Proceedings of COBEM 2009
20th International Congress of Mechanical Engineering
November 15-20, 2009, Gramado, RS, Brazil

DEVELOPMENT OF AN AUXILIARY DEVICE FOR THE APONEUROSIS CORRECTION SURGERY

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Abstract. *During pregnancy, the fetus may substantially increase the pressure over the woman's abdominal muscles, exceeding its own elasticity. This causes a softness of the aponeurosis (muscle's housing) which works as a defense mechanism of the body so the mother's organs will not remain pressed, in order to avoid breathing problems (among others). The loss of abdominal pressure may cause serious problems related to organs functionality and aesthetic issues, as well. To correct this lack of pressure, after the baby's birth, plicatures - addition of traction through sewing - are made in the aponeurosis. If the softness occurs below the navel, it is corrected during the cesarean procedure. On the other hand, if the softness is located in the region above the navel, it is required an increase of the cesarean's incision size, resulting in a much more aggressive procedure that often causes a reasonable aesthetic mark. Focusing on the aponeurosis softness correction, located in the region above the navel, this work presents the development of a mechatronic device capable of reestablishing the required pressure on the muscles with a minimum invasive procedure.*

Keywords: surgery, aponeurosis, mechatronic device, mechanisms

1. Introduction

During pregnancy, the fetus may substantially increase the pressure over the woman's abdominal muscles, exceeding its own elasticity. This causes a distension or softness of the aponeurosis (fig.1) (muscle's housing) which works as a defense mechanism of the body by releasing the pressure in the mother's organs, to avoid breathing problems (among others).[(1)]

The loss of abdominal pressure may cause serious problems related to organs functionality and aesthetic issues, as well. To correct this lack of pressure, after the baby's birth, plicatures - addition of traction through sewing - are made in the aponeurosis[(1)]. If the distension occurs below the navel, it can be corrected during the cesarean procedure. On the other hand, if the softness is located in the region above the navel, it is required an increase of the cesarean incision's size resulting in a much more aggressive procedure that often causes a reasonable aesthetic mark.[(1-5)]

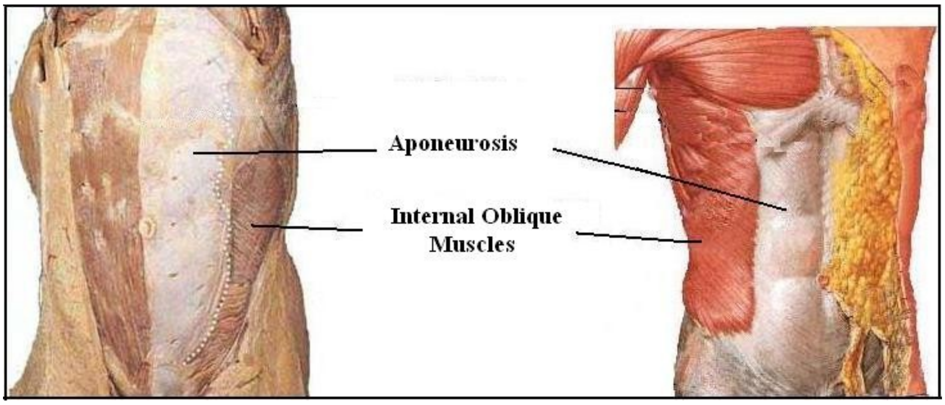

Figure 1 - Aponeurosis and Internal Oblique Muscles in a real body (left) and in a model (right) [(20),(21)]

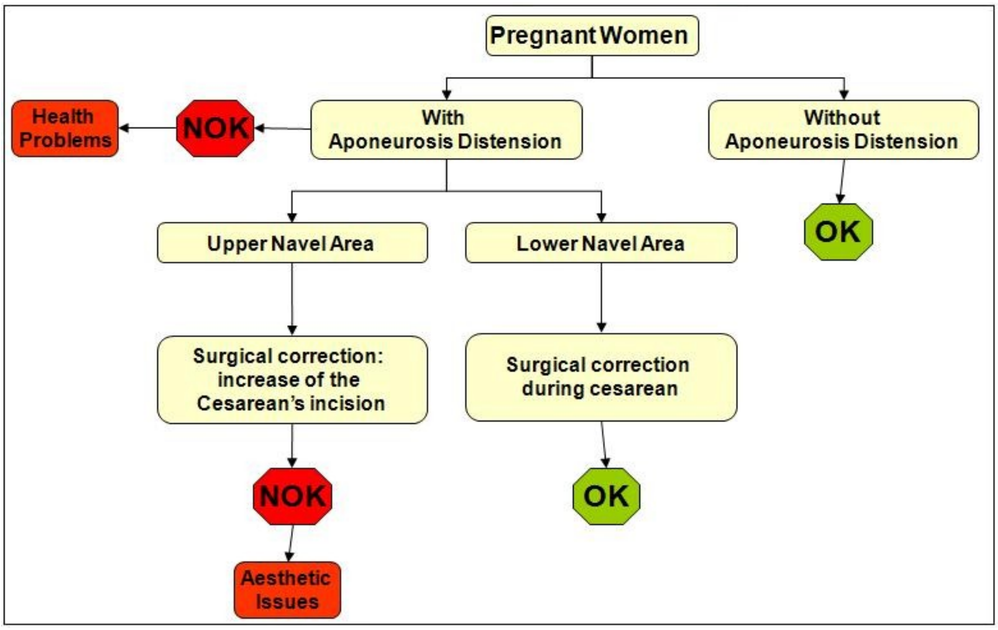

Figure 2 – Decision-making diagram

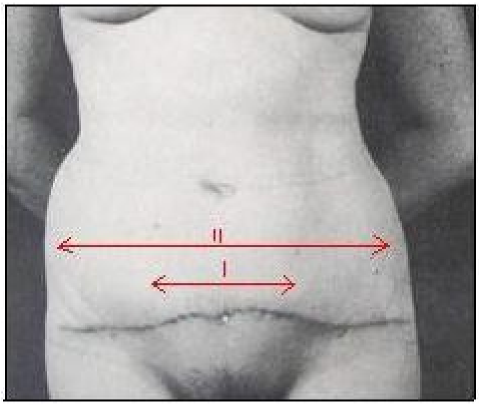

Figure 3 – Scar´s Sizes: (I) normal size after the cesarean surgery;
(II) size after the upper navel aponeurosis correction surgery [1]

Figure 2 shows a decision-making diagram that resumes the previously mentioned cases. Briefly, there are two kinds of pregnancy, with or without aponeurosis distension. When there is no distension, there are no problems to the patient. Otherwise, the patient will have health issues [1]. If the distension occurs in the lower navel area, a surgical correction may be executed during the cesarean procedure. However, if the affected area is above the navel, this results in a substantially increase of the cesarean's incision, causing aesthetic issues (see fig.3).

Focusing on the aponeurosis softness correction, specifically in the region above the navel, this work presents the development of an auxiliary mechatronic device which will be able to reestablish the required pressure on the muscles with a minimum invasive procedure. The following sections deal with the choice of suturing technique, the mechatronic device description, the built prototype and conclusions.

2. The choice of suturing technique

At first, a review of the existing techniques was conducted in order to find the most suitable suture technique to achieve the project's main goal, a non-invasive procedure. Even though abdominoplasty is a procedure also executed in the abdominal area, its main use is on obese patients with massive skin removal or skin deformation (2-5), what makes its techniques and procedures, in general, not recommended (6-9). On the other hand, microsurgeries and small procedures, in spite of being non-invasive and adequate in terms of aesthetic issues, in general they are not strong enough in order to support the traction and tension needed to execute the aponeurosis correction.

Therefore, different suture techniques were studied (10-16) and, to execute the aponeurosis suture focusing on the strong suture and minimum invasive simultaneous procedure, an alternative sewing technique – called *chain stitch* – was adapted. With this adaptation, the sewing can be made through a small incision in the abdominal region. This technique employs a special needle, commonly used in tunisian crochet, and requires lower complexity motions. To suture with this method, the needle perforates the tissue, captures the line on the other side, returns (creating a loop) and, through this loop, repeats the procedure, as shown in figure 4. In the way back through the tissue, the needle must rotate in order to avoid the needle's hook to clasp in the tissue. The sewing must be executed from the xiphoid appendix to the navel.

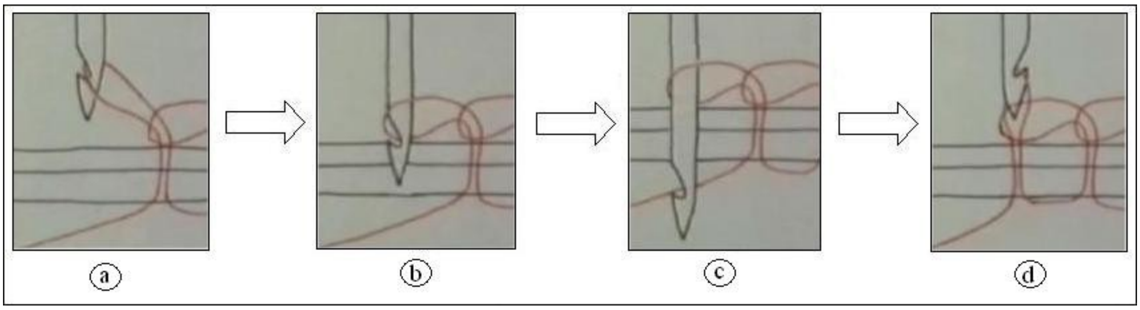

Figure 4 – The adapted chain stitch method: a) needle over the tissue hooked to the line; b) the needle penetrates the tissue; c) the needle captures the line in the other side of the tissue; d) needle returns, rotating 180º, and forms a loop. (22)

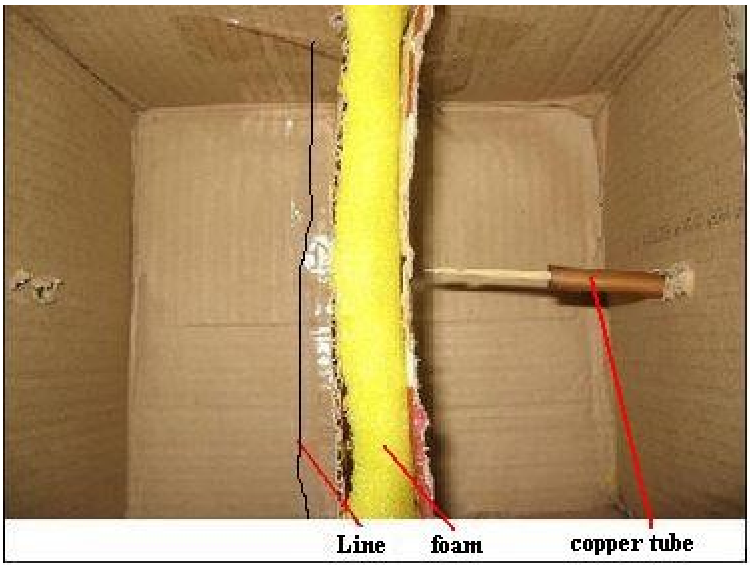

Figure 5 - Manually operated physical model

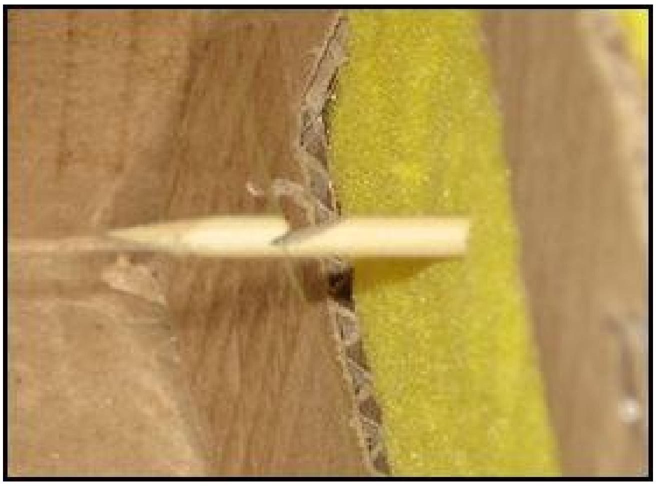

Figure 6 - The wooden needle

To evaluate the feasibility of the chosen sewing technique, a manually operated physical model was built. In figure 4, one can observe the relative position of: the suture line; the foam that mimics the aponeurosis; the wooden needle guided by a copper tube. During the sewing, the needle (fig.5) translates and rotates along the tube axis, while the tube angularly oscillates near the hole made in a paperboard box, employed to mimic the abdominal walls.

The operation of this physical model demonstrated satisfactory results once the chosen technique was tested and its functionality proved to be right. The stitches made were strong enough and their execution was relatively easy (fig.7).

Figure 7 - The obtained results in the physical model: the stitches made on the foam.

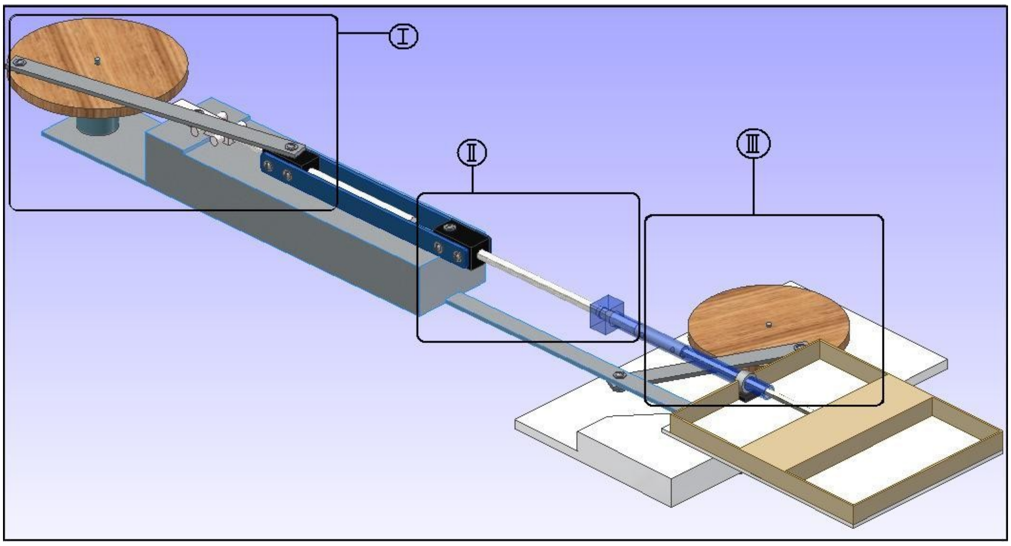

Figure 8 – CAD model of the Mechatronic Device and the three mechanisms to control the needle's motion: (I) the alternative reciprocating motion; (II) the rotation around its own axis, (III) the angular positioning

3. The mechatronic device description

Basically, the mechatronic device is responsible to automate the three necessary motions for the needle, described in previous section: the alternative reciprocating motion, the rotation around its own axis and the angular positioning (fig.8). To control these three motions, three planar mechanisms are employed. The following subsections describe qualitatively how each mechanism works and which specifications must be taken into account to size its parts.

3.1. The alternative reciprocating motion of the needle

The needle has to execute simple harmonic movements in order to repeatedly perforate the aponeurosis. In the manually operated physical model, this motion corresponds to the translation of the needle along the copper tube. Thus, a crank-slider mechanism [17-19] driven by a stepping motor was chosen (fig.9).

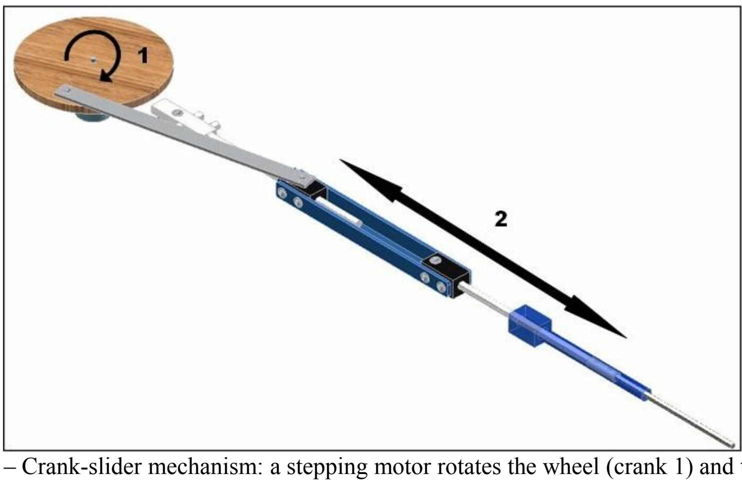

Figure 9 – Crank-slider mechanism: a stepping motor rotates the wheel (crank 1) and the slider (2) alternatively reciprocates.

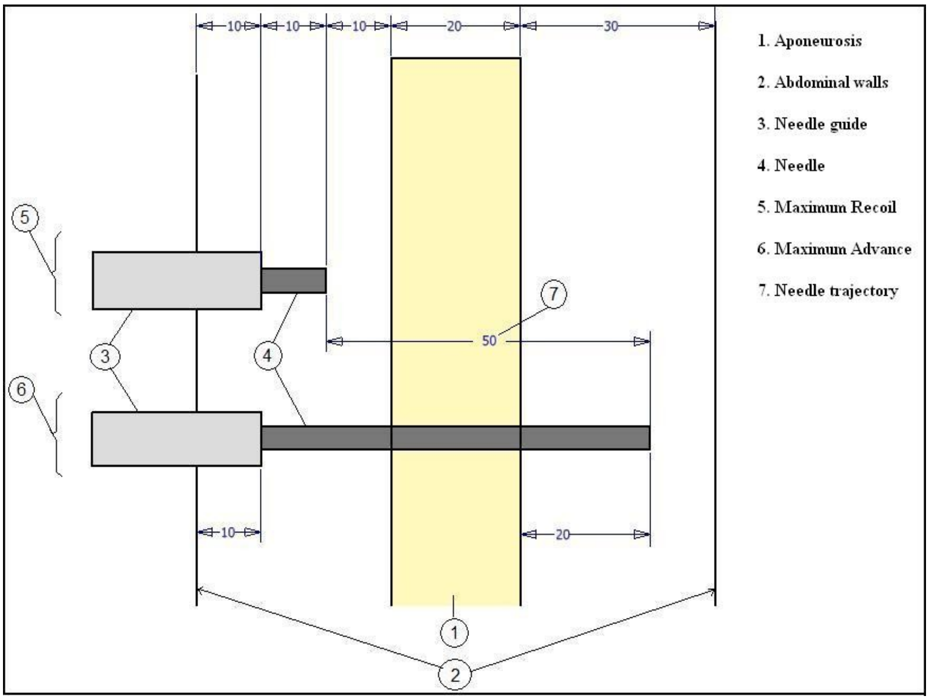

Figure 10 – Specifications of the working area for the surgery and the definition of needle´s stroke.

Taking into account the technical information provided by an expert surgeon, the working area for the surgery was specified (fig.10). In addition, the experience acquired from the physical model, allowed us to define the needle’s stroke. Consequently, the region to be sewed is 20 mm thick and, in order to suture, it is also required 10 mm recoil and 20 mm advance. Therefore, the complete needle stroke has to be 50 mm long. Once the stroke is defined, the crank-slider's wheel can be dimensioned. Therefore, the wheel’s diameter must be 50 mm.

3.2. The rotation of the needle around its own axis

As described in section 2, to suture according to chain stitch method, the needle also needs to rotate along its own axis. In order to do so, in the slider part (fig.9), a revolute joint is added [18], allowing the needle to turn around its own axis freely. To constrain this motion to only 180-degree rotation and to make it dependent to the translation, a pin-guided slot is added.

3.3 The angular positioning of the needle

Once the main goal is to perform a minimally invasive surgery, the needle needs to penetrate the abdominal area through a small incision and oscillate around this point. Then, a four-bar mechanism [17-18] driven by another stepping motor was chosen, being able to oscillate the crank-slider mechanism base around the incision point (fig.11).

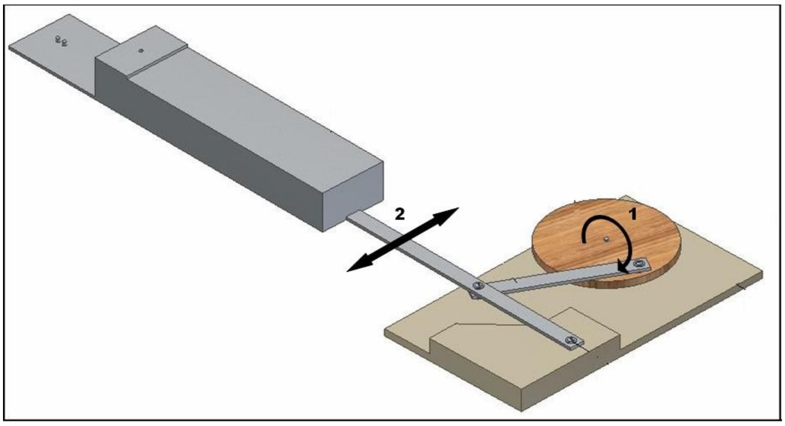

Figure 11 – Four-bar mechanism: another stepping motor rotates the other wheel (1) providing the angular positioning (2) of the needle around the incision point.

The area to be sutured corresponds to the region between the xiphoid appendix and the navel. According to the dimensions provided by the surgeon, this distance is approximately 130 mm. If the whole surgery was made with only one incision, the attack angle would be approximately 43º. This would imply that only 43% in the front aponeurosis surface and 71% in the back aponeurosis surface would be sewed. If, instead, three incisions were made, the attack angle would be 25º and the sewed surfaces would rise up to 71% in the front and 86% in the back surface (fig.12). As the incision size is insignificant to aesthetic issues and the bigger the sewed surface, the better, the last option was chosen. From this definition and knowing the rotation center point location, the arm/wheel joint point location and the attack angle, the position of the wheel and its diameter were calculated (fig.13).

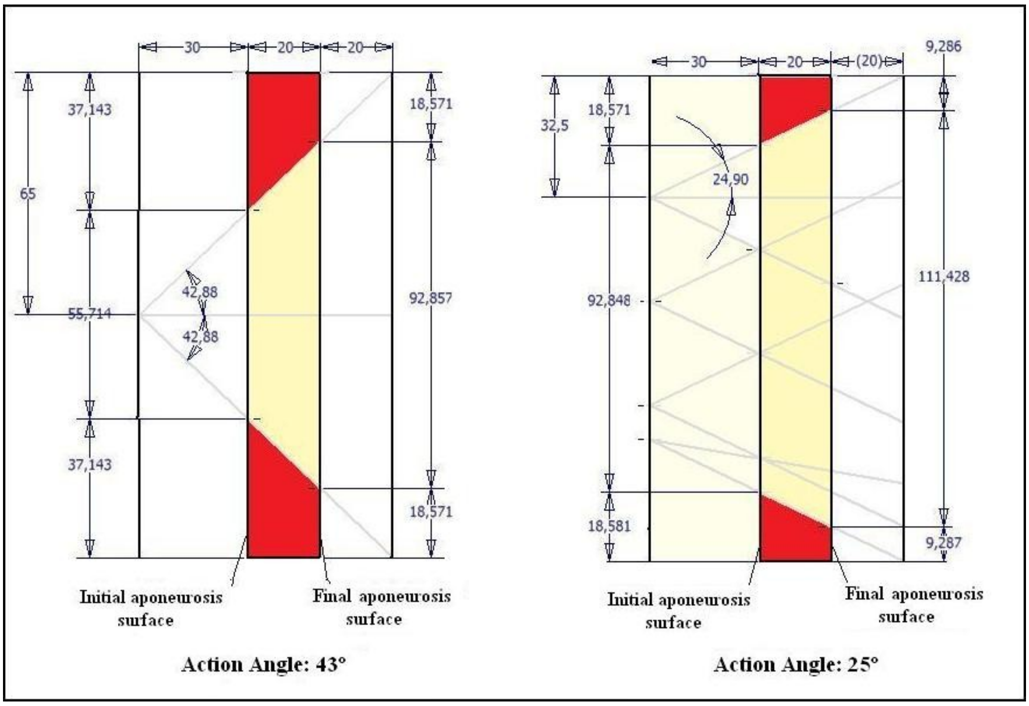

Figure 12 - Action Angle Definition

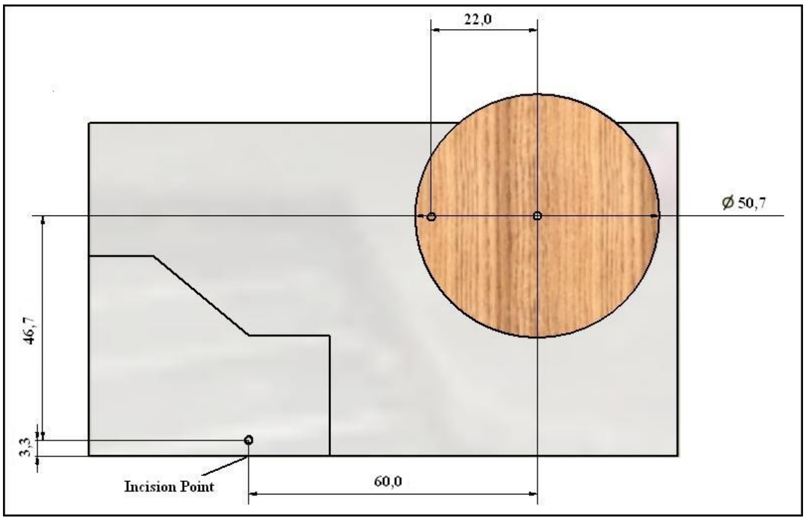

Figure 13 - The definition of the diameter and the relative positioning of the wheel that belongs to the four-bar mechanism.

4. The built prototype

The chosen mechatronic device was built in a large scale, as can be seen in fig. 14. The mechanical subsystem, actuated by two motors, is controlled by a real time application running under RT-Linux operating system (fig.15, fig.16). Once two motors are employed, it is possible to control the puncturing speed, the number of stitches and also the spacing between them. The built prototype demonstrated the operation feasibility of the proposed device in terms of performing the three required motions for the needle.

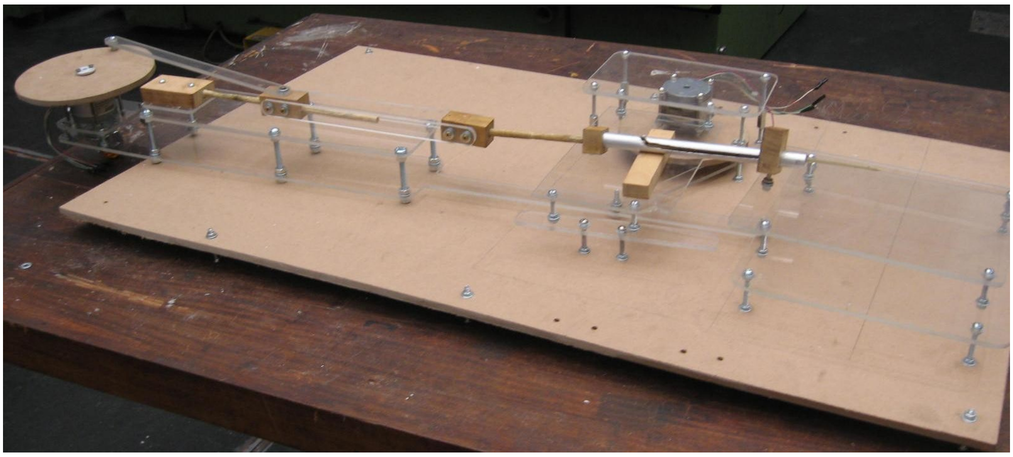
Figure 14 - Large-scale prototype

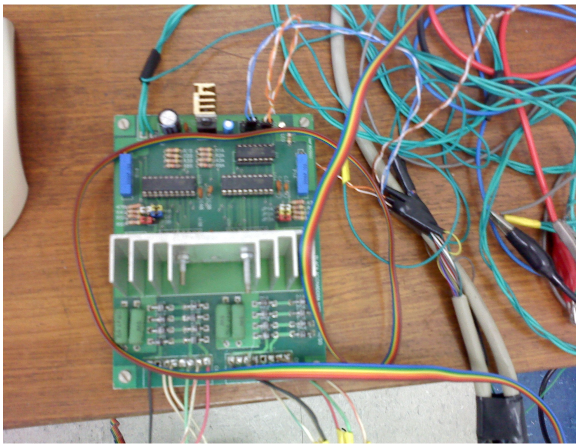

Figure 15 - Motor Drive Board

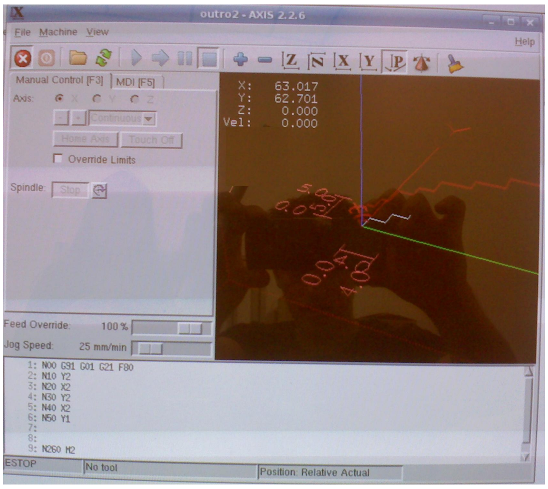

Figure 16 - Programming the motions through a Real Time Application

5. Conclusions

After the pregnancy, the aponeurosis correction's surgery is recommended in some special cases to avoid health and aesthetic problems. In some cases, the aesthetic problem could not be solved completely. This paper presented a novel auxiliary device suitable to help the surgeon during this procedure and solving completely the aesthetic issue. Basically, this device constitutes itself as a mechatronic system, composed of three mechanisms to control the needle's positioning during the suture of the aponeurosis.

By using the proposed device, we foresee that the estimated surgery time will be reduced resulting in a great benefit for both medical team and patient. In addition, this innovative technique causes the incision's size reduction, which is really important for the patient in terms of recovery time. Finally, employed equipment's low complexity will also reduce the procedure's costs. The device is still under development. The upcoming tests will demonstrate its behavior under conditions that imitate a real surgery.

Acknowledgements

Our special thanks to Dr. Paulo Henrique Facchina Nunes, the Plastic Surgery Chief of the State University of Campinas (UNICAMP), for his great support and assistance.

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