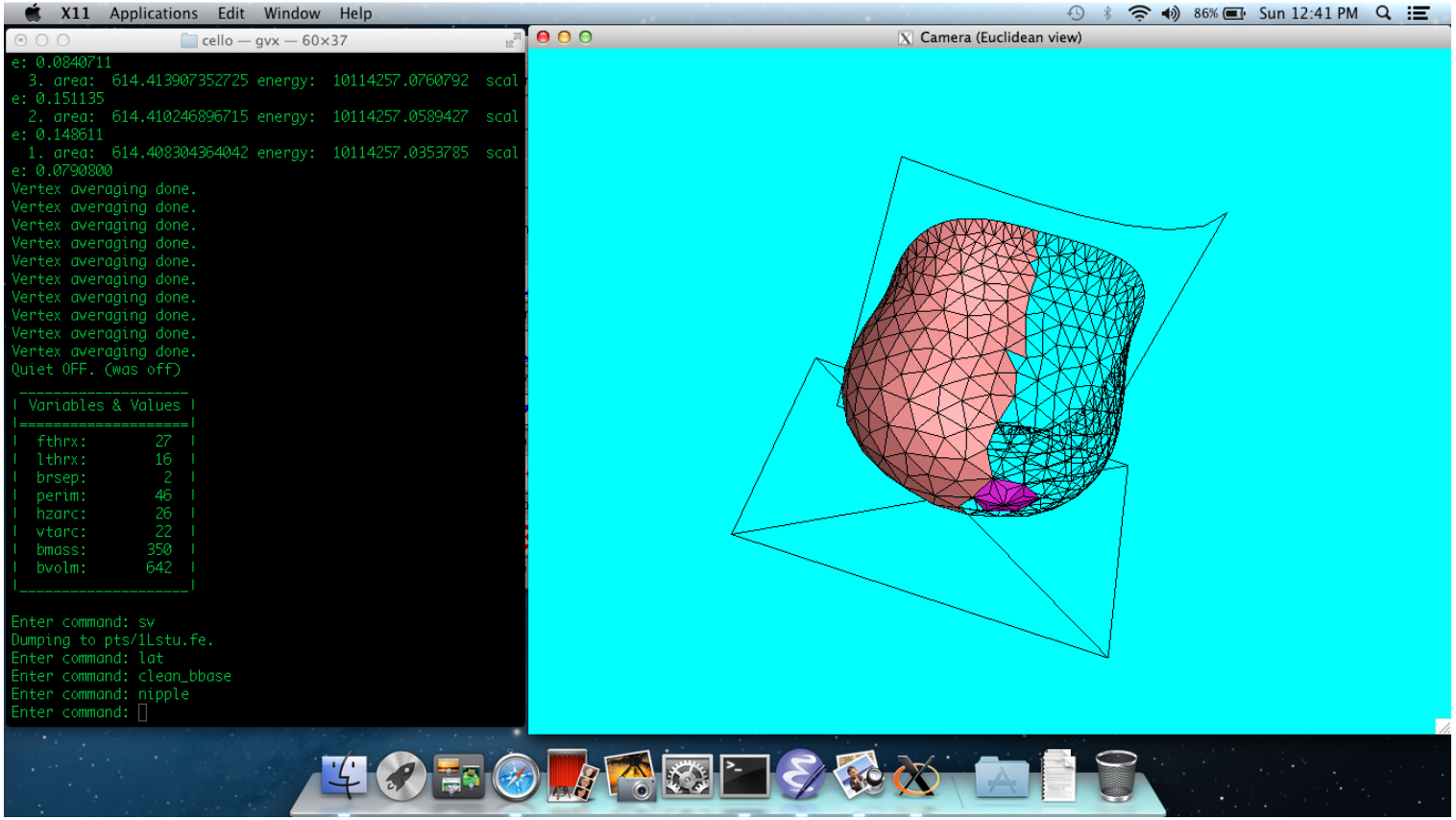

Figure 13: The LAT simulation.

4. Our Programme

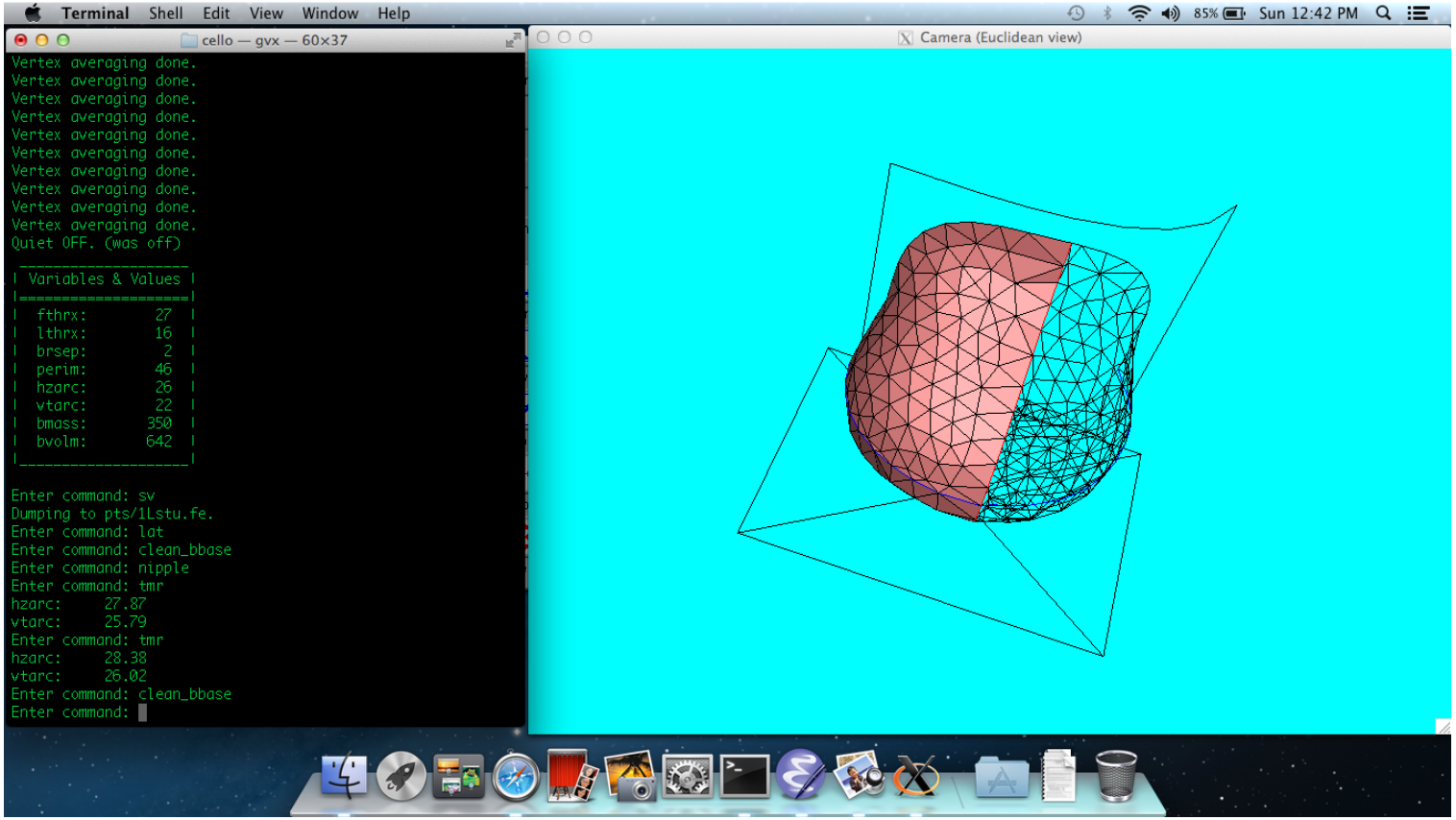

Figure 14: The virtual tape-measure at LAT.

5. Conclusions

5.1. Present State of Our Research

- We've just presented the first results of a long-term research.
- These initial results are *already* of high complexity. Therefore, the whole work *will have to* be subdivided.
- For instance, nipple location, changes in values and dimensions *do* follow geometric and physical laws. There are equated and implemented in the programmes.
- Technical details will be published in future.

5.2. Next Steps

- In the short-term: implementation of CRC, LET and MLO.
- In the middle-term: we'll get trajectories of nodules with the phantom and add them to the Evolver model.
- In the long-term: we'll add complexity to the model, like extra layers, veins and glands. Note: it *ought to be stuck* to the essential.

Acknowledgements

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References

[1] Bhatti, S. N. and Sridhar-Keralapura, M. (2012). A novel breast software phantom for biomechanical modeling of elastography. *Medical Physics*, 39(4):1748–1768.

[2] Bliznakova, K., Bliznakov, Z., Bravou, V., Kolitsi, Z., and Pallikarakis, N. (2003). A three-dimensional breast software phantom for mammography simulation. *Physics in Medicine and Biology*, 48(22):3699.

[3] Brakke, K.A. (1994). Surface Evolver Manual. *Minneapolis: Geometry Center, University of Minnesota*.

[4] Chopp, D. (1994). Computation of self-similar solutions for mean curvature flow. *Experimental Mathematics*, 3(1):1–15.

[5] Große-Braukmann, K. (1997). On gyroid interfaces. *Colloid Interface Sciences*, 187:418–428.

[6] Saba, M., Thiel, M., Turner, M.D., Hyde, S.T., Gu, M., Neshev, D.N., Mecke, K., Schröder-Turk, G.E. and Große-Braukmann, K. (2011). Circular Dichroism in Biological Photonic Crystals and Cubic Chiral Nets. *Physical Review Letters*, 106, 103902:1–4.

[7] Pathmanathan, P., Gavaghan, D. J., Whiteley, J. P., Chapman, S. J., and Brady, J. M. (2008). Predicting tumor location by modeling the deformation of the breast. *IEEE Transactions on Bio-medical Engineering*, 55(10):2471–2480.

THANKS

WE THANK YOU

VERY MUCH

FOR YOUR

KIND ATTENTION

EXTRA SLIDES (FOR QUESTIONS)

What do we mean by *compression*?

- The breast volume *decreases* from SRG to STU, and from STU to LAT.
- When the woman is lain down, the breast is uniformly distributed on its base. We have the least pressure due to gravity.
- The breast *mass* is constant and *mean density* = *mass/volume*.
- When the woman stands up, the breast mass concentrates at the bottom. Pressure due to gravity gets higher. The same happens to the mean density. This makes the breast volume smaller.
- When the woman lays her breast on the table, not only gravity by also the contact force acts. The volume decreases again.
- In this paper, we have used the word *compression* as *the action of pressing something into a smaller space*, rather than *pressing or squeezing together*.

EXTRA SLIDES (FOR QUESTIONS)

How do we weigh the breast?

- We need scales with a plate similiar to the one used in mammographies, where the woman lays her breast.
- She has to lay the breast on the plate, and feel the exact point where two important conditions are met.
- First condition: the plate cannot be pushing the breast upwards. Otherwise it'll weigh *more* than the real value.
- Second condition: she must feel that **most** of the breast is really **resting** on the plate. Otherwise it'll weigh *less* than the real value.