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Study on the influence of the fetus head molding on the biomechanical behavior of the pelvic floor muscles, during vaginal delivery

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ABSTRACT

Pelvic floor injuries during vaginal delivery are considered a significant risk factor to develop pelvic floor dysfunction. The molding of the fetus head during vaginal delivery facilitates the labor progress, since it adjusts to the birth canal geometry.

In this work, a finite element model was used to represent the effects induced by the passage of the fetus head on the pelvic floor. The numerical model used for this simulation included the pelvic floor muscles attached to the bones, and a fetus body. The model of the fetus head included the skin and soft tissues, the skull with sutures and fontanelles, and the brain. The fetus head movements during birth in vertex position were simulated: descent, internal rotation and extension. Two models of the fetus head were compared: a rigid and a deformable one, with the inclusion of the cranial sutures. The influence of the fetus head molding on the pelvic floor muscles was analyzed by evaluating their reaction forces, stretch, and stress and strain fields. Additionally, anatomical indices for the molding of the fetal skull were obtained and compared with clinical data.

The passage of the deformable fetus head through the birth canal leads to a reduction of 17.3% on the reaction forces on the pelvic floor muscles when compared to the ones of a rigid head. Furthermore, the fetus head molding implies inferior resistance to rotation resulting in a reduction of 1.86% in muscle stretching. Quantitative evaluation of the fetus head molding showed good agreement with clinical experiments.

1. Introduction

Female pelvic floor dysfunction (PFD) is a highly prevalent condition (MacLennan et al., 2000). The three most common and clinically definable conditions are urinary and/or fecal incontinence, and pelvic organ prolapse, and the statistics show that 1 in every 10 women will require surgery (Olsen et al., 1997). Pelvic floor injuries during vaginal delivery can be considered a significant factor to develop PFD (Dimpfl et al., 1998). However, it is widely recognized that the understanding of the mechanisms of damage to the pelvic floor components (muscles, nerves or, fascia) is still very limited (Parente et al., 2009b).

During vaginal delivery in vertex position, the fetus head is subject to elevated pressure during its passage through the birth canal, which molds it into an elongated shape (Bronfin, 2001). This occurs because the bones composing the calvaria are flexible and separated by cranial sutures and fontanelles (Lapeer and Prager, 2001; Cunningham and Heike, 2007). Depending on the duration of the delivery process, vaginal contractions may induce an overlap of the bones (Amiel-Tison et al., 2002; Peitsch et al., 2002), which reduces the stretch and stress to which the pelvic floor muscles undergo during childbirth.

Previous work focused on the computational analysis of the pelvic floor muscles during vaginal delivery (Hoyte et al., 2008; Li et al., 2008; Parente et al., 2009b). In those studies, the authors modeled the fetus head as an undeformable structure or having stiff material properties. To our knowledge, few studies simulated vaginal delivery with the fetus head modeled as a deformable body with adjusted material properties (Lapeer and Prager, 2001; Pu et al., 2011). Furthermore, in those works, the analysis was based on the first stage of delivery, simulating the pressure exerted by the cervix and the amniotic fluid on the fetus head.

For those reasons, this work shows the relevance of accounting for the fetus head molding during the second stage of labor. To accomplish it, biomechanical simulation based on the finite element method (FEM) is performed, including the pelvic floor muscles, the bony pelvis, and the fetus. Two different models of the fetus head were used: one with a rigid head and the other with a deformable one, with the inclusion of the cranial sutures.

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2. Materials and methods

2.1. Finite element model

The finite element model of the pelvic floor muscles was built using geometrical information obtained from an embalmed 72 years old female cadaver (Janda et al., 2003). The nodes corresponding to the pubic bone and the extremities of the *levator ani* muscle and pelvic fascia that attach to the pubic bone were considered fixed. The model of the pelvic floor muscles was connected to a model of the pelvic skeletal structure, assumed rigid. Further details can be obtained from previous works of the authors (Parente et al., 2008, 2009a,b).

A finite element mesh of the fetus body was also included (Parente et al., 2010). The dimensions were adjusted, and the arms and legs were repositioned to be in accordance with the literature for a full-term fetus (Amiel-Tison et al., 2002). To study the molding effect, the skin and soft tissues, skull, fontanelles and sutures, and brain were included on the deformable fetus head model.

The fetus skull and sutures, presented in Fig. 1, were built from Computed Tomography (CT) images, supplied by the Pennsylvania Open Research Scan Archive (ORSA) (Monge and Schoenemann, 2011). The CT images, from a final gestation stillbirth (Fig. 2), were segmented by a semi-automatic process based on the pixel density using the software Mimics® v.16 (Software and Services for Biomedical Engineering, Materialise HQ, Belgium). The skull model was then included into the fetus body model.

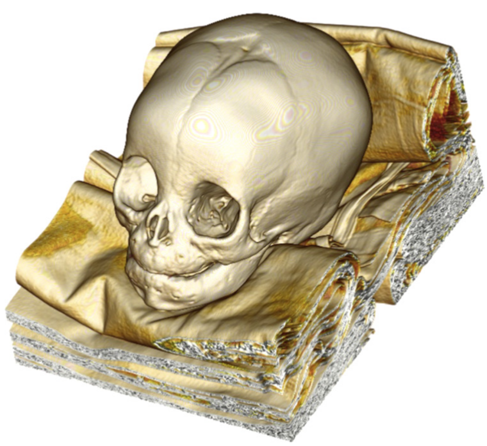

Fig. 1. 3D rendering of the fetus skull.

The model was then imported to Abaqus® software v.6.12 (Dassault Systèmes Simulia Corp., Providence, RI, USA). After creating the finite element mesh of the fetus skull, groups of elements were selected to define the cranial sutures, as represented in Fig. 3. The model of the fetus head contained 66,015 tetrahedral (C3D4) finite elements.

The cranial bones, sutures and fontanelles were assumed as having an homogeneous thickness of 2 mm (Lapeer and Prager, 2001). Anteroposterior and transverse diameters of 15 and 20 mm, respectively, were attributed to the anterior fontanelle, in accordance with the literature (Amiel-Tison et al., 2002) (see Fig. 3).

The standard Abaqus® contact algorithm was used to impose the kinematic contact constrains. Contact constrains were established between the fetus head skin and the pelvic floor muscles, and between the fetus head skin and the pelvic bones.

The movements of the fetus during birth in the vertex position and in an occipito-anterior presentation (in which the frontal bone and head are positioned facing the coccyx) were simulated. An initial head flexion was established in order to present the smallest possible head diameter in the birth canal at all instants. A group of elements in the craniocervical junction was considered as rigid body, controlled by a reference point. This reference point controls the fetus descent and head extension, see Fig. 4. The remaining degrees of freedom were left free, being imposed by the bones and pelvic floor contact constrains.

To verify the influence of the fetus head molding on the pelvic floor muscles during the second stage of labor, two different numerical simulations were conducted: one with a stiff, undeformable fetus head, and the other with a deformable one. The reaction forces, the stretch, stress and strain related to the pelvic floor muscles were evaluated.

The total values of the reaction forces on the pelvic floor muscles were obtained for each of the three components as a sum of all the fixed nodes, and then the respective magnitude was calculated. When used in this document, the term force will have the meaning of the sum of reaction forces. To evaluate the stretch on the pelvic floor muscles, a curve was defined on the inferior part of the pelvic floor mesh, as shown in Fig. 5. By measuring the length of the curve during the simulation and knowing its initial value its was possible to determine the evolution of the stretch values for the curve. The stretch ratio is defined as the ratio between the current tissue length to the original tissue length. The stress and strain were measured along the curve defined in Fig. 5 considering the position of the fetus head causing the maximum stretch value.

Additionally, anatomical indices for the molding of the fetal skull were obtained and compared with previous literature. For this purpose, during the simulation, three fetal diameters represented in Fig. 6 were monitored: the biparietal diameter (BPD), the maxillo-vertical diameter (MaVD), and the suboccipito-bregmatic diameter (SOBD). To evaluate the fetus head molding, Lapeer's molding index (LMI) was calculated based on the equation (Lapeer and Prager, 2001)

$$LMI = \frac{MaVD^2}{BPD \times SOBD}. \quad (1)$$

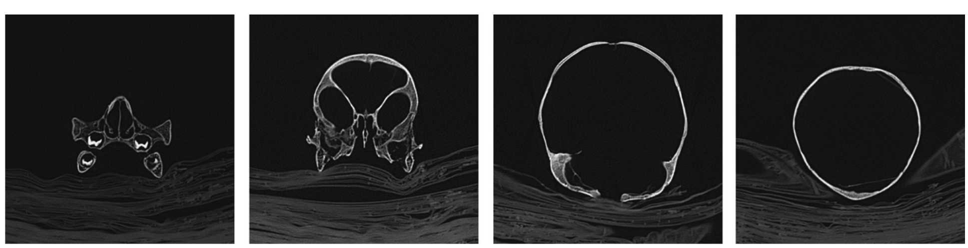

Fig. 2. Computed Tomography images from the OSRSA database. Axial images from the base to the calvaria were used to obtain the 3D model of the fetus skull.

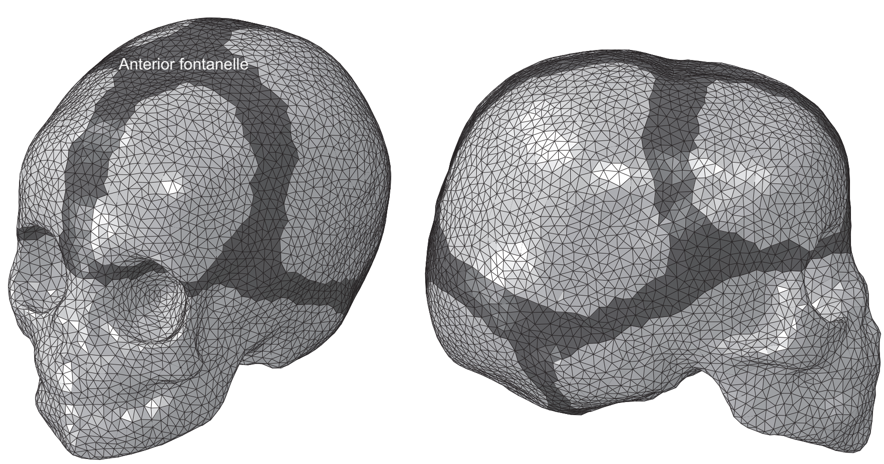

Fig. 3. Finite element mesh of the fetus skull. The sutures and fontanelles were included.