Aroj Bhattarai and Manfred Staat*

Computational comparison of different textile implants to correct apical prolapse in females

Abstract: Prosthetic textile implants of different shapes, sizes and polymers are used to correct the apical prolapse after hysterectomy (removal of the uterus). The selection of the implant before or during minimally invasive surgery depends on the patient’s anatomical defect, intended function after reconstruction and most importantly the surgeon’s preference. Weakness or damage of the supporting tissues during childbirth, menopause or previous pelvic surgeries may put females in higher risk of prolapse. Numerical simulations of reconstructed pelvic floor with weakened tissues and organ supported by textile product models: DynaMesh®-PRS soft, DynaMesh®-PRP soft and DynaMesh®-CESA from FEG Textiletechnik mbH, Germany are compared.

Keywords: Apical prolapse, hysterectomy, textile implants, minimal invasive surgery, female pelvic floor model.

1 Introduction

Post-hysterectomy apical prolapse can be defined as the herniation or the descent of the vaginal-cervical stump into the vaginal canal or outside the vagina after hysterectomy [1, 2] affecting about 43% female population [3]. Damaged nerve supply during childbirth [4], weakened tissue due to collagen remodeling after menopause [5, 6] or disrupted support mechanisms from the apical ligaments, the pubocervical fascia and the paracolpium around the cervix [3] are the presumed reasons for the apical prolapse. Various minimally invasive surgeries such as sacrocolpopexy, cervico-sacropey and pectopexy for the repair of apical prolapse have been reported [7–9]: the choice of the operation depends on the severity of the prolapse, co-morbidity, patient’s anatomical defect, nature of the operation to be performed and the surgeon’s preference [10]. Mesh implantation is often associated with postoperative mesh related complications [11] which require multiple re-operations including complete mesh removal. These events may significantly impair the patient’s quality of life [12].

In this study, the biomechanical performances of the post-hysterectomy apical prolapse repair techniques: sacrocolpopexy (anterior longitudinal ligament fixation of DynaMesh®-PRS soft), pectopexy (iliopectineal ligament fixation of DynaMesh®-PRP soft) and cervicosacropexy (bilateral reinforcement of the uterosacral ligaments using DynaMesh®-CESA) are investigated using a 3D finite element model of the female pelvic floor. Simulations are conducted with lax tissues modeled by reducing their stiffness to simulate the weakened pelvic floor being responsible for prolapse. Mesh implants are expected to reposition the vaginal-cervical stump at rest after surgery and during Valsalva maneuver. The results of the finite element (FE) analyses with different prosthetic devices are compared with respect to the stump position.

2 Materials and Methods

2.1 Female pelvic floor model

A three dimensional biomechanical model of the female pelvic floor (Figure 1) has been constructed from the ultra-thin plasti-
nated slices of a 70-year old cadaver with unknown history of pelvic pathology. The detailed methodology of creating the FE model of the internal morphology from the plastinated slices has been described. This FE model has been investigated for female pelvic floor pathologies and repair techniques. The uterus can be removed partially or completely from the model in order to represent the post-hysterectomy cervical or the vaginal stump needed for mesh suture.

2.2 Textile implants

The mesh implants to perform the sacrocolpopexy, the pectopexy and the cervicosacropexy techniques are shown in Figure 2. For the sacrocolpopexy repair, a Y-shaped implant is modeled as a strip with adjusted dimension (length \times width \times thickness: (7+4) \text{ cm} \times 2 \text{ cm} \times 0.04 \text{ cm}) to fit up to the half-length of the vagina (Figure 2a). The other end is later pulled towards the desired height of the sacrum bone between promontory to S3 for fixation or suture. The pectopexy implant is also modeled as a rectangular strip which is broader in the center and at its sides (Figure 2b). The broader parts are used to fix the implant to the vaginal stump as well as the left and right iliopectineal ligament with sutures. The cervicosacropexy implant is modeled as a rectangular strip with varying widths (Figure 2c). The center and end regions are wider whereas the implant part which passes inside the uterosacral ligaments is manufactured with three thicker polymer bundles, thus is modeled as a rectangular strip of 0.3 cm width.

2.3 Constitutive modeling

Biological tissues offer highly non-linear, incompressible, isotropic and elastic stress-stretch relations which can be obtained using the three term Mooney Rivlin type model as

\[
\sigma = 2\left(\lambda^2 - \frac{1}{\lambda}\right)\left[C_{10} + C_{01}\frac{\lambda}{\lambda^2 + 2}\right] - pI, \tag{1}
\]

where \(C_{10}, C_{01}\) and \(C_{20}\) are the material parameters with dimensions of stress (MPa), \(p\) is an indeterminate Lagrange multiplier identified as a hydrostatic pressure which can be determined from the equilibrium equations, \(\lambda\) is the stretch in uniaxial tension for an incompressible material and \(I\) is the second order identity tensor. For some organs anisotropic models could be used if sufficient data is available.

The pore architecture of the polyvinylidene fluoride (PVDF) made DynaMesh® implants to repair the apical prolapse provide optimal elasticity during physiological movement of the organs after implantation. In contrast to conventional polypropylene meshes such as GYNECARE GYNEMESH® PS Nonabsorbable PROLENE® soft from Ethicon, USA which offers extreme flexibility due to dramatic pore collapse, DynaMesh® preserves its effective porosity to ensure better biocompatibility and biofunctionality. The stress-stretch curves are derived from the force-elongation curves of the DynaMesh® implant that show nearly linear elastic orthotropic behavior. Therefore, the Young’s modulus is computed for both longitudinal \(E_L\) and transversal \(E_T\) mesh directions. The other necessary material parameters \((C_{10}, C_{01}, C_{20})\) for all pelvic tissues (organs, ligaments, muscles and fascias) as expressed in eq 1 and the mesh implants \((\nu_L, T)\) and \(G_L, T\) are presented in [13–15].

2.4 Cervicosacropexy implantation

The model of the DynaMesh®-CESA implant as shown in Figure 1 is included in the FE model of the female pelvic floor. Cervicosacropexy, a modified sacrocolpopexy procedure, reinforces or replaces the uterosacral ligaments by the surgical insertion of the implant. Bhattarai et al. [14] observed lesser physiological vaginal mobility during the repair of the apical
prolapse with unilateral DynaMesh®-PRS soft fixation to the sacral promontory. In contrast, bilateral DynaMesh®-CESA fixation to the second sacral bone (S2) is expected to provide better or maximum vaginal movement with the minimum use of material [8], though bilateral uterosacral ligament augmentation is its primary objective. The vaginal mobility in both cases may be compared with the measurement of the perpendicular distance of the post-hysterectomy vaginal apex with reference to the pubococcygeal line (PCL).

3 Results

The FE simulation of the deformation and the stump prolapse treatments using prosthetic mesh implants as shown in Figure 3 are performed with the open source finite element software Code−Aster. Using parallel solver technology on a Linux-based multi-core processor, each simulation took about 5 hours and 30 minutes with two Intel Xeon processors (8 core, 3.10GHz Turbo, 20MB, 8.0 GT/s). The pathophysiological post-hysterectomy apical prolapse and repair simulations using DynaMesh®-PRS soft and DynaMesh®-PRP soft implants have been performed with weakened supporting ligaments and fascias in [14, 15]. The results have been validated with respect to the vaginal apex positions measured from the PCL line drawn in the MRI scans of a female patient with prolapse after hysterectomy, see Table 1.

Tab. 1: Measurement of the vaginal cuff position (PVC), vaginal axis (VVC angle in Figure 3b) and urethral axis (Ur angle in Figure 1) during Valsalva maneuver for sacrocolpopexy [14], pectopexy [15] and cervicosacropexy repair simulations. Positive values represent the distance measured above the PCL line and negative values represent the distance measured below the PCL line. VVC and Ur represent the angle between the vaginal and urethral axis with the vertical line.

<table>
<thead>
<tr>
<th></th>
<th>PVC (mm)</th>
<th>VVC (°)</th>
<th>Ur (°)</th>
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<tbody>
<tr>
<td>Prolapse [14]</td>
<td>−10.0</td>
<td>70°</td>
<td>36.7°</td>
</tr>
<tr>
<td>Sacrocolpopexy [14]</td>
<td>37.2</td>
<td>22°</td>
<td>8.2°</td>
</tr>
<tr>
<td>DynaMesh®-PRS soft</td>
<td>15.3</td>
<td>42°</td>
<td>28.5°</td>
</tr>
<tr>
<td>Pectopexy [15]</td>
<td>15.3</td>
<td>42°</td>
<td>28.5°</td>
</tr>
<tr>
<td>DynaMesh®-PRP soft</td>
<td>15.3</td>
<td>42°</td>
<td>28.5°</td>
</tr>
<tr>
<td>Cervicosacropexy</td>
<td>−2.6</td>
<td>58°</td>
<td>33.5°</td>
</tr>
</tbody>
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As shown in Figure 3b, the yellow post-hysterectomy prolapsed vagina can barely be supported by weakened ligaments and fascias during the Valsalva maneuver and is dis-

located by −10 mm below the reference PCL line (Table 1). In such cases, the vaginal or cervical stump is surgically su-
tured to lift or to reposition at its healthy positions using tex-
tile devices. Three different DynaMesh products are available to correct: DynaMesh®-PRS soft, DynaMesh®-PRP soft and DynaMesh®-CESA, see Figure 2. At rest after surgery, the unilateral sacrocolpopexy DynaMesh®-PRS soft implant lifts the vaginal stump much higher from the PCL line than the rest of the DynaMesh products (37.2 mm vs 15.3 mm and −2.6 mm, see Table 1). This implant offers a lesser (22°) angle of the vaginal axis with the vertical than the other im-
plants (42° and 58°) providing relatively lesser mobility of the vagina during physiological Valsalva maneuver, see Figure 3b. The cervicosacropexy DynaMesh®-CESA implant man-
ufactured with minimum polymer material offers maximum movement of the vagina and is positioned near the PCL line (−2.6 mm below), whereas the pectopexy DynaMesh®-PRP
soft with shorter length supporting the cervical stump after hysterectomy provides moderate result between DynaMesh®-PRS soft and DynaMesh®-CESA, see Table 1.

The repair of the apical prolapse include of lifting the vaginal or the cervical stump which may eventually elevate and stabilize the dislocated bladder and disoriented urethral axis, Ur (36.74°), see Figure 1. Compared to the DynaMesh®-CESA repair, DynaMesh®-PRS and DynaMesh®-PRP implants provide better additional result on urethral axis, see Table 1. Bladder hypermobility and an urethral axis, Ur > 30° resembles symptomatic stress urinary incontinence [13].

4 Discussion and Conclusions

Apical prolapse is very common in multiparous elderly women for which sacrolcopexy, pectopexy and cervicosacropexy are some minimally invasive surgical techniques. However such surgical interventions using textile meshes may possess certain degree of long term mesh related complications, such as chronic pain, infection, mesh shrinkage and foreign body inflammations [11]. Unilateral sacrolcopexy is considered to be the gold standard to treat apical prolapse and found to provide better anatomical repositioning [14], however vaginal mobility is greatly restricted. It may also be posed to reduced pelvic space, defecation disorders and adhesion or injury of hypogastric nerves specially in obese populations [16]. For which laparoscopic pectopexy is a good alternative [9]. The cervicosacropexy method is found to provide greater vaginal mobility than the other DynaMesh products and may be preferred by the surgeons where vaginal mobility is desired.

Nevertheless, the model should be further studied with great detail to predict success and failure of surgical interventions caused by potential risk factors such as mesh wrinkling, injuries, infection of adjacent organs in the pelvic and peritoneal space. This can be obtained by calculating and comparing quantitative parameters such as stress or stretch in different structures including mesh implants which may lead to a better understanding of potential postoperative complications.

Author Statement

Research funding: The first author has been partially funded by the German Federal Ministry of Education and Research through the FHprofUnt project „BINGO“, grant number 03FH073PX2. Conflict of interest: Authors state no conflict of interest. Informed consent: Informed consent has been obtained from all individuals included in this study. Ethical approval: The research related to human use complies with all the relevant national regulations, institutional policies and was performed in accordance with the tenets of the Helsinki Declaration, and has been approved by the Medical University of Vienna to use the pelvis for 3D reconstruction obtained as the human donation program: EK Nr: 1191/2011.

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