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Analysis of stretch and stress distribution in pelvic floor structures during vaginal delivery using computer modeling

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Female pelvic floor dysfunction, such as urinary incontinence, fecal urgency or pelvic organ prolapse, is very often associated with injuries of pelvic floor structures during childbirth. This trauma usually causes lifelong complications leading to poorer social or/and sexual life. The paper from Great Britain published that only 9.6 % of primipara and 31.2 % of sekundipara deliver with intact perineum [5]. In addition, the older study showed that 85 % women are suffering from injury of perineum during vaginal delivery [4]. Therefore, it is essential to understand the anatomy and physiology of these structures to avoid or at least to decrease the trauma of vaginal delivery. The computer modeling is a sophisticated tool how to achieve that.

The main objective of this study was to improve already existing finite element model of the female pelvic floor [2]. The model consists of the female pelvis; pelvic floor muscles – the levator ani muscle (iliococcygeus, pubovisceral, puborectal) and the internal obturator muscle; perineal structures – the external and internal anal sphincter, the perinal body, the superficial transverse perineal muscle, the bulbospongiosus muscle, the ischiocavernosus muscle, the anococcygeal body; and the fetal head. All supporting structures were replaced by boundary conditions. The model geometry was based on live-subjects MRI data – women: 25-years-old, Caucasian, no previous vaginal delivery, normal POP-Q points, absence of PFD symptoms, no pathological changes, healthy in general; neonate: 1-day-old, after uncomplicated vaginal delivery at term, neurological indications for a MRI brain scan. The volunteers as well as the imaging protocol are described in more details in author's publication. The asked volunteer/legal representative gave written consent. The study was approved by the local ethics committee from the institution of authors. The considered simulations and analyses focused on the muscle pelvic and perinal muscle structures only. Thus, other surrounding organs and tissues were neglected. It was assumed that these organs (bladder, urethra, rectum, etc.) are pushed during the vaginal delivery without any significant reaction forces.

The bony segments were modelled by rigid bodies without any possibility of deformation, the soft tissues were modelled by hyperelastic Ogden material model to enable such a huge deformation [3]. The model constants were fitted using the stress-strain characteristic published in literature sources and least-square method in MATLAB (lsqcurvefit, optimization toolbox; R2013a; The MathWorks, Inc. Natick, Massachusetts, USA).

The initial model geometry was reconstructed from in-vivo scanned MRI using a free semi-automatic software 3D Slicer (3.0; BWH, Boston, MA, USA). The resulting geometry and mesh were created in commercial software HyperMesh (11.0; Altair, MI, USA). Rigid parts, such as female pelvis and fetal head, were constructed with 2D triangular mesh including more than 100 000 elements in summary. Deformable parts, such as muscles, were modeled by 3D tetrahedral mesh consisting of almost 700 000 elements. The accuracy and efficiency of the finite element simulations considered in presented work is highly predisposed to the quality of the finite element mesh [1]. And thus, the process of element quality control was not neglected.

Vaginal delivery scaled in seconds was simulated for the optimal fetal head position - left occipitoanterior positon. The distribution of stretch and stress von Mises generated in pelvic floor structures during vaginal delivery was analysed using the finite element method and the commercial software Virtual Performance Solution (VPS 9.0; ESI Group, Paris, France). The final model is depicted in Fig. 1.

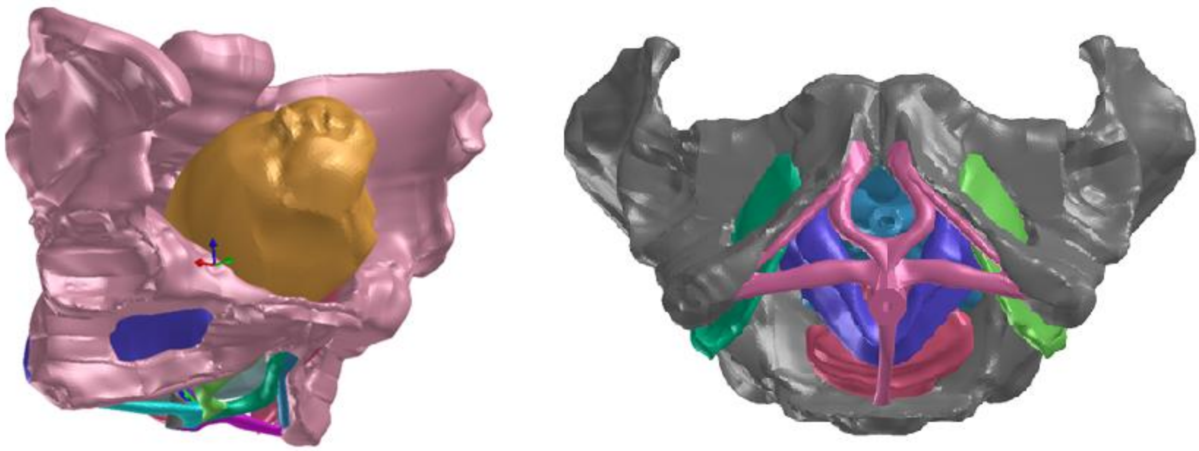

Fig. 1. The FE model of female pelvic floor; simulation of vaginal delivery considering the rigid fetal head in optimal initial position

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