FINITE ELEMENT MODELING OF INTRANEURAL GANGLION CYSTS OF THE COMMON PERONEAL NERVE

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INTRODUCTION

Intraneural ganglion cysts (IGC) are mucinous cysts which form within the epineurium of peripheral nerves, most commonly the common peroneal nerve (CPN), and are known to produce neurologic deficit (e.g. a foot drop with CPN involvement). There has been much debate amongst clinicians about their origin and treatment. Previous research [1] supports the theory that synovial fluid from the superior tibiofibular joint enters the articular branch (AB) of the CPN subsequent to joint capsule disruption through injury or degeneration. The increased pressure caused by continuous influx of fluid compresses nerve fascicles, expands the nerve radially (Fig. 1 - stage I) and causes further propagation proximally into the CPN (Fig. 1 - stages II, III and IV). To effectively treat IGC and eliminate the common situation of postoperative recurrence, surgeons would benefit from an understanding of the underlying mechanics that influence cyst growth. It has been recently suggested [2] that Finite Element Analysis (FEA) be used to predict the growth behavior of cysts.

The objective of this study is to use FEA to study proximal cyst propagation at the AB/Deep Peroneal Nerve (DPN) junction just before it reaches the CPN.

METHODS

A three-dimensional finite element model of the junction between the AB and DPN branches of the CPN was constructed, as shown by the cut-away mesh shown in Fig. 2. The AB meets the DPN at an acute angle of 16.5°, as measured with cadaveric studies. The negative X-axis represents the proximal direction and the positive X-axis represents the distal direction. The model contained two regions: red elements representing the fascicular region, surrounded by blue elements representing the epineurium. Due to the high degree of morphological similarity between nerve and human ligament, each region was modeled as a Mooney-Rivlin hyperelastic isotropic material with transverse properties of the human medial collateral ligament [3]. Dimensions were taken from

Figure 1: Stages of Intraneural Ganglion Cyst Propagation

Figure 2: Finite Element Model
cadaveric studies. The cyst is represented by the hollow crescent-shaped region along the length of the articular branch, as shown in Fig. 3. The model was meshed with tetrahedral elements using ANSYS. The boundary conditions included translational restraints at the two ends A and B (Fig. 3) and the application of a pressure load of 1 MPa, corresponding to that estimated to be exerted by the cyst fluid onto the interior faces of the cyst in the AB.

RESULTS AND DISCUSSION

The FEA modeling with the material properties and boundary conditions as described above produced a contour plot of the von Mises stress on the cyst left face where the magnitude varied between 19.29 to 33.75 MPa (Fig. 4). The stress distribution on the right face was similar since the model is symmetric about the XY plane (Fig. 2). Similarly, the von Mises stress distribution on the cyst tip varied between 3.78 to 22.62 MPa. The distortion energy theory failure criteria were applied and the volume of all elements in which the von Mises stress exceeded the ultimate tensile stress of the tissue (assumed value 1.44 MPa) was determined. The material encompassed by the volume of failed elements was removed and the geometry of the cyst was remodelled as shown in Figure 5, where cyst dimensions have increased by $\Delta l$ and $\Delta \theta$ in the length and arc angle, respectively. After the growth of the cyst, the pressure was again applied and the cyst growth cycle was repeated. Such remodeling steps indicate that the cyst predominantly wants to propagate along the sides, circumferentially, as opposed to along the AB. However, when it is assumed that side face material failure strength is much higher than that at the cyst tip, remodeling steps indicate that the cyst propagates along the AB towards the junction which matches the clinically observed growth pattern.

REFERENCES

