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Biomechanical model of the fetal head for interactive childbirth simulation

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1 Introduction

Obstetricians and midwives practical training is mostly done through an apprenticeship on real parturient. In addition to the risks for the parturient and the fetus, this approach does not allow the student to see a large variety of cases and acquire related dexterity, especially for the least performed interventions such as forceps or vacuum delivery. For these reasons, the use of simulators appears to be a practical and safe approach to acquire task-oriented skills in obstetrics [3] as well as confidence.

There is a large variety of obstetrics simulators from the simple passive manikin to complex actuated device with graphic feedback. These simulator give a qualitative information on the user gesture. On the other side, [2] have proposed a finite element based biomechanical simulation of the fetal descent that gives quantitative information on the effort undergoing by the pelvic organs and related potential tissue injuries during childbirth. But finite element based simulation are computational expensive and could not be run in interactive time needed for training. The goal of this work is to provide a 3d biomechanical model of the fetal head that could be coupled with haptic simulator [5]. Precision and computation time aspects have to be taken into account to provide an interactive simulation focused on the possible damages undergoing by the fetal head.

2 Method

The fetal head is the part of the fetus where the largest deformations (fetal head molding) and potential injuries can occur. To simulate the its deformation

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during childbirth, we propose a triangular shell model combined with a volume constraint that guarantees the incompressibility of the fetal head.

Shell models of the cranial bones have already been used to statically simulate the fetal head molding during the first stage of labor [4]. However, this simulation is static and do not take into account the intra-cranial matter since it model only the fetal skull. The shell mechanical model proposed integrates a membrane behavior using CST elements (Constant Strain Triangle) as well as bending behavior with DKT (Discrete Kirchhoff Triangle) elements [1]. The CST membrane element is a two dimensional triangular element used for plane stress problem. It has six Degrees of Freedom (DOF), to model the plane displacements at each node. The DKT bending element is based on the well-known Kirchhoff thin plate theory where transverse shear deformations are neglected. This element has nine DOF to model the out-of-plane displacements and the rotations around x and y axis.

Our formulation use an element-based co-rotational formulation where the element stiffness matrices are expressed in their respective local frame. Combined with a linear material, this formulation models a small-strain and large rotation behavior. The mesh model was reconstructed from a medical manikin. It has 8928 triangular elements divided in two material zones : one corresponding to cranial bones and one corresponding to fontanelles and sutures (see Fig. 1a). The isotropic linear material properties for these two areas were taken from Lapeer and Prager [4]. The cranial bones area has a Young Modulus of 2.65 GPa , a Poisson Coefficient of 0.22, a density of 1800 kg.m^{-3} and a thickness of 0.8 mm . The fontanelles and sutures area has a Young Modulus of 7.23 MPa , a Poisson Coefficient of 0.49, a density of 1000 kg.m^{-3} and a thickness of 0.6 mm .

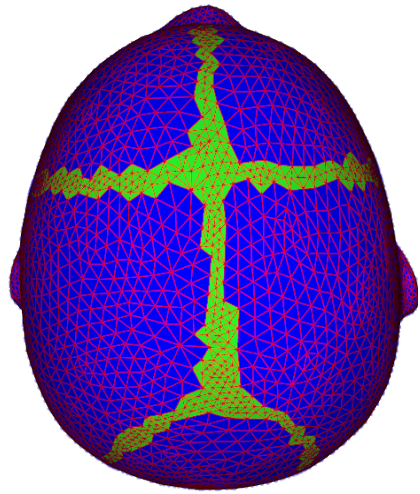
To approximate the effect of the biological matter inside the fetal head, an incompressibility constraint is enforced on the volume defined by the shell element mesh.

Both the shell model and the volume constraint codes are implemented in GPGPU using a parallelization on elements. We use an implicit backward euler scheme for time integration with a matrix-free conjugate gradient as linear solver.

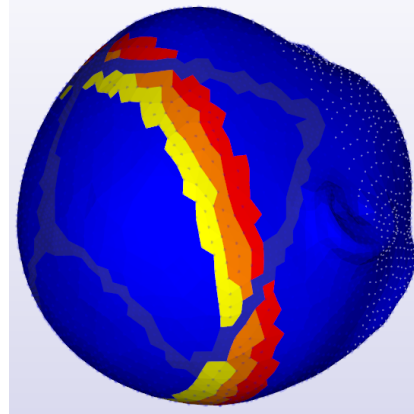
Three fetal head diameters were monitored during the simulation : the maxillo-vertical diameter (MaVD), the orbito-vertical diameter (OrVD) and the suboccipito-bregmatic diameter (SOBD) (see Fig. 1c).

3 Results

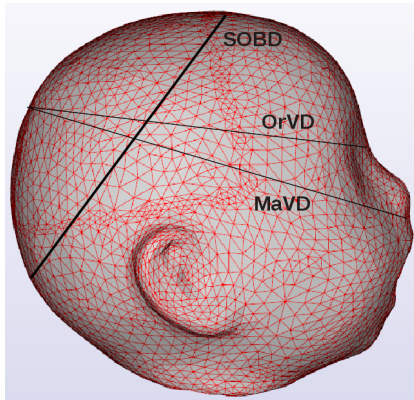
We present in Fig. 1 a simulation of the fetal head in the first stage of labor when it undergoes intra-uterine and cervix pressure (see Fig. 1b). The geometric model chosen results from the scan of the head of a generic manikin used in the haptic simulator of Silveira et al. [5]. The pressure load were computed using the Bell idealized model with a maximal pressure of 45 kPa . Our results were coherent with the in-vivo experiments from Sorbe and Dahlgren [6] and static fetal skull simulation from Lapeer and Prager [4] (see Table 1). We notice an



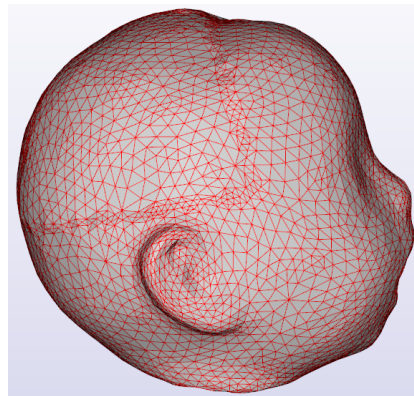
(a) The two material areas (cranial bones and fontanelles/sutures)



(b) Pressures load



(c) Tracked diameters



(d) Deformed fetal head

Figure 1: Fetal head undergoing intra-uterine and cervix pressure. Model and simulation results.

overlapping of the two parietal bones (see Fig. 1d).

This simulation was run with a time step 0.01 seconds and a frame rate of 21 frames per seconds on an NVIDIA Quadro 600 with 96 cores.

4 Conclusion

The biomechanical model presented in this paper offers precise dynamic simulation of the fetal head molding in a reasonable computational time making it suitable for use with haptic training simulators such as the one presented in

	Sorbe 1983		Lapeer 2001		Ours	
Measures	\varnothing	disp	\varnothing	disp	\varnothing	disp
MaVD	140.5	+1.90	129.3	+1.43	124.6	+1.29
OrVD	126.9	+2.20	119.3	+1.24	110.9	+1.13
SOBD	117.1	-1.70	88.7	-2.52	107.4	-3.57

Table 1: Fetal head diameter (\varnothing) and its variation (disp) in mm.

Silveira et al. [5]. The conjunction of an haptic device providing qualitative information of the gesture and biomechanical simulation providing quantitative information will improve the training experience of the student. Nevertheless, the biomechanical model can be improved by considering anisotropic material for the cranial bones. In future work, we plan to use our model with more complex scenarios involving the fetal head such as forceps and vacuum delivery. It could also be noticed that at this stage, a patient specific approach is not considered because the simulation is focused on training.

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