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RESEARCH ARTICLE

STUDY OF THE ELEMENTARY SURGICAL PROCEDURES AND INSTRUMENTS WITH APPLICATIONS IN THE MICROMECHANICS OF SURGERY

***Andra-Maria Ciutac and Carmen-Gabriela Popa**

University of Manchester. I, Carmen, Gabriela Popa, am currently studying at University Politehnica of Bucharest, Romania

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ABSTRACT

The theme of this research project is creating different methods suitable to analyze one's accuracy. Starting from theoretical studies of medical instruments and procedures, as well as studies of biomechanics of the tissue, we introduce a number of devices that can be used to monitor precision and accuracy. This paper presents and analyzes the most important surgical procedures, all in order to develop several mechanisms able to teach and evaluate aspiring surgeons and even specialists within their subject of work. Final models of the prototypes are also included, where the performance of the surgeon can be interpreted from the pressure they apply to the tissue and the precision of their incision.

Domains of value of the micro drive:

- Specific geometry and the structure of the micromechanics of surgery
- Angular displacement areas
- Linear displacement areas
- Micro forces of the drive
- Mechanical micro couples

Characteristics and mechanical parameters:

- Spherical diameters: 0-250 mm
- Linear areas: 0-5 mm
- Angular areas: 0-60
- Meridian plans
- Micro forces areas: 0-100 cN
- Power: 0-100 W
- Speed: 0-100 cm per second
- Speed area: 0-30 rpm
- Pressure: 0-200Pa

INTRODUCTION

Over millenniums, people have understood the importance of surgery and medical practice, continuously developing it. Even if through major scientific and medical break-outs, the mortality rates of patients undergoing an invasive treatment have steadily decreased, it is often the art of the doctor that leads to a successful outcome. Therefore, we believe that by developing several mecha-nisms providing data regarding the manner a procedure is executed, surgeons can be more easily and accurately assessed in relation to the modern operating guidelines.

Corresponding author:** ***Andra-Maria Ciutac
University of Manchester. I, Carmen, Gabriela Popa, am currently studying at University Politehnica of Bucharest, Romania

These devices could only have a positive impact on the surgical domain, as they are meant to monitor and improve, when necessary, the abilities of specific users.

Functions of Surgical Instruments

The functions of the basic surgical instruments vary, but can be classified within six categories, considering that an instrument might have several uses: [1]

- ***Cutting and dissecting***: scalpels, scissors, dissector, ultrasonic cutting device, LASER, amputating knife, saws;
- ***Grasping***: thump forceps, needle holders, organ clamps;

- ***Hemostasis (mechanically or thermically stop a bleeding)*:** homeostatic forceps, Argon bean coagulator, Deschamp Ligation needle, Payr sonda;
- ***Retracting*:** hand-held retractors, self-retraining retractors;
- ***Closing/Tissue unifying*:** needles, staplers, self-adhesive strips, surgical adhesives
- ***Special*:** Volkmann curette, round-ended probe, suction set, X-RAY, implants, prosthesis etc.

Medical Equipments and Procedures [2]

The scalpel is one of the most frequently used cutting and dissecting surgical instruments. It can be either conventional (reusable), disposable (with a plastic handle) or with a detachable blade. Depending on the dissected tissue, the blade can have various forms: thin-bladed, sharp-tipped, ducts or abscesses (Fig. 1).

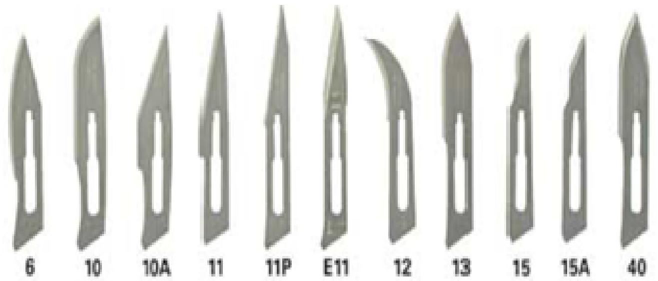


Fig. 1. Types of scalpel blades

There are two distinct methods in which the scalpel is used:

Long incision: The scalpel has to be held like a fiddle bow, the handle being gripped horizontally between the thumb and the middle fingers with the dominant hand; the index finger offers precision and is kept above the handle. The ring and middle finger are placed towards the end of the handle (Fig. 2) The non-dominant hand puts the skin under tension by using the thumb and index finger.

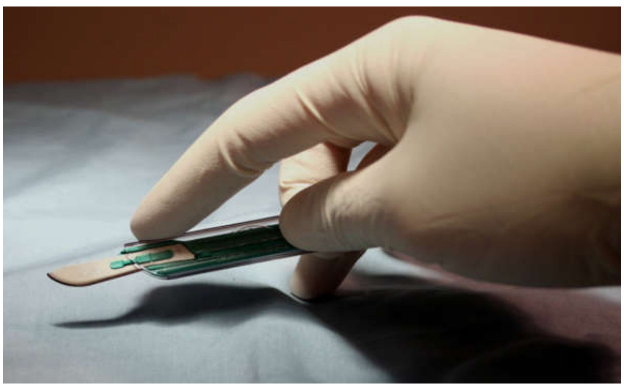


Fig. 2. Holding the scalpel for a long incision

Short incision: The scalpel has to be held like a pencil, while the cutting occurs mostly with the tip. The handle is being grabbed approx. 3 to 4 cm from where the blade meets the handle (Fig.3).

Fig. 3. Holding the scalpel for short incision

Scissors are another important cutting device, that come as well in numerous forms, differing not only through the blades (straight, curved, angular), but also through the tips (blunt-blunt, blunt-sharp, sharp-sharp). Even if the blades and tips suggest the tissue intended to be cut, the same technique applies for all the surgical scissors. The thumb and the fourth finger have to be placed each in a ring, while the index finger is placed distally, over the handle, in order to stabilize the scissors. It is relevant to mention that similar procedure is applied when operating with clamps. (Fig 4).

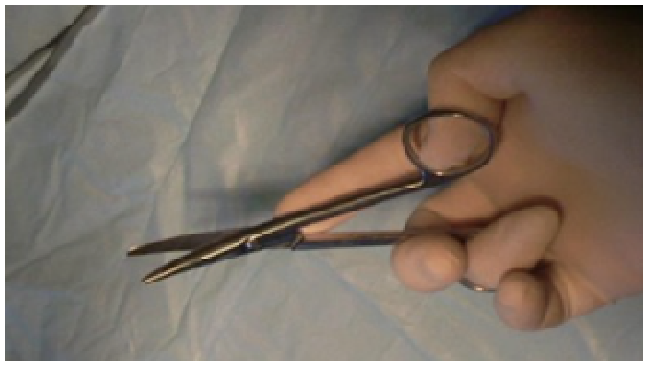


Fig. 4. Correctly holding scissors

The dissector is another cutting device that is long-handled and ring-ended. A unique characteristic is that usually it is bended at an angle of 90° at its distal part (Fig. 5). However the technique that is being performed while using a dissector is similar to the scissors.

Fig. 5. The distal part of a dissector

Needles and needle holders represent the most important system of tissue unifying, suturing. The most used needle holders are Mathieu and Hegar. Mathieu has curved shanks, a spring and different locking mechanisms (Fig. 6). It is hold like a pencil and should be compressed by the thumb and index finger. Hegar is similar to the homeostatic forceps, but having longer shanks and shorter jaws (Fig. 7). It is gripped similar to the scissors in the first phase and then rotated at an angle of 180° (Fig. 8).

Fig. 6 & 7. Hegar (left) and Matthieu (right) needle holders

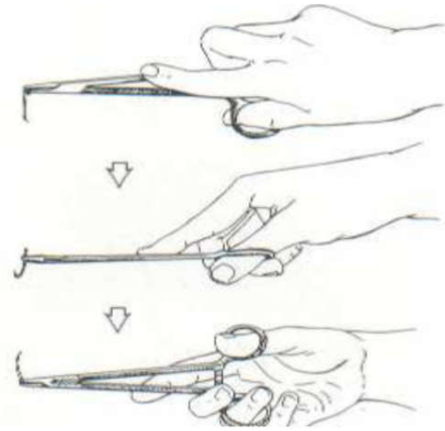


Fig. 8. The method of using Hegar needle holders

There are many types of suture that can be performed depending on the tissue operated or the intended resistance. However there are two main types of suture:

- Interrupted: simple, vertical mattress, Allgower, horizontal mattress;
- Continuous: simple, locked, intracutaneous, purse-string;

The simple interrupted suture (Fig. 9) is usually performed on skin fascia and muscles. Its main principle is that after each knot is tied. Ideally the skin is undertaking an equal amount of tension with each suture. Even if it is time consuming the doctor has the guarantee that the suture will remain closed.

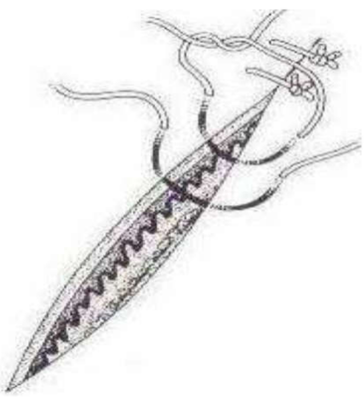


Fig. 9. The simple interrupted suture

The vertical mattress suture (Fig. 10) occurs in the deep layers of the skin and is called either Donati or Vertical U-shaped. It is performed on a vertical plane, perpendicular to the wound and consists of the deep suture in the subcutaneous layer and a superficial one on the surface of the skin, at the wound edge.

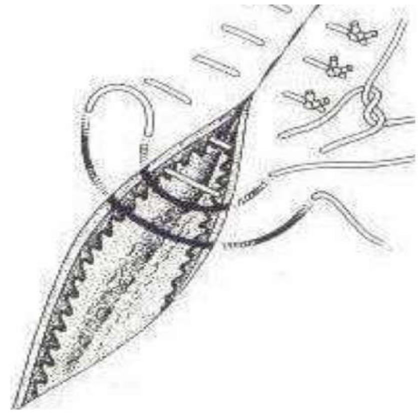


Fig. 10. Vertical mattress suture

The Allgower suture is a subcategory of vertical mattress suture, but differentiates itself by not coming out from the skin (Fig. 11).

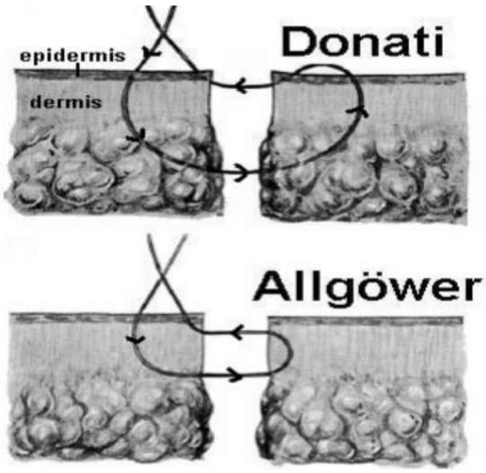


Fig. 11. Comparison between the Donati and Allgower suture

The horizontal mattress suture (Fig. 12) is normally used for a short skin wound. It is a double suture, in the same skin layer, made every one cm.

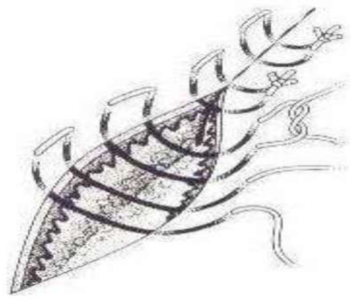


Fig. 12. Horizontal mattress suture

The simple continuous suture (Fig. 13) can be used for multiple type of tissues such as the inner wall of organs, the stomach, the intestines, and the mucosa. It is extremely time-efficient as it only requires two knots, one at the beginning and one at the end. Moreover, surgeons do not worry about the tension applied as it distributes equally upon all the suture.

Fig. 13. Simple continuous suture

The locked continuous suture (Fig. 14) is an improvement brought to the simple continuous suture, as the external locks allow for the wound tension to be quickly and accurately adjusted, but also prevent the sutures to loosen.

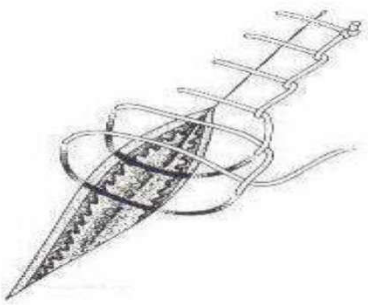


Fig. 14. Locked continuous suture

The intracutaneous suture (Fig. 15) is parallel to the skin surface and enters the skin at the beginning and only exists at the end. It takes an aesthetically pleasing form as it reduces the dimensions of the scar.

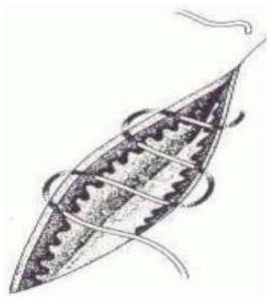


Fig. 15. Intracutaneous suture

The purse string suture (Fig. 16) is only used for cylindrical, circular wounds such as the gastrointestinal tract. It runs continuously around the opening. Afterwards, the edges are pulled together with a dressing forceps and the threads are knotted.

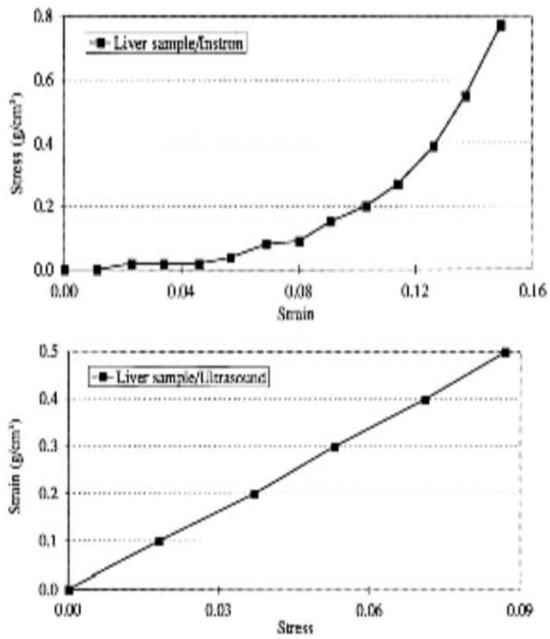
Fig. 16. Purse string suture

Micro Biomechanics of the Tissue

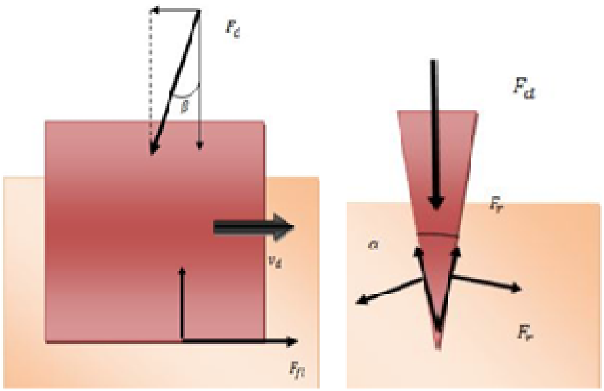
In order to understand the procedures occurring during a surgery, a comprehensive study of the micro biomechanics of the tissue is required. The forces that action upon specific tissues are: compressive (tend to deform the tissue by compressing them), flexure (tend to deform the tissue by bending them), torsion (tend to deform the tissue by twisting them), shear (result from combining the 3 forces mentioned above) and tensile (tend to deform the tissues by stretching them). Deformation or strain can be described as being elastic (reversible) or plastic (irreversible). Out of all the mechanical properties it is important to mention the viscoelasticity- integrates both elasticity and viscosity - of the tissue determined by the Young Modulus (E) as it determines from what point a deformation becomes plastic and afterwards fractures (according to Hooke's Law $\sigma = E * \varepsilon$, where σ is the applied stress and ε the resulting strain). (Graph. 1) [3]

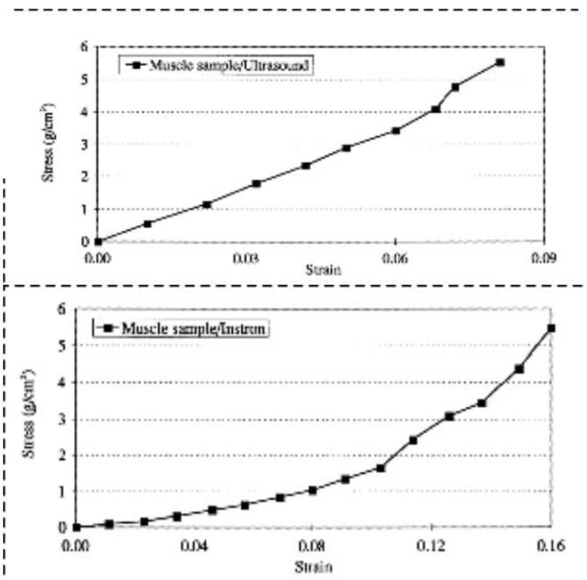
Graph 1. General stress-strain curve

The stress-strain curves were further analyzed by numerous scientists to determine the Young's Modulus for specific tissues. For accuracy and observation the researchers used two methods- with Ultrasound technology and Instron. [4]



Graph 2. 3. The stress-strain curve for the muscle tissue using both methods





Graph 4, 5. The strain-stress curve for the liver tissue using both methods

Table 1- The ultimate tensile strength of different soft tissues [5]

Material	Ultimate tensile strength [Mpa]	Ultimate tensile strain [%]	Collagen (% dry weight)	Elastin (% dry weight)
Tendon	50-100	10-15	75-85	< 3
Ligament	50-100	10-15	70-80	10-15
Aorta	0.3-0.8	50-100	25-35	40-50
Skin	1-20	30-70	60-80	5-10
Articular Cartilage	9-40	60-120	40-70	-

Furthermore, we have developed a study of the incision of the scalpel through a soft tissue, where equations are included, in order to determine the force applied to the tissue: [6]

$$(Ox)\ -F_{fl} - F_{ft}\cos\left(\frac{\pi}{2}-\frac{\alpha}{2}\right) + F_{ft}\cos\left(\frac{\pi}{2}-\frac{\alpha}{2}\right) + F_d\cos\left(\frac{\pi}{2}-\beta\right) + F_r\cos\left(\frac{\alpha}{2}\right) - F_r\cos\left(\frac{\alpha}{2}\right) = 0 \quad (1)$$

$$(Oy)\ F_d\cos\beta - 2F_{ft}\cos\frac{\alpha}{2} + 2F_r\cos\left(\frac{\pi}{2}-\frac{\alpha}{2}\right) = 0 \quad (2)$$

$$F_{fl} \cong \mu_{bt}F_d\cos\beta$$

$$F_{ft} \cong \mu_{bt}F_r$$

Methods of Analyzing Accuracy

After studying in depth the basic surgical techniques, instruments and the biomechanics of several types of tissues, we have developed systems that are able to identify the steadiness of a surgeon's hand. These systems track the motion of needles, scalpels and clamps. Tracks of the scalpel are composed of two metallic bars, connected to a power source. The space between the bars may differ, from 1.5 centimeters to 0.2 centimeters. The surgeon is asked to effectuate an incision along the track. Whenever the metallic bar is being touched with the scalpel, an audio warning is emitted to inform that an error has been occurred. Tracks of transportation work on the same principle, the only difference is that the surgeon is asked to pass an object (a small ball or a piece of cotton) through a multitude of forms, without touching the margins, or otherwise the same audio warning is emitted.

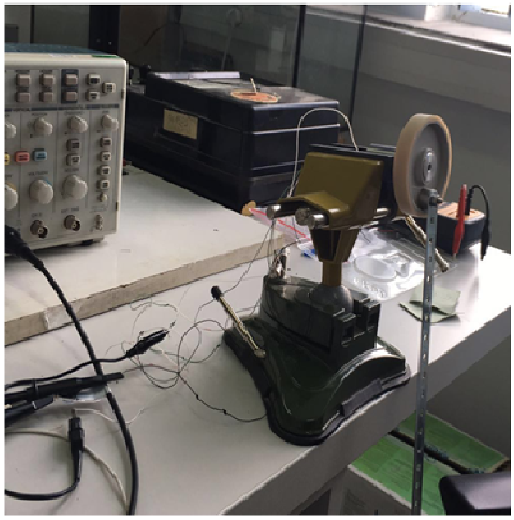


Fig. 17. Performing experiments on tracks of scalpel

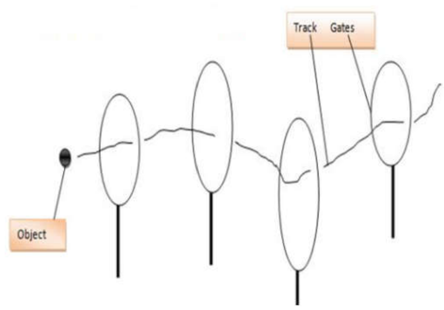


Fig. 18. Scheme of linear tracks of transportation

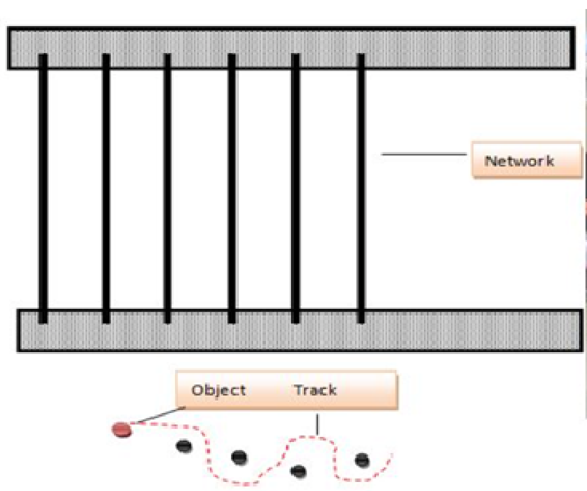


Fig. 19. Scheme of track of transportation at equal lengths

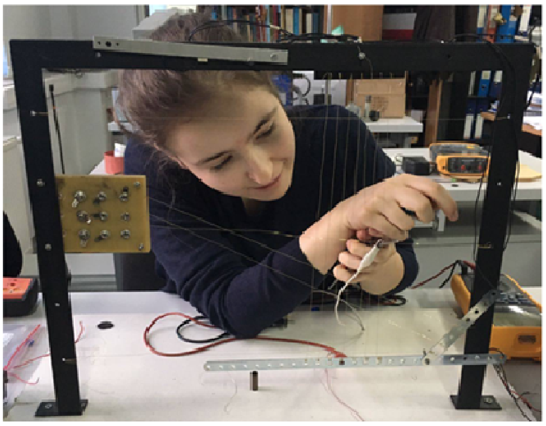


Fig. 20. Performing experiments on tracks of transportation at equal lengths

The resolver is a type of rotary electro-mechanical transformer. Its main purpose is to convert the linear mechanical movement, to record the angular variations and afterwards to display it in accordance with a change of potential. In our case, we have attached the resolver to a fixed clip. To the rotor part of the resolver, a long metallic bar has been screwed, letting however a loose grip. There is also a signalised position, placed towards the back in order to reduce errors, on which the trainee is supposed to hold the bar. Accordingly, the trainee's hand will produce a chain effect, having as a final result a change of potential.

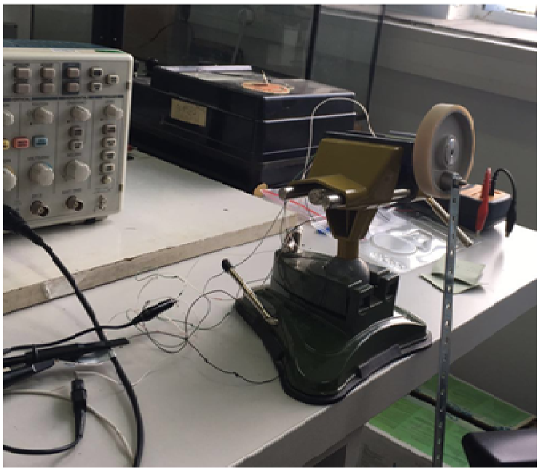


Fig. 21. Set up for the resolver

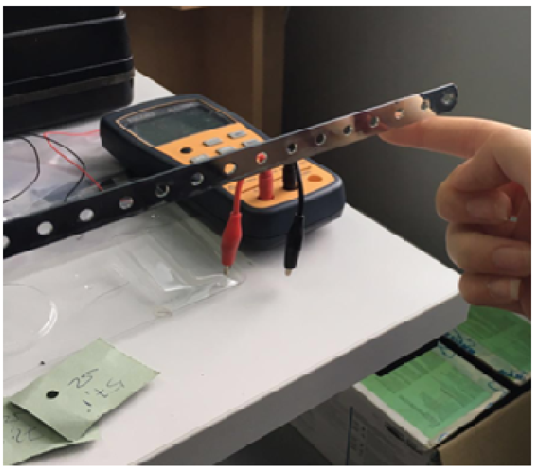


Fig. 22. Using the resolver and measuring the accuracy

Additionally, we created a phone application which converts the difference of potential into angles, according to the following formula[7]:

$$\alpha = \arcsin\left(\frac{V_{out} - Offset}{Sensitivity}\right)$$

Offset is the nominal output of the device of 2.5V at 0 degrees and Sensitivity is approximated at 2V/degree.

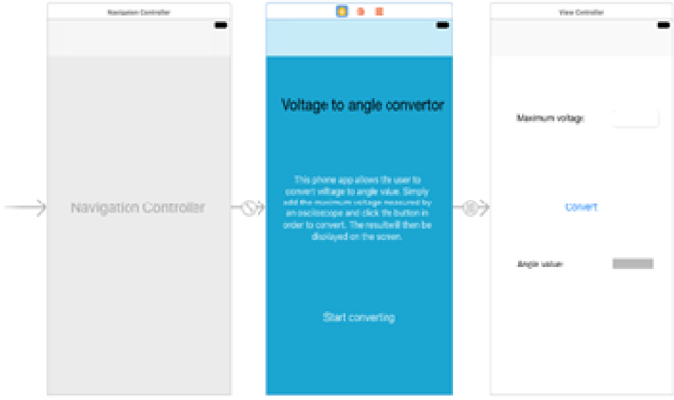


Fig. 23. Screen from the phone app

FUTURE PLANS

We plan on continuing working on this research project, despite the fact that we will be studying at different universities, in separated countries. We intend to improve the abovementioned devices that can measure the accuracy of the surgeon, as well as to come up with new ideas. Apart from the physical devices, we are currently working on creating a set of web and phone applications for the same purpose.

Fig. 24. Web application for future plans

We have already started to work on a web game meant to determine the accuracy of the users. It will be created as a web page, using HTML, CSS and JavaScript. It will have 3 levels, distinguished by the radius of the circle – the element which had to be transported through the tunnel, as shown in the image above. The tunnel is a complex curved line, generated randomly and in a continuous movement. The user will choose for how long the session will last (one minute being the shortest period and ten minutes the longest). At the end of the session, the final result will be displayed on the screen, showing the accuracy of the user. This will be calculated with the following formula:

$$\text{Accuracy} = \frac{n+v}{n+v+\Delta t} * 100$$

Where n is the number of mistaken made in the time given (mistakes are counting when the ball touches the wall of the tunnel); v is the average speed (measured in m/s) with which the ball is being moved through the tunnel and t is the time interval chosen by the user (measured in seconds). Another device that is not yet finalized is to measure the pressure inflicted upon the tissue whenever incisions are made. For this particular enquiry detachable blade scalpels are needed. A small piezo-electric crystal is implanted at the joint place, in the back of the blade. For this use, the direct piezoelectric effect is applicable. Therefore, when mechanical stress is applied (the crystal is squeezed) and thus an electric charge is being produced. This electric manifestation is recorded and then easily converted back to a specific pressure indicated in mmHg, also in a mobile application. The above described product has again multiple applications that can improve the surgeon's skills. One of them would be dissecting, with this scalpel, either bionic or real specialized tissue, taking into account the fact that each tissue has a recommended dose of stress, when incisions are being made. An ideal cut would apply stress just above the fracture resistance (toughness). In particular, the soft tissue's fracture resistance (R) is calculated with the formula:

$R = W/l$,

where W is the fracture work and l is the length. Such an example of a resistance would be the one of the liver, ranging normally from 187 J/m2 to 225J/m2.[8]

Another similar application would be for the surgeon to be given an ideal target pressure. During several sessions lasting from one minute to fifteen the trainee should try and keep the stress applied steady and similar to the targeted one. This experiment can be performed on rough surface, but soft tissue or materials are to be preferred.

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Conclusion

We believe the prototypes that we developed could be of great use in teaching employee in hospitals and members of Medical Universities, as they can not only asses a surgeon's precision but also benefit the students by practicing and developing their surgical ability.
Our prospects are to analyze more of the mechanical parameters of the tissue and reflect this knowledge and thus broaden our spectrum of applications in order to be capable of sensing the pressure redirected to the tissue. Given the trends in modern medicine, for example surgery becoming less and less invasive, we understood the importance of not only developing devices meant to ease the doctors' job, but also creating products helping the medical staff to increase their surgical abilities: precision and timing, both being an essential factor in the success of each surgery.

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