INVESTIGATING THE MECHANISM OF NEOBATAL BRACHIAL PLEXUS PALSY USING BIOMECHANICAL TESTING

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INTRODUCTION

Despite considerable research and improvements in obstetrical care, permanent Neonatal Brachial Plexus Palsy (NBPP) continues to occur in 1.1-2.2 out of 10,000 births and remains a regular challenge for the affected families and treating physicians [1]. The brachial plexus (BP) is a network of nerves that originate in the neck and run through the shoulder to the arm [2]. Stretching of the BP or avulsion of the roots can occur during birth when the infant's shoulder impacts with the bony pelvis of the mother due to maternal (endogenous) forces as well as clinician-applied (exogenous) forces [2,3]. The effects of these forces on the BP are directly related to: magnitude, loading rate, surrounding tissue properties, and how the applied force is transmitted to the BP. Since in vivo measurements of the endogenous and exogenous forces, fetal shoulder deformation, and the response of the BP are difficult to assess during delivery, computational and physical models are used to simulate these events. However, a complete lack of biomechanical properties and data on the neonate BP limits the correct assessment of the risk of injury using these models. Thus, the goal of this study is to determine the biomechanical properties of the BP using a neonatal porcine model (piglets).

MATERIALS AND METHODS

Twenty fresh neonatal (3-5 days old) piglet BP cord segments were harvested and immediately preserved in 1% BSA (bovine serum albumin) until testing. A digital microscope was used to obtain images of harvested BP segments before stretch (5X; Digital Microscope, Elmwood Park, NJ). A 2mm scale (Leitz,Ernst-Leitz-Wetzlar GmbH, Germany) at the same magnification measured the segment diameter. The BP segments were divided into two groups based on tensile loading rate. Group A (n=10) specimens were subjected to a stretch rate of 0.01 mm/s (quasistatic) and those in Group B (n=10) were subjected to a stretch rate of 10 mm/s (dynamic). Maximum stress, strain, and modulus of elasticity were calculated from the obtained load-displacement data during tensile testing. An ADMET material testing machine (eXpert 7600, ADMET Inc., Norwood, MA) was used to stretch the nerve (Fig. 1). Each BP segment was anchored by specially designed and fabricated clamps (Fig. 1). The design of the clamp allows for clamping of each segment firmly between the padded plexiglass and flat surface of the cylinder. The padded side facing the segment helped minimize the stress concentration at the clamping site [4,5,6]. The two clamps were initially set at a distance of 10-20 mm (depending on the initial length of the BP segment) and the segments were clamped with no initial tension prior to stretch. Stretch rates were controlled by built-in GuageSafe software (ADMET Inc., Norwood, MA). The actuator was triggered, which stretched the BP segments at their assigned rates (0.01 mm/s or 10 mm/s) until complete failure. During this test, the load and displacement data was acquired at a sampling rate of 25 Hz for quasistatic and 1000 Hz for dynamic stretch rates. After completion of the experiment, the failure site was recorded and the clamps were checked for the presence of BP tissue. No tissue in the clamps implied that the tissue had completely slipped, and the results of those experiments were disregarded. Load data and the cross sectional area was used to calculate nominal stress. Displacement data was used to calculate the tensile strain that results from the applied tension. The load-displacement and stress-strain curves were plotted and the maximum and failure load, maximum and failure stress, strain at the point of maximum
failure and stress, and modulus of elasticity (the slope of the stress-strain curve after toe region and below the proportional limit, E) were determined.

![Image](image1.png)

**Figure 1:** Biomechanical Testing Machine and Clamps

![Image](image2.png)

**Figure 3:** Preliminary Testing of BP Cord Segment at 0.01 mm/sec

<table>
<thead>
<tr>
<th>Rate</th>
<th>Failure Stress (MPa)</th>
<th>E (MPa)</th>
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<tbody>
<tr>
<td>Quasistatic (0.01 mm/sec)</td>
<td>11.7</td>
<td>48.5</td>
</tr>
<tr>
<td>Dynamic (10 mm/sec)</td>
<td>18.8</td>
<td>108.2</td>
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</tbody>
</table>

**Table 1:** Mechanical Data of BP Segments

RESULTS

Stress at the proportional limit and apparent elastic modulus were used as indicators of strength, elasticity, and stiffness. Nerve rupture typically occurred immediately after reaching the proportional limit as shown in Fig. 3. Table 1 contains experimental data for brachial plexus segments tested at both quasistatic and dynamic rates. The average values for the modulus of elasticity are greater for the dynamic rate data than the quasistatic rate data.

CONCLUSION

At a quasistatic strain rate, a lower modulus of elasticity and failure stress was observed and a higher stress and modulus of elasticity was observed at the dynamic rate. This is because the nerve tissue acts in a viscoelastic manner and becomes stiffer at a faster strain rate. Overall, the experimental data provides an accurate approximation to the biomechanical properties of the BP nerve tissue. The dynamics and quasistatic rates are good representations of the various forces acting on the infant during birth. The quasistatic rate could represent the maternal forces of the mother pushing during labor. The dynamic rate could represent sudden impact of the infant’s shoulder with the mother’s pelvis or a sudden clinician-applied force. The data obtained from studying the BP nerve at these two rates helps to better understand the biomechanical properties of the BP and assess the associated injury mechanisms associated with NBPP. This information can be used to develop a biofidelic computational model that accurately illustrates the predisposing risk factors for BP injury.

REFERENCES