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Upper Extremity Sling for Dynamic Rehabilitation of Traumatic Brachial Plexus Injury

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Abstract

The brachial plexus is a network of nerves that conducts signals to the shoulder, arm, and hand. When these nerves become damaged loss of motor control and sensory perception can occur.[1] Karen Blaschke, an occupational therapist with UW Hospitals and Clinics, works with patients suffering from brachial plexus injury and has requested a sling that will allow these patients to return to an active running lifestyle. Our aim was to create a sling that would properly support the should and arm, and adapt to patients within different stages of rehabilitation. After considering three different designs, a one-piece vest design was chosen as the most viable option. A prototype of the new design was created using neoprene and a nylon-polyester blend, and will be tested for its efficacy using quantitative and qualitative methods.

Introduction

The brachial plexus is a network of nerves that provide motor control and sensory perception to the shoulder, arm and hand.[1] It originates from the lower four cervical nerves (C5 – C8) and the first thoracic nerve (T1). The five major nerves that make up the brachial plexus include the auxiliary, median, musculocutaneous, radial, and ulnar nerves.[2] The anatomy of the brachial plexus is shown in Figure 1.

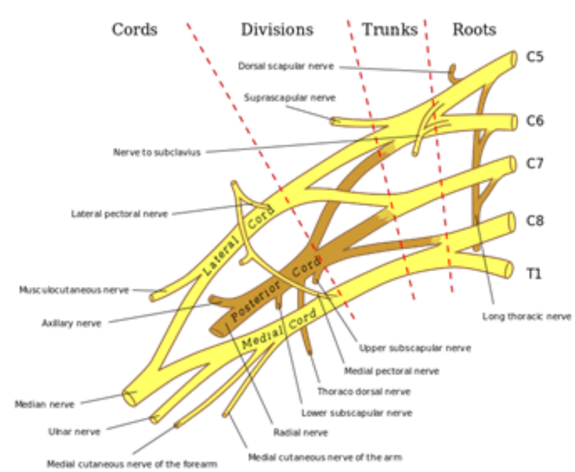

Figure 1: The anatomy of the brachial plexus. http://en.wikipedia.org/wiki/Brachial_plexus

An injury to the brachial plexus network most often results from substantial trauma either as a consequence of physical recreation or motor vehicle accidents. It is also common for newborns to sustain brachial plexus injuries during difficult child birthing sessions. Altogether, these types of impacts involve a force pushing the shoulder down, while the head is stretched in the opposite direction, causing a displacement of the spine relative to the shoulder and stretching or tearing of the brachial plexus nerves. Infections, inflammation, and tumors can also be the cause of brachial plexus related pain and disability.[4] The severities of brachial plexus injuries range widely and are grouped into three main classes that identify the degree of nerve damage: stretched, ruptured, or avulsed. In a case of an avulsion, the nerve root is torn completely from the spinal group.[3] Rupture and avulsion almost always require surgery whereas a stretch injury may be successfully treated with therapy.[1]

Although various slings are available to treat brachial plexus injuries, none are capable of providing dynamic rehabilitation to facilitate the patient's return to an active lifestyle. The sling that was designed accomplishes this by being constructed from an anchoring vest, which includes a shoulder cuff, and an arm support sleeve. Furthermore, the design utilized tension cables that are guided and placed in appropriate positions to reduce the weight of the arm and provide added stability to the shoulder and elbow regions. The current prototype is being worn and displayed in the image to the left labeled Figure 2.

Figure 2: Sagittal view of the sling includes shoulder strap, arm sleeve, bands, attachment points, belt loop holes, and forward facing adjustable arm bands.

Methods

Various methods and approaches were used to examine the validity and efficacy of our proposed dynamic sling design. A preliminary force analysis was first completed to examine the loads placed on the shoulder created by the arm, and the information provided by this analysis was then used in SolidWorks modeling. In addition to these analyses, cyclic loading tests on the sling material, motion capture studies, and user surveys were conducted to further examine the device's effectiveness. All methods used are discussed individually in the proceeding sections.

- *Preliminary Dynamic Analysis*

A preliminary dynamic analysis involved developing equations for the force due to angular acceleration of the shoulder. This calculation studied a pendulum, representative of the arm, rotating about a fixed point, which is representative of the shoulder. The outputs of the equation are variable due to height, weight, and arm movement. The overall final equation derived from the theoretical study is included in the Appendix.

- *SolidWorks Modeling*

SolidWorks modeling was used to investigate the loads applied to the device and to determine if failure would result under normal conditions of use. The preliminary dynamic analysis provided us with an expected maximum tension force of 50 N. It was also decided to incorporate a factor of safety of 2. With the expected load and factor of safety determined, this load was applied to areas of the sling that were most likely to fail, which included connection points on the shoulder and arm, the outer auxiliary region, and the inner auxiliary region. Six tests were conducted, including two tests on each region of failure. Both 50 N and 100 N of tensile force were applied to each region. After completion of each test, the von Mises stresses, displacement, deformation, and factor of safety analysis were collected.

- *Cyclic Load Testing*

Cyclic loading analysis of the neoprene constituent from the prototype design gives insight into the time dependent rate at which the device fatigues. Linear cyclic loading of a segment of neoprene was implemented in order to recapitulate a running scenario, since a swinging load is difficult to test. Analysis under 50 N and 100 N linear cyclic loads was done, with intervals between loads similar to the natural gait of a running motion. Stability of our device was assessed, as well as failure stress. The projected life expectancy of the prototype is available from extrapolation from the cyclic loading data.

- *Motion Capture/Kinect Testing*

Motion testing was necessary to determine if the sling facilitated proper running mechanics. Since high quality video capture was inaccessible, the team sought after a cheaper alternative, the Microsoft Kinect. The Kinect system uses infrared lasers that act as depth sensors to capture a full three-dimension image and it is very successful at capturing joint locations to outline an entire human frame. The program used to collect the data, known as SkeletalViewer, is free software that can be downloaded from Microsoft's website. The program was modified to allow the joint location data to be outputted into a text file for easy computation. To interpret and analyze the data, a MATLAB program was used. The basis code was obtained from Dr. Thelen's Neuromuscular Biomechanics Lab. The team modified the code to be able to calculate two angles: one from the auxiliary region of the right arm, and one from the top of the right shoulder. MATLAB would then plot these angles over time for easy recognition of the arm swing's maximum and minimum angles, as well as the changes in the shoulder angle indicating support at this region.

- *User Survey*

A user survey was implemented to determine the comfort and ease of use of the device. This survey was composed of questions designed to determine how the sling performed for individuals and how ergonomic the device was. Data regarding past and current shoulder injuries was also collected to evaluate if the device had potential to be used for rehabilitation of other shoulder injuries. Ten individuals wore the sling for a one-mile run. After completing the exercise, each user filled out the survey to the best of their ability.

Results

- *Preliminary Dynamic Analysis*

Using the derived equations from the dynamic analysis, it was found that a man of 6' 2" and 200 lbs would induce a maximum force of 46.55 N.

- *SolidWorks Modeling*

Based on the generated results from these tests, it was found that our design would withstand the expected tensile forces in all three predicted regions of failure. Although the inner auxiliary region was determined to be the weakest under these loads, it would take approximately 700 N of tensile force to cause failure. Stress concentrations were also found to never approach values that would exceed the failure of our design. Safety factors for the six conducted tests are tabulated below in Table 1. From these values, our design ultimately lead to an average factor of safety of 32, making our design considerably more durable than initially anticipated.

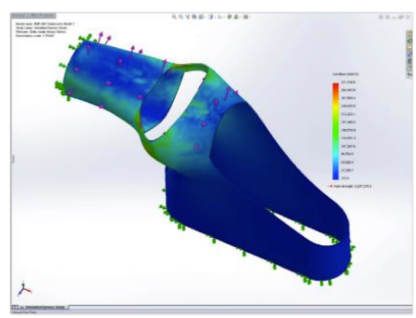

Figure 3: Von Mises stress for the shoulder strap.

Failure area	Factor of Safety for 50 N load	Factor of Safety for 100 N load
Shoulder strap	28	14
Outer Auxiliary	51	25
Inner Auxiliary	15	7

Table 1: Factor of safety outputs by SolidWorks for both testing loads.

- *Cyclic Load Testing*
  To be written after testing is complete.
- *Motion Capture/Kinect Testing*
  To be written after testing is complete.
- *User Survey*
  To be written after testing is complete.

Discussion

To be written after all testing is complete.

Acknowledgements

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References

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3. Hassan, S and Kay, S. 2003. *Brachial Plexus Injury*. Surgery (Oxford), 21 (10):262264.
4. Feinberg J.H. and Radecki, J. *Parsonage Turner Syndrome.* HSS J. 2010 September; 6(2): 199-205.

Appendix

- *Preliminary Dynamic Analysis*

Final calculation for the tension produced by the arm:

$$T_{arm} = \left(m_{arm} g\right)\left(\sqrt{1-\left(\frac{L_e}{L_{u-arm}}\right)^2}\right) + \frac{m_{arm}}{L_{u-arm}}\left(\frac{\left(v_{x-arm}\right)^2}{1-\left(\frac{L_e}{L_{u-arm}}\right)^2}\right)$$

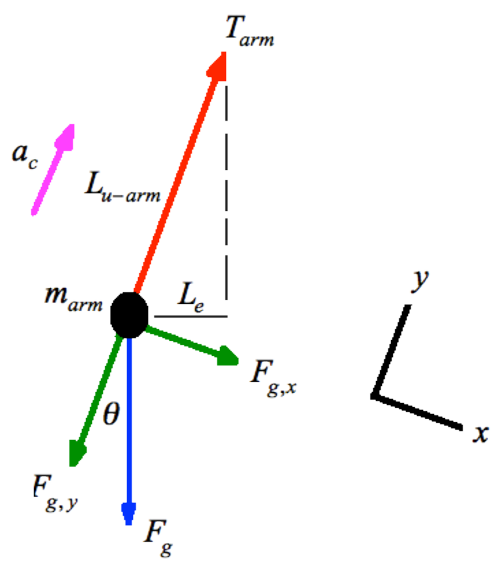

Figure 4: The free body diagram depicting the mass of the pendulum and corresponding forces at any given angle from the vertical to the mass.