DEVELOPMENT OF A MADYMO MODEL TO INVESTIGATE FETAL BRACHIAL PLEXUS INJURY DURING COMPLICATED VAGINAL DELIVERY

Ning Zhang (1), Bernard Gonik (2) and Michele J. Grimm (1)

(1)Department of Biomedical Engineering
Wayne State University
Detroit, MI 48201

(2)Department of Obstetrics/Gynecology,
Sinai-Grace Hosipital, Wayne State University
Detroit, MI 48235

INTRODUCTION

Shoulder dystocia occurs during delivery when the fetal head descends, but the fetal shoulders are too broad to pass through the maternal pelvis. The brachial plexus (BP) is a large network of nerves that originates in the neck and extends through the shoulder into the arm. Excessive deformation of the fetal neck and shoulder during the delivery is thought to result in the excessive stretch of nerve fibers and induce injury to the brachial plexus nerve**s**. Injuries primarily occur to the anterior presenting shoulder during delivery, although they have also been noted in the posterior shoulder. Despite longstanding empiric reasoning that clinician-applied traction is the primary mechanism for obstetrical brachial plexus palsy, recent investigations have suggested that maternal propulsive efforts may also play a role [1]. Therefore, forces associated with injury may be either endogenous (maternal and uterine) or exogenous (clinician-applied) in nature. Because direct *in vivo* measurement of these forces and fetal shoulder deformation is technically difficult, mathematical modeling has been used to simulate these events [1,2]. The purpose of the present study is to develop a multi-body, dynamic, mathematical model that simulate**s** the event of fetal shoulder delivery and to quantify the effects of both endogenous force and exogenous force on the stretch of the brachial plexus.

METHOD

MADYMO (MAthematical DYnamic MOdel, Version 5.4, TNO Automotive, Delft, Netherlands) is a commercially available computer software package for biomechanical, multi-body modeling. It has been widely used in the automotive industry to simulate motor vehicle crash situations and to assess injuries sustained by the victims. The software program has a full age range of crash dummies and a large adult and child human model database.

In the present study, a fetal model was developed based on a nine-month old child crash dummy model from the MADYMO dummy database, which was downscaled to 90th percentile geometrical parameters for a newborn infant (Figure 1). The defined weight of the whole fetal model was 3.85 kg, head circumference was 36.2 cm, thoracic circumference was 33.1 cm, and biacromial diameter was 14.2 cm. The model consisted of 32 ellipsoid bodies. The original dummy model was further modified in the neck and shoulder regions to better represent the biomechanical characteristics of the fetus. Seven ellipsoids were used to represent the cervical vertebrae, with translational-universal joints were defined between two adjacent vertebrae. Axial tension and lateral bending stiffness at each vertebral level were defined based on experimental data from the newborn goat neck by Pintar *et al*.[3]. The shoulder complex was downscaled with modification from the MADYMO 50th percentile adult male model. The clavicle and scapula were modeled as two ellipsoid groups. Spherical joints were defined for the sternoclavicular and acromioclavicular joints, and joint stiffnesses were assumed to be 2.5% of adult values in order to represent newborn shoulder characteristics (based on the ratio of body weight and material properties between adult and 95th percentile newborn infant). The left (anterior presenting) brachial plexus was simulated using a spring element starting from the space between C5 and C6 and ending at the midpoint of the upper arm ellipsoid (7.5 cm total length). The nonlinear mechanical properties of the nerve element were based on experimental test data performed on rabbit tibial nerves [4]. The linear axial strain of the nerve element was calculated to represent the quantity of BP nerve stretch.

The maternal pelvis was built according to the 50th percentile dimensions of a female bony pelvic model. This multi-body model consisted of 14 ellipsoids. The pelvis was assumed to be rigid with no motion or rotation between ellipsoids. The anterior-posterior diameter of the pelvic outlet, measured from the lower border of the symphysis pubis to the coccyx, was 12.5 cm. Pelvic orientation was defined by the angle between the symphysis pubis and the horizontal plane, or maternal long axis. For lithotomy positioning (normal delivery position), this angle was estimated to be 45 degrees.

Two types of loading forces were studied: endogenous (ENDO, maternal pushing with uterine contractions) and exogenous (EXO, physician applied to the fetal head). Endogenous force was applied at the center of gravity along the long-axis of the fetus (approximately 25 degrees). Exogenous force was applied to the fetal head in a 45 degree direction. Two types of exogenous force were considered: applying the force while allowing lateral bending of fetal neck, and applying the force by trying to prevent the fetal neck from bending. To simulate the effort of the clinician to align their fingers along the fetus' neck and reinforce the neck from lateral bending while applying exogenous force, the degree of freedom for neck lateral bending was locked at each cervical vertebral level. The applied forces were transferred to acceleration based on the mass of the total fetus (endogenous) or fetal head (exogenous) as the input loading condition for MADYMO. The acceleration pulse was assumed to be an idealized, triangular pulse with a duration of 10 seconds. Initial applied loads were 50 N and were increased in a step-wise manner, with the end point values based on fetal shoulder delivery. This final force was then defined as the delivery force. The contact interfaces between the fetus and pelvis were defined using the ellipsoid-to-ellipsoid contact option in the MADYMO program. To simulate the effects of maternal soft tissue resistive forces, the friction coefficient at the interfaces was assumed to be 0.6.

Initially, the fetus was positioned in such a way that the fetal head was already delivered and the fetal shoulders were situated in an anterior-posterior position within the maternal pelvis. As either endogenous or exogenous force was applied, the anterior shoulder lodged itself behind the symphysis pubis. This situation simulates the occurrence of shoulder dystocia. With increasing amounts of force, the anterior shoulder, followed by the posterior shoulder and torso, negotiated passage through the pelvis to complete delivery.

RESULTS

The loading force required to deliver the anterior fetal shoulder differed based on whether it was endogenous or exogenous in origin. The minimal endogenous loading force needed to accomplish delivery was 125 N compared to 75 N for exogenously derived forces.

Brachial plexus stretching can be seen with both endogenously and exogenously applied forces. The least amount of brachial plexus stretch in association with successful delivery was seen with axially applied, exogenous loads to the fetal head (14.0%). When endogenously applied loads alone were relied on to accomplish delivery, a greater amount of brachial plexus stretching was noted (15.7%).

Within the model, the fetal neck can be either fixed in an axial position or allowed to laterally flex with exogenously applied load forces. Interestingly, 6% more exogenously applied force was needed to achieve delivery when lateral bending of the fetal neck was allowed. This was also associated with a 30% increase in brachial plexus strain (18.2% vs. 14.0%).

DISCUSSION

A biomechanical computer model was developed to simulate the childbirth process during a shoulder dystocia event. Substantial brachial plexus stretch was predicted to occur for both endogenously and exogenously applied forces. Exogenous bending of the neck caused the most severe nerve stretch, while exogenous axial loading of the neck caused the least amount of BP strain.

Because there are no currently established thresholds for nerve avulsion or disruption for newborn infants, these data on brachial plexus strain cannot currently be directly related to BP injury occurrence or severity in the clinical arena.

The shoulder dystocia process is a dynamic problem involving both material and geometrical non-linearities and also complex contact boundary conditions. Further parametric studies should be conducted to increase the confidence and stability of this model. The newly developed stochastic simulation method may also be useful to generate scatter data for unknown parameters by a statistical approach. Finite element analysis (FEA) modeling may also be helpful in further defining geometrical details of the fetus and maternal pelvis.

Lack of data on the mechanical properties of the fetal neck, shoulder and brachial plexus nerve from existing literature makes it difficult to build a biofidelic fetal model to simulate the shoulder dystocia event. In addition, the birth event itself and the rarity with which shoulder dystocia occurs precludes *in vivo* validation of these predictions. The observed motion response of the fetus during the simulated delivery process matches that seen clinically, allowing for some degree of confidence with the model's construction and execution. Nevertheless, this model represents an objective means by which to evaluate the reaction of the fetus to variations in delivery procedures as well as physician and maternal efforts. This knowledge may in turn provide guidance for obstetrical education.

REFERENCES

1. Allen R, Sorab J, Gonik B., 1991, "Risk factors for shoulder dystocia: An engineering study of clinician-applied forces." Obstet Gynecol, Vol. 77, pp. 352-355.
2. Gonik, B, Walker A, Grimm M., 2000, "Mathematic modeling of forces associated with shoulder dystocia: A comparison of endogenous and exogenous sources." Am J Obstet Gynecol., Vol. 182, pp. 689-691.
3. Pintar FA, Mayer RG, Narayan Y., 2000, "Child neck strength characteristics using an animal model." Stapp Car Crash Journal, Vol. 44, pp. 77-83.
4. Rydevik BJ, Kwan MK, Myers, RR, Brown RA, Triggs KJ, Woo SLY, Garfin SR. 1990, "An in vitro mechanical and histological study of acute stretching on rabbit tibial nerve." J Orthopaedic Research, Vol. 8, pp. 694-701.
5. Schueller, G.I., Bucher, C.G., and Pradlwarter, H.J., "Computational Methods in Stochastic Structural dynamics." Structural Dynamics, ed. by Kratzig et. al., 1990, pp599-636.

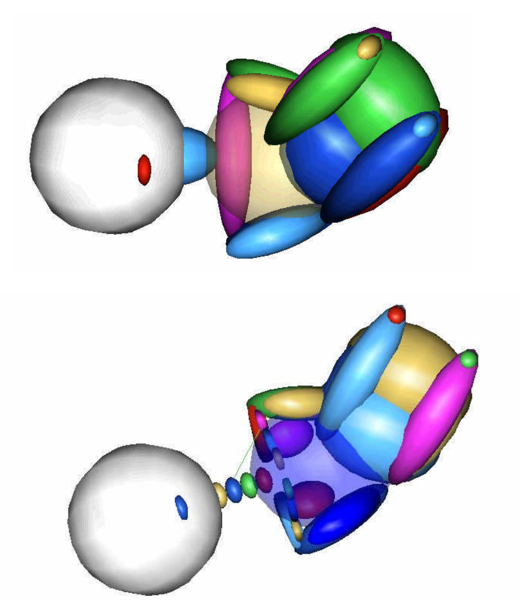

Figure 1. Original MADYMO 9 month-old crash dummy and modified 90th percentile fetal model (not to scale).