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Precision Engineering of Neuroprotective Prosthesis for application in Fibular and Tibial Nerves

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Abstract

The recovery of lesions in peripheral nerves is usually painful and time consuming. In addition, nervous recovery can be compromised by patient movements in the surrounding region. Recovery therapies may be impaired by motion, or even, a worsening of overall health may occur in these cases. In order to stabilize movement of peripheral nerves in the affected region, a Neuroprotective Prosthesis (NPP) was designed to promote nerve reconstruction by Tissue Engineering. A bioresorbable scaffold in tubular shape with 80% of porosity is implanted to wrap the affected nerve and perform its anchorage and protection. After nerve recovery, the bioresorbable material should be totally integrated with no need of a second surgery for prosthesis removal. Design methodology was based on mechanical behaviour requirements. First, histological studies were conducted in cadavers. Fibular and Tibial Nerves were measured in different sections both relaxed and stretched. Three-dimensional computational models were created for a static numerical analysis simulating flexion and stretch with material mechanical properties. The results were considered satisfactory for flexion efforts, the most critical during prosthesis implant surgery. Thus, it was possible to simulate the mechanical behaviour of the Neuroprotective Prosthesis and to suggest a special attention in its positioning during the surgery to promote stretch relief in peripheral nerves.

Neuroprotective Prosthesis, Bioresorbable Scaffold, Tissue Engineering, Numerical Simulation

1. Peripheral Nerve Lesion

Peripheral nerve lesions represent about 80% of the cases of nerve injuries, the most common being the fibular lesion, responsible for sensory and motor innervation for parts of the leg and foot, due to its superficial location around the fibular neck [1]. Such lesions significantly affect patients' quality of life due to their restricted mobility. Although the central peripheral nervous system has a greater axonal regeneration capacity than the central nervous system, spontaneous repair of the peripheral nerve is almost always incomplete, with poor recovery of function, especially if the wound gap is very long [2].

2. Materials and Methods

Based on this application, the construction of new devices to promote lesions repair in peripheral nerves has become a promising trend in Tissue Engineering [3-7]. Bioresorbable scaffolds can be implanted to wrap the affected nerves, performing anchorage and protection, Figure 1.

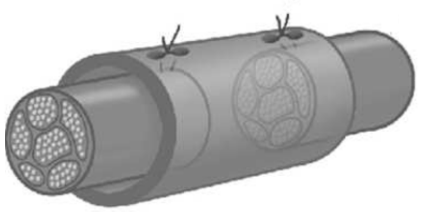

Figure 1. Two injured nerves wrapped by prosthesis and the gap between them.

After total recovery, the bioresorbable material should be totally integrated with no need of a second surgery for prosthesis removal.

This work presents the Design Requirements for a Neuroprotective Prosthesis (NPP) based on Precision Engineering, Figure 2.

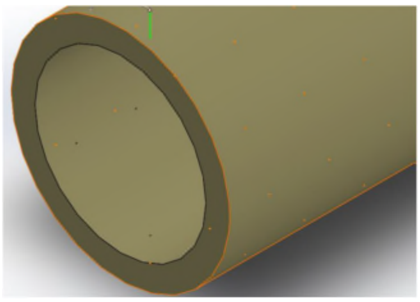

Figure 2. Neuroprotective Prosthesis (NPP) Tridimensional model with porous in detail.

Those requirements were collected from histological studies and its mechanical properties were simulated in numerical static analysis.

3. Histological Studies and pictures analysed

Previous histological studies were conducted in nine fresh human cadavers. Tibial and Fibular nerves were manually stretched between 20% and 25% and fascicular images were collected [1]. In order to simulate the NPP mechanical behaviour histological pictures were analysed with Image J software [3], Figure 3.

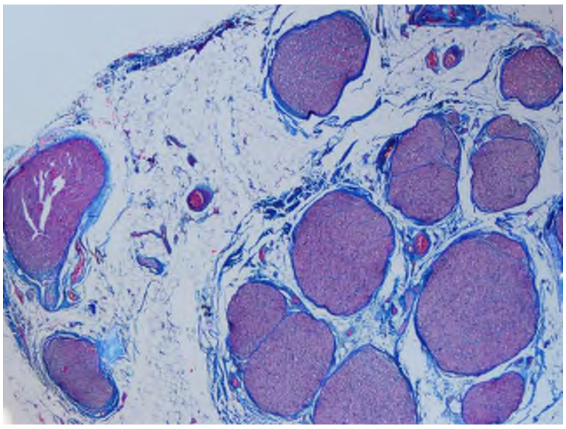

Figure 3. Fascicular images of cadavers peripheral nerves analysed with Image J software [3].

In parallel with Schraut group [1], a new image processing analysis was conducted, now focused on mechanical deformation and not only by dimensions before and after stretching and bending.

4. Results

Fascicles from stretched tibial nerves were found significantly oval if compared with unstretched and peroneal nerves. Tibial nerves had a greater proportion that was extrafascicular tissue (50-55%) compared with peroneal nerves (38%–42%) [8-11].

The prosthesis should be 30 mm long in order to provide better results in lesions between 3 and 5 mm, so that it may be possible to adequately protect the nerve, having an area of 5.5 mm by 0.6 mm and 80% of porosity having a diameter of 25 µm for each pore, these values were considered being the ideal for this type of prosthesis.

Based on these findings, a computational simulation of Finite Element Method (FEM) was performed with software Simulation (SolidWorks v. 2016, Dassault Systèmes, France), Figure 4.

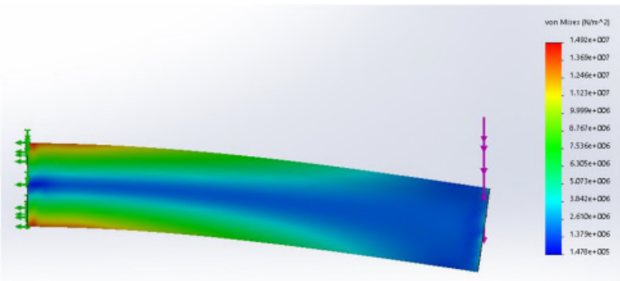

Figure 4. Stress distribution during von Mises Flexural analysis.

The results of Figure 4 were considered satisfactory for flexion efforts, the most critical during prosthesis implant surgery.

5. Discussion and conclusions

The prospective study initiated with Schraut [1] served as basis to ImageJ analysis and mechanical behaviour mapping, prescribing limits and material's elasticity.

With the parameters obtained from Histological Studies in cadavers it was possible to design a tridimensional model of NPP. Thus, the relevance of Precision Engineering applications in Biomedical Sciences since conception and design. Also, according to the mechanical behaviour results, the best reabsorbable material would have an intermediate Young modulus and it should be a blend of PLGA and PLLA or PCL [12-14].

Computational numerical analysis was capable of plot important areas of more condensed von Mises Stress around NPP tips, close to anchor sites.

A future dynamic analysis should clarify how size and shape of fascicule would interact with NPP to promote nerve protection and regeneration before physical prototypes.

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