



Design and processing of a virtual female pelvic cavity for gynaecological and obstetrical teaching of medical students

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Abstract

Purpose:

The proposed study aims at designing and developing pedagogical means to teach the technical acts that students in gynaecology and obstetrics will need to perform on patients. The major difficulty stems from the fact that the female pelvic floor is not accurately defined in literature. Moreover, the pedagogical model must match the real mobility and the behaviour of the tissues.

Method:

Magnetic Resonance Imaging, Medical scanner and 3D scanner have been used to define the most accurate 3D anatomic geometry. Materials have been chosen in agreement with the experimental information obtained during destructive characterization of the mechanical properties of female pelvic tissues. With rapid prototyping techniques the designed female pelvic cavity has been partially processed.

Result:

One has designed a 3D model of a female pelvic system including organs, ligaments and muscles. A first prototype including pelvic bone and muscles has been developed. The polymer materials used are able to mimic the physical properties of biological tissues.

Discussion & Conclusion:

The 3D model obtained can already be used as a pedagogical mean for teaching anatomy. One is confident in the possibility of manufacturing such a whole complex structure with industrial partners already involved in the project.

1 Introduction

The purpose of using pedagogical models for medicine is to improve the teaching of caregivers: physicians, midwives, physiotherapists or nurses.

Improving the teaching of professionals through learning technical gestures with simulation models prior to clinical contacts aims at reducing morbidity and mortality associated with poor mastery of these gestures, while reducing their learning curves. There are many models to learn gestures such as blood sampling, blood pressure measurement, placing a catheter or management of a heart attack. Some more improved models for learning thoracic or abdominal surgery gestures also exist. Currently, the existing models in the field of gynaecology only allow a few simple gestures (IUD insertion and placement of a speculum). None of them teaches obstetrical yet very common techniques (under revision cervical valves, manual removal of placenta, ...).

The aim of the presented work is to design and process a gynaecological and obstetrical model for medical teaching and/or training. To design such a model several difficulties had to be overcome.

In the first section of the paper, we will focus on the methods used and developed to define the geometry, the constitutive materials and the processing techniques used to process the physical model of the pelvic cavity.

The first part focuses on the definition of the geometry of the physical model. Developing physical models for teaching requires first to define the geometry of the system, in our case the pelvic system. Among the various existing physical models, most of them are based on an empirical description of the anatomy. Moreover there is currently no consensus to define the pelvic system support device, especially ligaments and pelvic floor muscles. This lack of information is mainly due to the difficulty, if not impossibility, to study the pelvic ligaments and muscles system in a non-destructive way.

The second part deals with the selection of the proper polymer materials. The physical system must also be processed with materials with mechanical properties that can mimic the soft tissue properties. Fortunately the outcome of destructive tests that were performed in the past decade can be found in literature [1-8], thus providing information on human pelvic soft tissue. The method has consisted in selecting the proper polymer materials that might mimic the mechanical properties defined in literature, taking into account the processing influence on the mechanical properties of the polymer.

The third part deals with the processing methods used to develop the prototype of the pelvic cavity. One has chosen rapid prototyping processes taking into account the need to handle each anatomical structure to validate its geometry, the complexity of the shapes of the objects which must be produced and finally the need to produce the part to assess the ability of the chosen material to mimic the biological tissue. One will show how FDM (Fused Deposition Modelling) and vacuum casting are adapted in such a case.

Results, conclusions and perspectives will close this paper.

2 Method

2.1 Anatomy reconstruction

In order to be as accurate as possible, the virtual model to be produced will necessarily hold all the anatomic structures that influence the pelvic system mobility. There are four structures in total: the pelvic bone, organs (bladder, rectum, vagina and uterus), pelvic floor (levator ani, obturator internus and coccygeus muscles) and ligaments.

What sources of information?

The anatomy of the pelvic system can be defined thanks to the use of medical imaging devices such as the medical scanner and MRI (Medical Resonance Imaging) in order to define the geometry of the organs, pelvis and muscles. However the ligaments as well as some thin muscles can be difficult to observe or identify individually due to a lack of contrast on the images produced by these technical devices (Fig. 1).

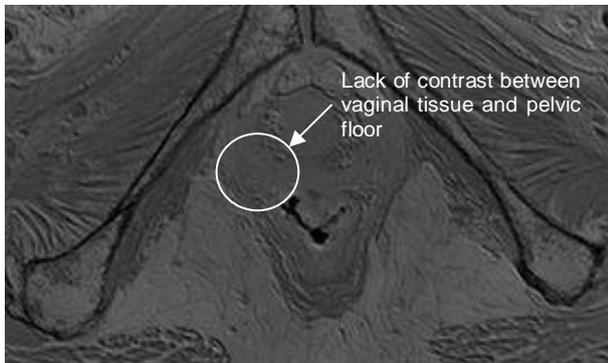


Fig. 1 MRI slice showing the lack of contrast between anatomic structures

The missing anatomic structures are scanned by a portable 3D scanner (Handyscan 3D by CREAFORM). A transparent PMMA (Polymethyl Methacrylate) device allowing to scan surfaces and to focus on the 3D scanner positioning targets at the same time was designed and produced for that purpose (Fig. 2). The resulting 3D scan therefore perfectly matches the scale and the real geometry.

Although the use of the 3D portable scanner was meant to help identify anatomic elements that were difficult to observe or isolate.

It was necessary to work on successive dissections in order to progressively highlight the structures that had to



Fig. 2 Scanning device with RevScan (CREAFORM)

be observed. Prior to dissection the corpse was first placed in a MRI and then a medical scanner. The use of a cadaveric specimen rather than a living patient enabled for longer periods of examinations (over 45 minutes). It also made it possible to use the highest image resolution for the devices as well as increase the number of slices (table 1).

| Imaging technique | Image resolution (pixels) | Number of slices | Voxel size (mm) |
|-------------------|---------------------------|------------------|-----------------|
| MRI | 512x512 | 150 | 0,6x0,6x1,2 |
| Scanner | 512x512 | 519 | 0,9x0,9x0,7 |
| 3D Scanner | - | - | 0,8x0,8x0,8 |

Tab.1 Data scanning resolution

These radiologic checks were later followed by a series of fifteen stages of dissections. The dissection device was equipped with fixed markers enabling the adjustment of the point clouds resulting from the various 3D scans. Each scan sequence produced a point cloud represented by a marker depending on the position of the scanner at the time the first point was collected (Fig. 3a and Fig. 3b).

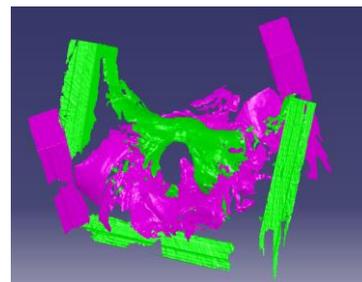


Fig. 3a Point clouds before adjustment

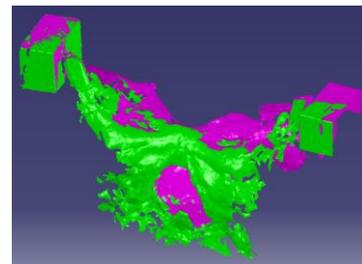


Fig. 3b Point clouds after adjustment

The collection of all the data from the three sources provided the necessary geometric information for the model reconstruction.

What methods of reconstruction?

The chosen method consisted in segmenting the outlines, first using Avizo® Fire software. The anatomic structures are identified and outlined on each image (Fig.4). Once the outlining of each slice is completed, Avizo® Fire allows for the construction of a meshed surface using all the outlines provided (Fig. 4). All of the images provided by the medical imaging devices (medical scanner or MRI) are processed through this method.

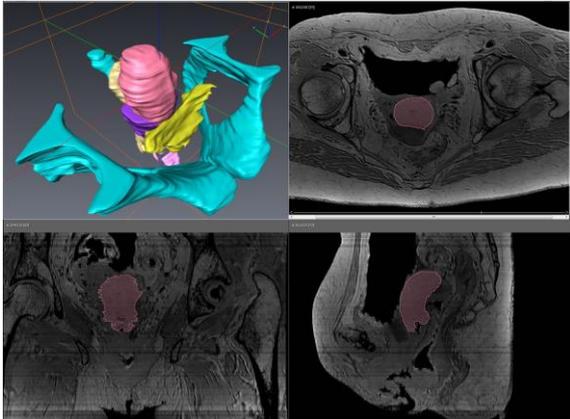


Fig. 4 MRI images segmentation and meshed surface of the uterus (in pink) -Avizo® Fire Software

The surfaces produced are then imported into Catia V5 (Digital Shape Editor module) in the shape of a point cloud. The point cloud of an anatomic element is screened, meshed and smoothed out. The meshing produced is used to define the wrapping surface of an anatomic structure (Fig.5).

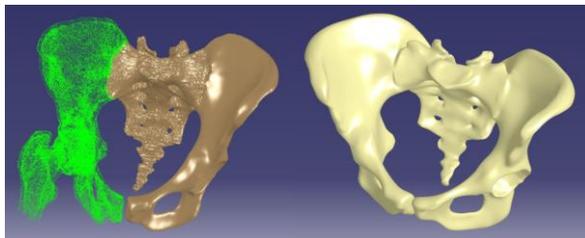


Fig. 5 Stages of processing of points cloud in Catia V5 From left: point cloud, raw mesh, smoothed mesh and explicit interpolated surface.

For 3D scans, the reconstruction method is as follows: The 3D scan file is imported into Catia V5. The anatomic structure to be reconstructed is identified thanks to the annotated images taken during dissections (Fig. 6).The meshing elements matching that structure are then selected and used to reconstruct the anatomic structure geometry (Fig.7).

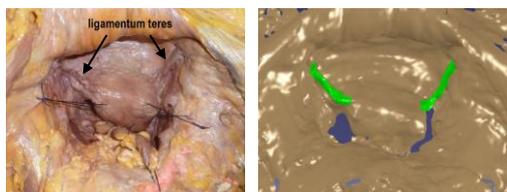


Fig.6 Round ligaments identification

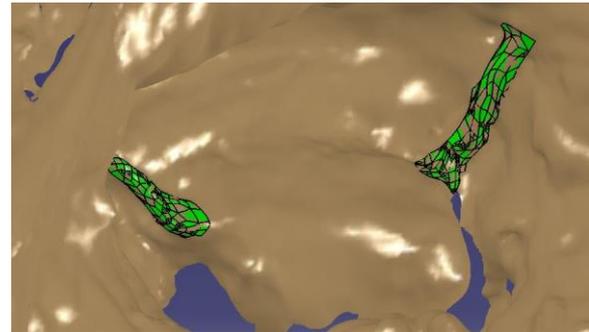


Fig.7 Round ligaments modelling

Which method for which anatomic structure?

As mentioned before, different imaging techniques are used because all of the anatomic elements can not be observed with only one technique. The various anatomic elements have been defined as follows:

- Pelvic bone
The pelvic bone has been reconstructed using medical scanner images. On these images, bone structures appear in white and are very contrasted against vaginal tissue.
- Pelvic floor
The pelvic floor has been reconstructed by coupling MRI and 3D portable scanner images.
- Pelvic organs
They were reconstructed according to the MRI provided data.
- Ligaments
Ligaments were reconstructed using 3D scans obtained through dissections.

Once each anatomic structure has been digitally defined using the most appropriate method, the final complete model made up of the different elements was spatially adjusted. The pelvic bone which had been partially or fully completed using each information source was used as a fixed marker, assuming that no changes had occurred throughout the various checks (MRI, medical scanner and dissections). Fig. 8 shows the deviations between the rough meshing of the pelvis using the MRI (in pink) and the reconstructed pelvis using the scanner (in white). Very few discrepancies can be noticed, therefore confirming our assumptions. Fig.9 shows the main muscular heads positioned around the pelvic bone.

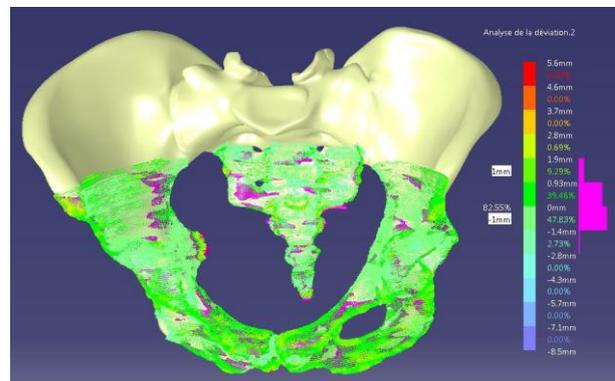


Fig. 8 Analysis of the deviations between the segmented MRI and explicit interpolated geometry extracted from the medical scanner images.

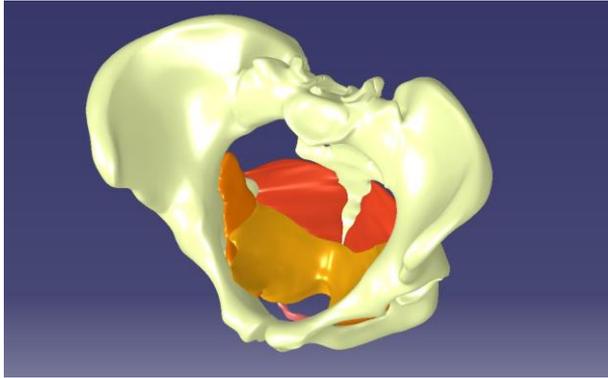


Fig.9 CAD Model of pelvic bone and muscles after adjustment

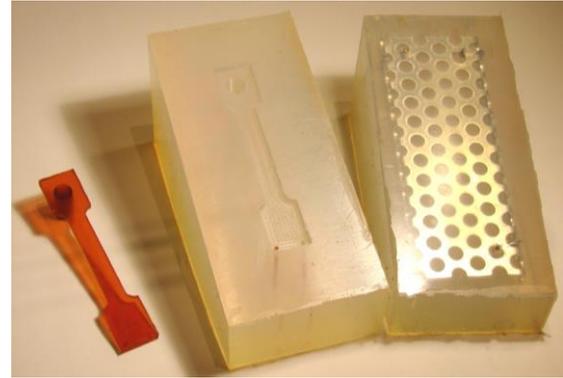


Fig. 12 uniaxial samples prototyping to assess polymer properties and process influence depending on thickness

2.2 Selection of the accurate polymer

The development of a physical model of the pelvic cavity ensuring the setup of a learning pedagogical device requires the use of rapid prototyping techniques. These techniques require the use of polymer materials the characteristics of which must match those of vaginal tissue as closely as possible. The choice of materials was determined after some preliminary studies had been carried out to perform some mechanical trials on tissues from fresh corpses, in compliance with ethical legislation, in order to map out the mechanical properties of vaginal tissue [1-8].

Vaginal tissue turned out to have non-linear hyper elastic behaviour. Yet as part of the pedagogical model context, the expected deformations would remain moderate and the behaviour could be compared to initial linear behaviour at the origin. In this case, all of the studies carried out by the team can be summed up using the data in table 2.

| Anatomic element | Organs | | | Ligaments | | | Muscle |
|-------------------------------------|--------|---------|--------|--------------|-------|-------|--------------------------------|
| | Rectum | Bladder | Vagina | Utero sacral | Round | Large | Pelvic floor (Estimated prop.) |
| Tangent modulus at the origin (MPa) | 4 | 2 | 15 | 72 | 45 | 20 | 3 |

Tab. 2 Mechanical properties of soft tissues of the pelvic system

Given the low levels of rigidity involved, some polymer materials were used. The elaboration process first required the moulding of the materials before the polymerization of the materials itself. As there are thickness variations in the anatomic elements, some thermal gradients are likely to be found within the various anatomic elements to be produced, hence causing variations to mechanical properties. In order to select polymer materials, characterization trials were performed using uniaxial tensile of variable thickness, so as to assess the influence of thermal gradients on the induced mechanical properties. (Fig. 10)

2.3 Prototyping of the pelvis cavity

Three successive steps are necessary to prototype the physical model of the pelvic cavity:

- 3D printing of the physical model of each anatomic structure.
- Duplication of the geometry of each anatomical structure with accurate materials.
- Assembly of the structures composing the pelvic cavity.

To process each anatomical structure, one used a 3D printer using an additive manufacturing technology called FDM (stands for Fused Deposition Modelling). A semi-liquid thermoplastic material (Acrylonitrile Butadiene Styrene) is extruded through a temperature-controlled print head. The selected 3D printer is a Dimension Elite from STRATASYS. This printer enables the deposition of layers of 0.254 mm or 0.178 mm thick. The precision of the obtained parts is about 0.1mm in the plan of the layers and less than 0.4 mm perpendicular to layers [9] which is compatible with our application. This technique allows obtain models one can handle without risk of deterioration and facilitate the validation of the geometric model. Fig 13 shows the 3D printing of an assembly of the pelvic floor (levator ani, obturator internus and coccygeus muscles).



Fig. 13 Results of the 3D printing of the pelvic floor in ABS

Next, one proceeds to the over moulding of the printed part with silicone. Silicone elastomer ESSIL 291 marketed by ASXON Technologies SAS is used. The mould is cut to extract the model. An installation of vacuum casting of

two-component resins (model V-400 of KLM GmbH) allows the duplication of parts using the silicone mould. Fig. 14 shows the pelvic bones duplicated with polyurethane (PU) PX 226 resin (AXSON Technologies SAS).



Fig. 14 Vacuum casting of the prototype of pelvic bones in PU

The assembly of the anatomical structures, constituted of various materials, may be performed by gluing or over moulding. Over moulding, when possible, has been preferred for its efficiency due to the physicochemical compatibilities of co-polymerization of structures (Fig. 15).

3 Results

A 3D geometrical model, anatomically valid, taking into account the anatomical structures having an impact on the physiologic mobility of the pelvic system has been constructed.

The combination of the various medical imaging techniques and 3D manual scanner allowed us to define a numerical model including all the pelvic organs (vagina (V), bladder (B), rectum (R) and uterus (U)), pelvic floor muscles (obturator internus, levator ani, coccygeus muscles) and the suspension ligaments (utero sacral, round, large, para-vaginal and umbilical ligaments) and the pelvic bones as illustrated on Fig. 15.

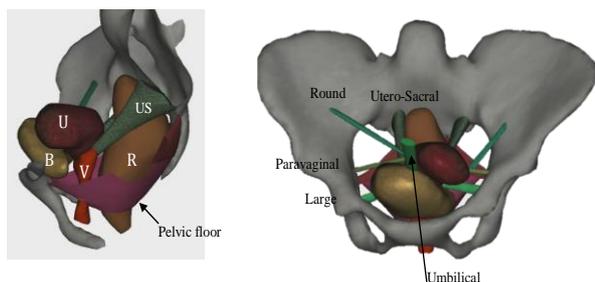


Fig. 15 Complete numerical anatomy of the pelvic system

As Fig 15 shows, the anatomical aspect ratio of each element is respected on the numerical model validating the multi incidence imaging repositioning and reconstruction methods.

Among the polymer available, according to the preliminary mechanical tests performed on manufactured samples (see Fig. 12), PU rubber UPX 8400 from AXSON Technologies SAS has been selected. The stiffness and strength of this PU Rubber might vary by adding additive.

The main advantages of this PU rubber are that:

- The pelvic bone is manufactured in PU. Consequently having one single polymer for each part will enable to glue them by a co-polymerization process of high stiffness.
- Using the same PU Rubber for each organ, modifying only the ratio of additive simplifies the processes.
- Using only one type of polymer PU, allows to master its process and to reach easy processing control.

Pelvic floor bone and obturator internus, levator ani, coccygeus muscles have been manufactured. Next they have been glued with over moulding techniques (see Fig. 16). The adhesion of each part reveals to be very efficient.



Fig. 16 Over moulding of the pelvic floor on the pelvic bone

4 Discussion

The final aim of our work is to manufacture a complete pelvic system as presented on Fig 15 including organs and ligaments.

The difficulties to be solved are the following:

- Stiffness of pelvic organs and ligaments are different from one to another.

According to the selection process of the PU Rubber, one knows that the stiffness of the PU rubber may vary with respect to the ratio of additive. However, one has to define precisely for each organ, taking into account its thickness, the exact volume fraction of additive that might be added.

- Thickness also varies.

The variation of thickness may affect the polymerization process and subsequent stiffness must be controlled in accordance.

- Organs are very thin structures, modelled as nearly closed shells

Manufacturing a very thin and nearly closed structure might be a difficulty.

However, the results already obtained let the author being confident.

Processing polymer with specific thickness and stiffness is under study. Because, we need to know the specific volume fraction of additive to be added for a specific couple thickness/stiffness, uniaxial samples are manufactured with different thickness (Fig. 12) and tested. Manufacturing parts, with a given polymer/additive, almost being closed shells will be solved by using lost wax core technique. The adhesion between each part will be performed, if possible, by over moulding techniques or gluing with added PU Rubber.

5 Conclusion

One defined a 3D virtual model of a female pelvic cavity which is the only one so complete with a whole definition of bones, muscles, organs and ligaments involved in the mobility of the pelvic system. Our model has been validated by medical doctors. A similar 3D model has been created using plastinated cross sections [10]. This model does not integrate the suspension devices (ligaments).

Our model is a useful educational mean for gynaecology and obstetrics teaching for the medical students. Indeed, it can advantageously replace the usual 2D representations in the anatomical study of the pelvic system for a better understanding of the adjacent relationship and arrangement of respective pelvis structures.

One selected rapid prototyping techniques and materials which relevance was verified. The first prototype shows that one will be able to achieve the manufacturing of a female pelvic cavity matching the physical behaviour of real anatomy. This simulation mannequin will allow medical students to learn technical gestures prior to clinical contacts. To this end, one will need to work together with industrial partners, already involved in the project, to develop the external shell of the mannequin.

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References

- [1] Goh JT, Biomechanical properties of prolapsed vaginal tissue in pre and postmenopausal women, *Int Urogynecol J Pelvic Floor Dysfunct.*; 13(2); pp76-79; discussion 79, (2002).
- [2] Moalli P.A., Remodelling of vaginal connective tissue in patients with prolapse, *Obstet Gynecol.*;106 (5 Pt 1): 953-63 (2005)
- [3] C. Rubod, M. Brieu, M. Boukerour, P. Dubois, M. Cosson, Biomechanical properties of vaginal tissue: New experimental protocol, *J. Urology*, 178, 1 pp. 320-325 (2007).
- [4] C. Rubod, M. Boukerrou, M. Brieu, M. Cosson, Biomechanical properties of vaginal tissue: Results and implication, *Int. Urology J.*, 18, 1 pp. 54-63 (2007).
- [5] C. Rubod, M. Boukerrou, M. Brieu, C. Jean-Charles, P. Dubois, M. Cosson, Biomechanical properties of vaginal tissue: Preliminary Results, *Int. Urogynaecology J.*, 19, 6, pp. 811-816 (2008).
- [6] Goepel C., Differential elastin and tenascin immunolabeling in the uterosacral ligaments in postmenopausal women with and without pelvic organ prolapse. *Acta Histochem.* 110(3): pp. 204-9. (2008).
- [7] G. Rivaux, C. Rubod, M. Brieu, M. Cosson, Biomechanical properties of pelvic ligaments, *Pelvi-perineology*, 6, 2, pp. 67-74, (2011).
- [8] C. Rubod, M. Brieu, M. Cosson, G. Rivaux, JC. Clay, B. Gabriel Biomechanical properties of human pelvic organs, *Urology J.*, 79, 4, pp. 1346-54 (2012).
- [9] Debarre E., Application du prototypage rapide à l'aide au diagnostic en chirurgie traumatologique et orthopédique, PhD thesis, Artois University, France, (2011).
- [10] Sora M.C., Jilavu R., Matusz P., Computer aided three-dimensional reconstruction and modelling of the pelvis, by using plastinated cross sections, as a powerful tool for morphological investigations, *Sur. Radiol. Anat*, 34 pp. 731-737, (2012).