

A biomechanical model of the pelvic cavity: first steps

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Abstract—The surgical treatments of genital prolapsus are still empirical and poorly valued. We plan to achieve a method for the objective assessment of the troubles of the pelvic statics and of the various surgical strategies. The methodology considers 3 axes: building a 3D mechanical model of the pelvic cavity, mechanical characterization of the concerned organic tissues, in-vivo measurement of the intravaginal pressures. The MRI images are acquired according 3 orientations (sagittal, axial and coronal); the organs (bladder, vagina and rectum) are manually outlined and their 3D shape is then rebuilt. Uniaxial tensile tests are initially developed on animal samples before being applied to peroperative human samples. In-vivo measurements of the intravaginal pressures are made thanks to a set of 8 strain gauges specially designed. We show results obtained on 2 patients with a different rank of prolapsus. These first steps will be continued by a more detailed geometry of the organs and a characterization of healthy tissues. Dynamic behaviour of the mechanical stresses will also be investigated.

Keywords—Biomechanics, 3D modeling, Pelvic cavity, Pressure measurements.

I. INTRODUCTION

The treatment of the woman's genital prolapse is a functional surgery for anatomical restitution of the troubles of the pelvic statics. This surgery of the vaginal wall is based on anatomical considerations and usually makes use of the medical images. The frequency of the prolapse's relapses still remains high (up to 60%) [1]. Most of the offered treatments are still empiric and poorly valued. That's why some works recently rose, tempting to provide new tools to the surgical decision [2, 3]. We are planning to achieve a method for the objective assessment of the troubles of the pelvic statics and of the various surgical strategies [4]. The ultimate ambition is to deliver a genuine functional exploration of the prolapses.

Our objective is to develop a mechanical approach to this problem in the choice of the operative decisions and/or of the prosthetic materials. The tuning of a customised 3D mechanical model of the pelvic cavity could help, by means of the simulation, the preoperative decision as well as the postoperative checkup.

II. METHODOLOGY

The considered process rests on three methodological axes, which will be developed thereafter:

- 1) the building of a 3D mechanical model of the pelvic cavity
- 2) the mechanical characterization of the concerned organic tissues
- 3) the in-vivo measurement of the intravaginal pressures.

1) *The 3D organic geometry*: The female pelvic cavity is divided into three parts: the bladder, the rectum and the genital space. In our model, we will restrict this genital space to the vagina, insofar as it is the location where the considered surgical acts are performed. The customized anatomical description of these organs can be obtained from medical imaging.

The standard preoperative protocol indeed includes for every patient a MRI acquisition according to 3 orientations (axial, sagittal and coronal). We can thus take benefit from the obtained images (3mm thick contiguous slices) on which the contours of the 3 bodies are manually outlined. The 3D shapes are then reconstructed from the 3 incidences by fusion in fuzzy logic [5].

2) *The mechanical behaviour of the organic tissues*: The mechanical properties of the human soft tissues are still very poorly known [6,7]. Our objective is to draw up an experimental protocol allowing a reliable quantitative determination of these properties by means of uniaxial tensile tests (Fig. 1). First we studied samples from vaginal tissues.

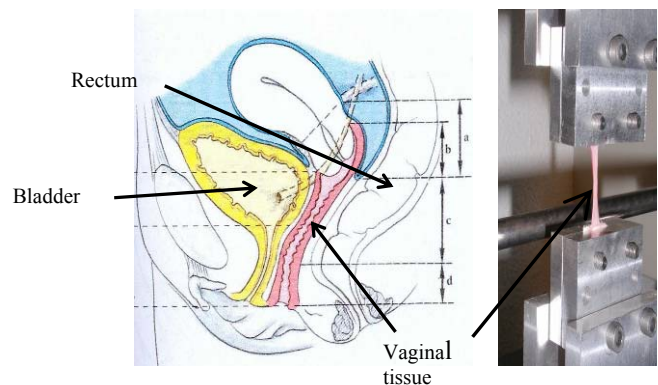


Fig. 1. Anatomical configuration of the pelvic cavity (at left) and tensile test on a vaginal tissue sample (at right).

The whole of the experimental parameters was observed (temperature, hydration, orientation of the sample, speed of elongation...): their respective influence was studied by varying them separately. The protocol was developed with measurements on animals (ewes) and then applied to human peroperative samples. Test samples of standardised shapes were cut out with a punch from the vaginal tissues. Because

of our conventional tension test machine (Instron 4302™), all samples were tested in the open air: that is the only restriction to the good conformity with the in-vivo conditions.

3) *In-vivo measurement of the intravaginal pressures:*

The simultaneous collection of in-vivo intravaginal pressures in several locations not having never been made - to our knowledge-, we thus designed a device inspired of the urologic ones: it puts together on a cylindrical body a set of 8 subminiature strain gauges (SSC1001GA, Sorsortech™, Fig. 2): after introduction of the device into the vaginal orifice, the patient being in laid down position, real time measurements are made during the usual tests of effort (cough, abdominal thrust's stress) and recorded on a microcomputer.

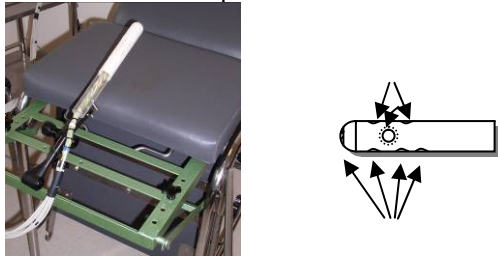


Fig. 2. The pressure probe and its supporting arm (at left) and locations of the measurement's points (at right) pointed by arrows.

So as to prevent the bias induced by a manual holding of the probe, we conceived an articulated supporting arm whose base is screwed on the gynecological bed.

III. RESULTS

1. *3D organic geometry:* In order to match the geometry of the probe and to allow a good registration of the measurements' points with the model, a probe's phantom is inserted into the vaginal cavity of the patient during the MRI examination.

The internal walls of the 3 bodies are separately reconstructed (Fig. 3). As the three processes result from same MRI examination, the software joins them together into a common reference frame which moreover respects the anatomical ratios of the shapes.

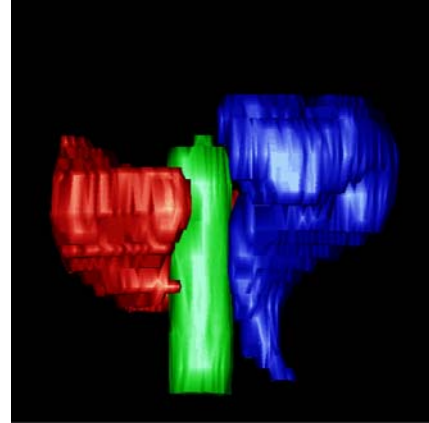


Fig. 3. The 3 reconstructed volumes: at left the bladder, in the centre the vaginal probe, at right the rectum

2. *Mechanical behaviour of the organic tissues:* The retained conditions of tensile tests are as follows: the vaginal tissue must be frozen at -18°C in a physiological solution and then be defrosted over a period of 9 hours before being tested. All samples must be cut out with the punch in the same orientation (because of the great anisotropy of the tissues). They must be stored in a physiological solution for a maximum duration of 24 hours before being tested. Each sample is submitted to a unidirectional tension test at room temperature and at constant deformation rate of $2.10^{-2} s^{-1}$. Under these conditions, a good reproducibility of the tests is guaranteed, as illustrated by Fig. 4.

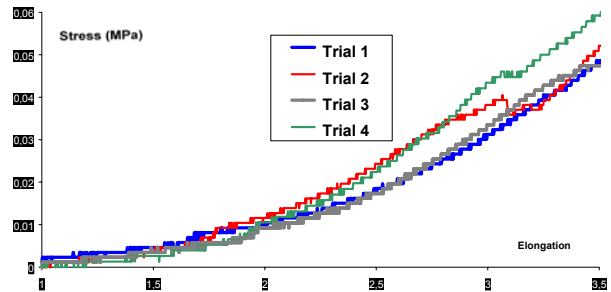


Fig. 4. Intra-animal reproducibility.

This protocol was then applied to various peroperative samples harvested on patients suffering from different pathologies. The corresponding curves seem to be somewhat different, as showed by Fig. 5.

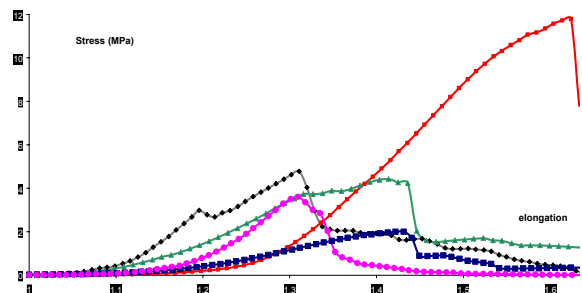


Fig. 5. Rupture tests on 5 different patients.

3. *In-vivo measurement of the intravaginal pressures:* These measurements are taken as the input data of the mechanical model. For each of the 8 points of measurement, we applied to the model the maximum amplitude like value of the local constraint at the corresponding location.

4. *3D mechanical model of the vagina:* The three organic shapes are introduced into a 3D finite element software (MARC MENTAT™ 2002, MSC Software). Several assumptions are made to establish the boundary conditions, both for the bone attachment's points, for the geometry and for the contact properties of (and between) the different neighbouring organs. In particular, the bladder and the rectum are restricted to their respective area (supposed to be rigid) in contact with the vagina: we consider the exerted constraints by these surfaces ("glue" type contacts with a full transmission of the stresses) as being constant. The experimental data of the vaginal tissue are applied to the meshes of the vaginal cavity.

This model is illustrated by Fig. 6.

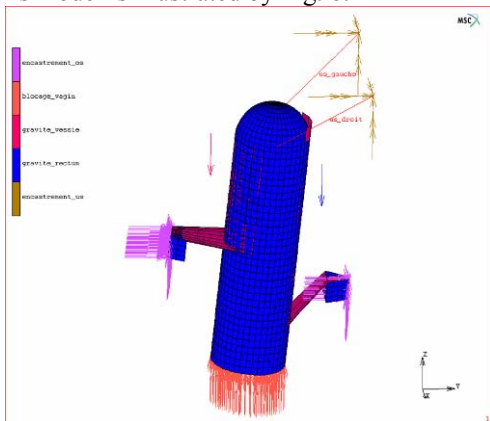


Fig. 6. Boundary conditions on the mechanical model of the vaginal cavity. Up right: the 2 ligamentary suspensions; middle left and right: contact areas with the bladder and the rectum; bottom: rigid area of the vulva.

We made several types of deformations' calculations by applying, as for example, the pressure constraints recorded during the abdominal stresses. We present here (Fig. 7) the results obtained on 2 patients. These patients, recruited in the frame of gynaecologic consultations, suffer from diseases of the pelvic statics. The rank of the prolapse was less important for patient 1 (grade II-III) that for patient 2 (grade IV).

At abdominal thrusts' stresses, the deformed meshes are visually different for the two patients: the displacement on the patient 1 is greater forward and it shows a more important ptosis at the anterior wall of the vagina. The patient 2 gives a deformation showing a more important posterior ptosis, in good agreement with the clinical conditions.

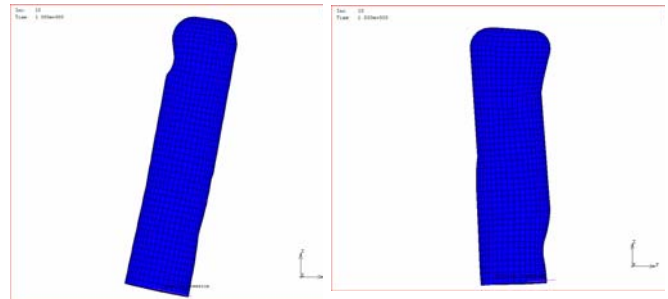


Fig. 7. Abdominal thrusts' stresses computation: left patient 1 (lower grade), right: patient 2 (worse grade).

IV. DISCUSSION

IRM imaging delivers a satisfactory representation of the geometry of organic shapes. The mechanical analysis of any physical object requires allotting to him a thickness of wall which is non-null; more, the realistic definition of surfaces of contact is of primary importance to know the interactions between the bodies. We are working in this field to refine our protocol on these points.

Faced with the ethical impossibility of taking healthy tissues for characterizing their mechanical behavior, we studied samples coming from fresh corpses. We also carried out measurements on other organic samples (from bladder and rectum). Though failing to constitute true normal references, all these first tests carried out on corpses confirm the good reproducibility of measurements. These first studies very clearly showed the visco-hyperelastic nature of the behaviour of these tissues. We will also study the dispersion of their characteristic parameters. We will continue our studies under experimental conditions closer to physiology: it will be therefore necessary to reconsider the experimental set up for the tension tests.

With regard to the study of the intravaginal pressures, we hope to access, thanks to our temporal measurements, to a finer characterization of the topography and of the frequency domain of the exerted mechanical constraints. By studying the space-time correlation between the various channels of measurement, we will try to better know the dynamic behaviour of the organic structures. This work is still in progress.

V. CONCLUSION

The determination of the biomechanical properties of vaginal tissue is an essential step in producing a model of the pelvic cavity. Such a model could help in our understanding of the physiopathology of prolapse.

In the longer term, a customized mechanical model could allow us, for every patient, to simulate the existing

constraints and the results of the planned surgeries. This prospect for a predictive mechanical model of the vaginal cavity is interesting both for the simulation of surgical strategies and for the pre- and post-operative diagnosis. Such simulations could make it possible to bring an efficient help in the choice of the best suited technique to each patient. Current techniques make use of synthetic intra-vaginal prostheses to replace defective tissues: the mechanical characteristics of these synthetic tissues could also be valued with the same manner.

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