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**TITLE:** Myoelectrically Controlled Power-Assist Upper Extremity Exoskeleton

**PRINCIPAL INVESTIGATOR:** Kenton Kaufman, PhD, PE

**CONTRACTING ORGANIZATION:** Mayo Clinic

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<b>13. SUPPLEMENTARY NOTES</b>					
<b>14. ABSTRACT</b> Upper extremity peripheral nerve injuries accounted for 6% of all recorded battlefield injuries during Operation Iraqi Freedom. Upper extremity peripheral nerve injuries are the silent, unrecognized injuries that result in loss of function and sensation in specific patterns depending on the nerves that are injured. In the most severe form, a traumatic brachial plexus avulsion injury, all the nerves to the upper extremity are severed, resulting in an upper extremity lacking motor function and sensation from shoulder to hand. This injury is akin to a functional amputation; the extremity is present, but completely nonfunctional. Restoration of elbow flexion is the primary goal following brachial plexus injury since it is a critical motion for daily living. Multiple surgical options exist to achieve this goal. There is a delay of 6 – 12 months after surgery before muscle reinnervation occurs and muscle strength takes 2 years to mature. During this period a powered exoskeleton would be beneficial for assistance with functional activities. The <i>objective</i> of this program is to design, develop, and validate a powered exoskeleton system to assist elbow flexion in patients with traumatic peripheral nerve injuries who have inadequate motor function. Over the second year of this project, we have integrated the mechanical and electrical designs along with the myoelectric control algorithm into an alpha prototype of the powered exoskeleton.					
<b>15. SUBJECT TERMS</b> Peripheral nerve injury, brachial plexus, exoskeleton, orthotic, bionics					
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## 1. INTRODUCTION

Upper extremity peripheral nerve injuries accounted for 6% of all recorded battlefield injuries during Operation Iraqi Freedom. In contrast, amputations accounted for 2.7% of injuries. Upper extremity peripheral nerve injuries are the silent, unrecognized injuries that result in loss of function and sensation in specific patterns depending on the nerves that are injured. In the most severe form, a traumatic brachial plexus avulsion injury, all the nerves to the upper extremity are severed, resulting in an upper extremity lacking motor function and sensation from shoulder to hand. This injury is akin to a functional amputation; the extremity is present, but completely nonfunctional. Restoration of elbow flexion is the primary goal following brachial plexus injury since it is a critical motion for daily living. Multiple surgical options exist to achieve this goal. There is a delay of 6 – 12 months after surgery before muscle reinnervation occurs and muscle strength takes 2 years to mature. During this period a powered exoskeleton would be beneficial for assistance with functional activities. The **objective** of this program is to design, develop, and validate a powered exoskeleton system to assist elbow flexion in patients with traumatic peripheral nerve injuries who have inadequate motor function. This project addresses “optimization of Warfighter performance following limb trauma or loss”.

2. **KEYWORDS:** Peripheral nerve injury, brachial plexus, exoskeleton, orthotic, bionics

## 3. ACCOMPLISHMENTS

### • **What were the major goals of the project?**

This project has three specific aims.

- (1) Perform an analysis of the engineering requirements and design the powered exoskeleton
- (2) Develop an EMG algorithm that measures user intent
- (3) Perform efficacy testing of clinical patients using the system in a laboratory setting

### • **What was accomplished under these goals?**

The overall vision for the powered exoskeleton is a device that can be donned on the affected side with minimal weight supported by the affected arm, a low profile to allow clothing to be worn over the device, and a brake that allows the arm to be held in any position without the need for sustained muscle activity to hold the arm in a fixed position. The exoskeleton will be neurologically controlled by the user and respond directly to their intent to move via an EMG signal associated with initiation of muscle movement, which will be processed using a microprocessor-controlled algorithm. The battery, motor, and electronics is in a small backpack that the user will wear. The primary goal for the second year of the study was integrated the mechanical and electrical designs along with the myoelectric control algorithm into an alpha prototype of the powered exoskeleton. This goal has been accomplished as follows:

#### *Aim 1. Electromechanical design*

We designed a system that uses a motor, belt drive, ball screw and break-away mechanism to allow for volitional control of additional elbow flexion and passively lock the system to resist elbow extension (Figure 1). The motor control system is worn on the back and a Bowden cable is used to transmit the flexing force to the elbow.

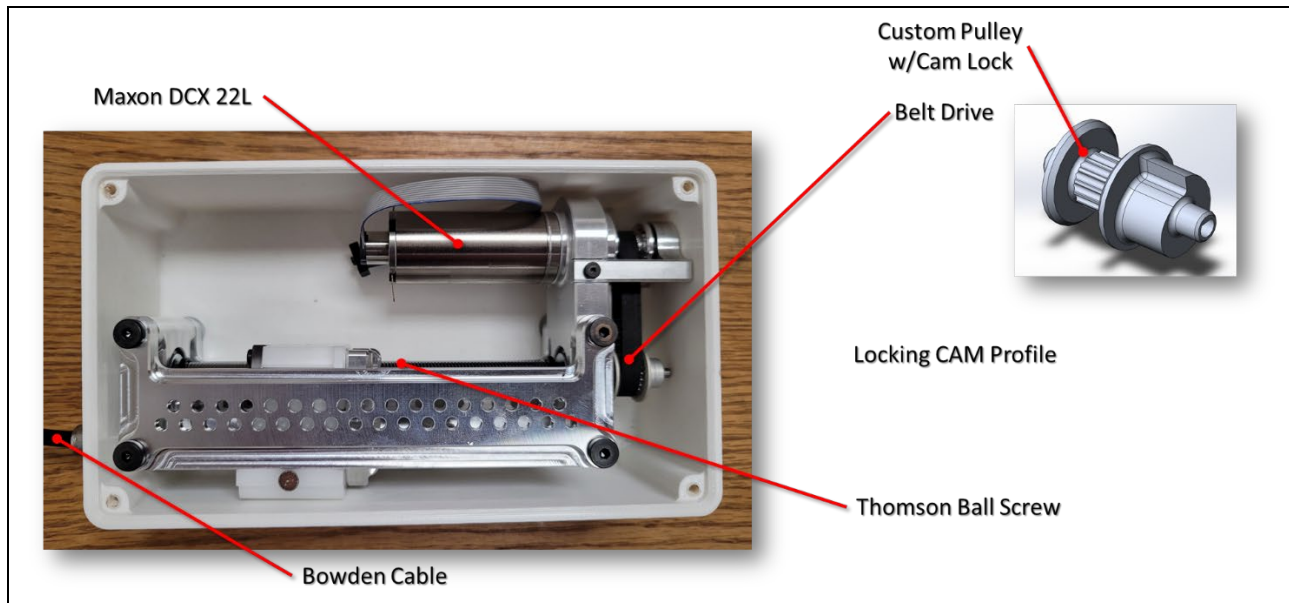


Figure 1. Ball screw drive and back drive locking mechanism.

A Thomson 1mm pitch, 8mm diameter ball screw was selected as the primary drive mechanism. The ball screw is linked to the DC electric motor via a 1.43:1 belt drive system. To prevent back drive, a custom pulley/cam/locking solenoid system was created to passively allow elbow flexion and passively resist elbow extension. A solenoid is activated to allow the system to drive in the elbow extension direction.

The elbow joint mechanism was designed to provide flexion assistance for either the left or right arm (Figure 2). The only modification required is the insertion location of the Bowden cable sleeve and a 180-degree reversal of the connection to the cable barrel end. A sensor aligned with the mechanism joint, will sense flexion angles.

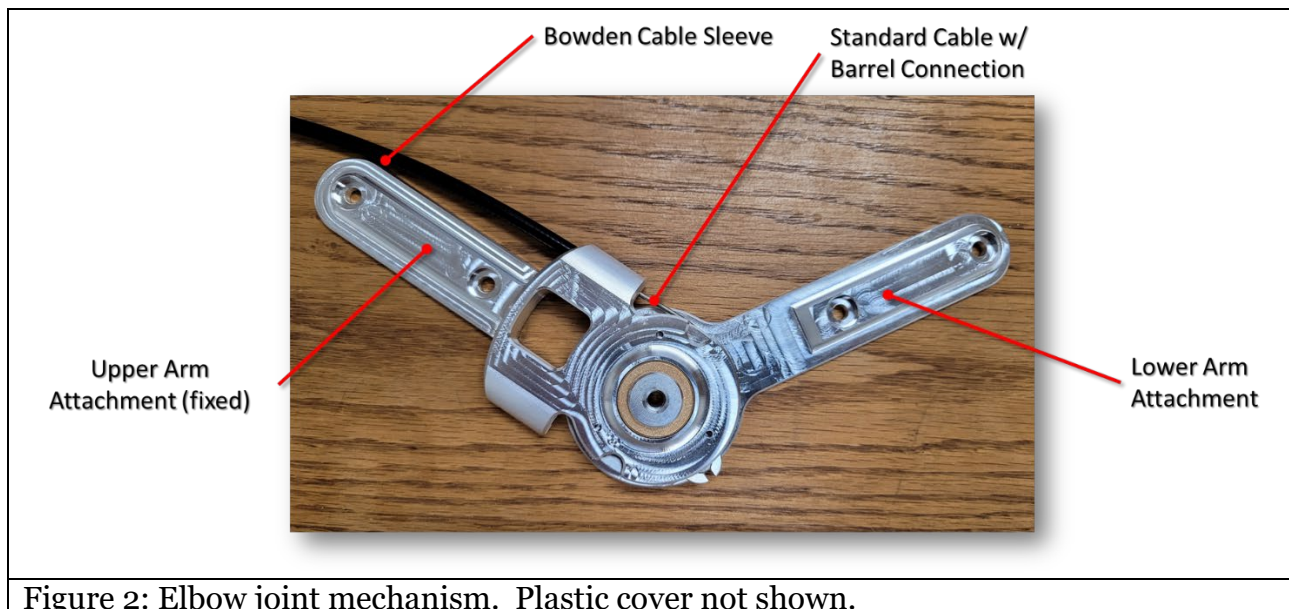


Figure 2: Elbow joint mechanism. Plastic cover not shown.

Safety Considerations: Numerous features were incorporated into the engineering design to assure safe operation by the user. These included the following:

Pinch points: Mechanical stops on actuator to eliminate pinch points and limit motion.

Release mechanism: If there is a loss of electrical power, it is possible to manually release the drive mechanism.

**Fail safe:** If the motor continues to operate without stopping, there will be a fail-safe stop to prevent the elbow from continuing to flex, which result in injury to the user.

**Electrical shutoff:** If the motor stays on too long, it will timeout and be shut off.

**Battery:** The battery cannot be charged while the system is being worn. There is a quick disconnect for the battery to facilitate changing batteries.

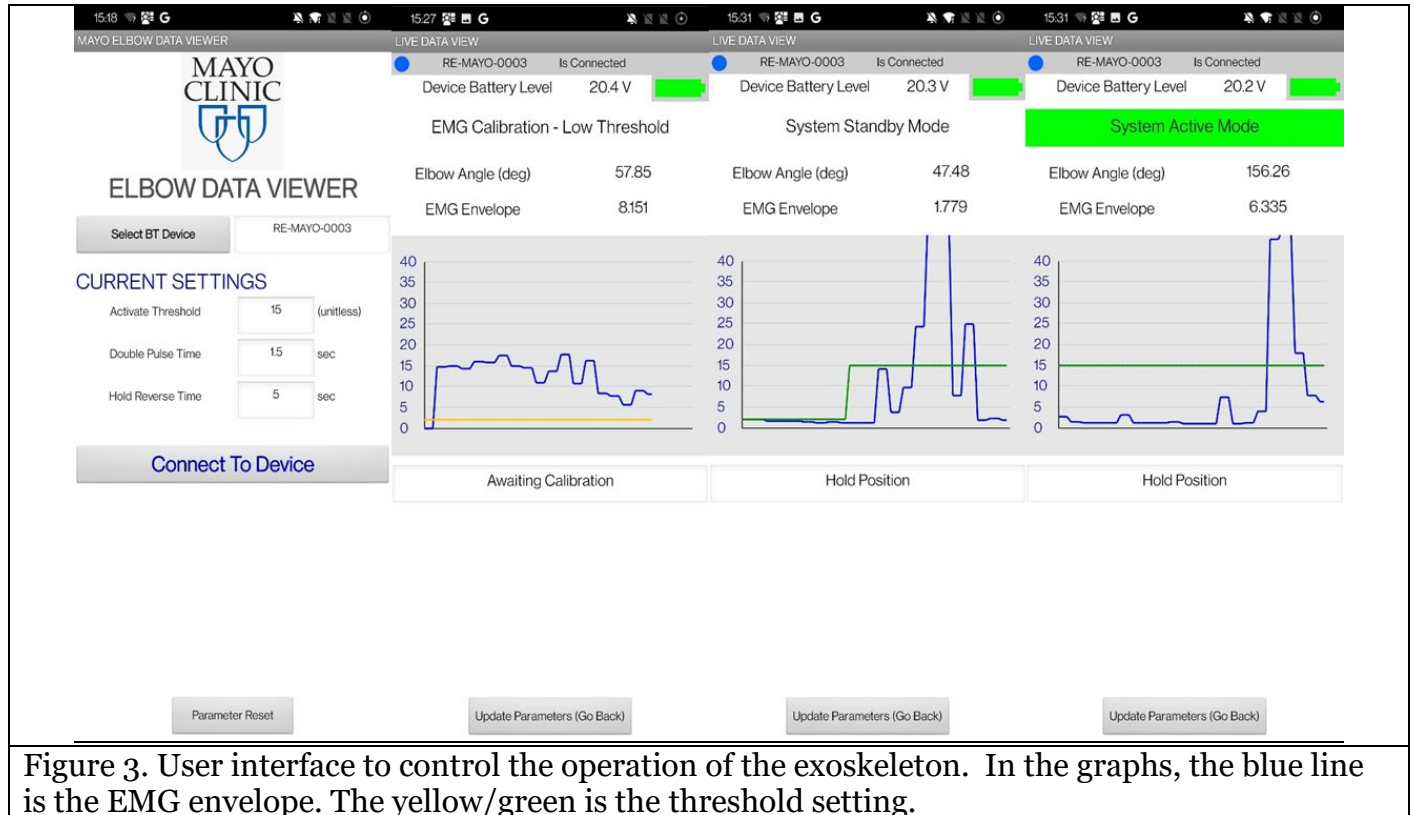
### *Aim 2. Control Algorithm*

The user will don the orthosis on their affected side and use their muscle activity to activate an electrical motor to provide the user power-assist, allowing them to achieve their desired movement. The electromyographic (EMG) signals will be collected and processed by a microprocessor-controlled algorithm and respond directly to the user's motion intention. The EMG is used to drive the motor and ballscrew to travel between lower and upper limits. The speed of movement is controlled by the magnitude of the EMG signal.

**Real-time Control system:** Programming has been done in the Matlab/Simulink environment. The robotic elements architecture and base system consists of

- Main control board w/microchip microcontroller
- Firmware for Maxon motor controller
- Bluetooth connectivity for wireless firmware updates, real-time data logging, and real-time parameter updates
- Base software in Matlab/Simulink

A custom Android application has been created to allow updating of key variables in the control algorithm (Figure 3). The application provides feedback on the operating mode, battery charge level, and EMG signal.



### *Aim 3. Prototype*

The prototype has been fitted to 3 unimpaired subjects (Figure 4). Each subject could operate the flexion mode successfully. The subjects were able to trigger the double pulse routine. It was determined that the double-pulse detection and isolation algorithm needs improvement.

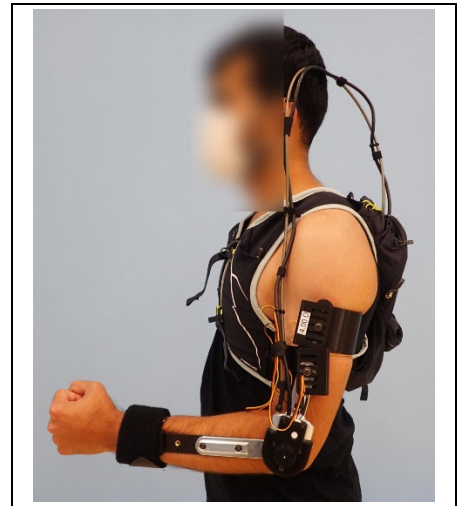


Figure 4. Prototype

- **What opportunities for training and professional development has the project provided?**  
Nothing to report.
- **How were the results disseminated to communities of interest?**  
No results have been disseminated at this time.
- **What do you plan to do during the next reporting period to accomplish the goals?**
  - Test the prototype operation. Identify and redesign components that require improvement
  - Revise hardware and software based on initial test results
  - Build beta prototype
  - Begin prototype testing
    - Recruit 10 subjects with a Brachial Plexus Injury and subsequent reconstructive surgeries
    - Custom fit powered exoskeleton to the recruited subjects
    - Test all the operation modes and safety features in laboratory
  - Publish a report describing the study

## 4. IMPACT

- **What was the impact of the development of the principal discipline(s) of the project?**  
Nothing to report.
- **What was the impact on other disciplines?**  
Nothing to report.
- **What was the impact on technology transfer?**  
Nothing to report.
- **What was the impact on society beyond science and technology?**  
Nothing to report.

## 5. CHANGES/PROBLEMS

- **Changes in approach and reasons for change**  
No changes to report.
- **Actual or anticipated problems or delays and actions or plans to resolve them**  
There may be electronic supply chain issues which would be a barrier to completion. Fortunately, there are none currently.

- **Changes that had a significant impact on expenditures**  
Nothing to report.
- **Significant changes in use or care of human subjects**  
None.

## 6. PRODUCTS

- **Publications, conference papers, and presentations**  
Nothing to report.
- **Website(s) or other Internet site(s)**  
Nothing to report.
- **Technologies or techniques**  
Nothing to report.
- **Inventions, patent applications, and /or licenses**  
Nothing to report.
- **Other products**  
Nothing to report.

## 7. PARTICIPANTS & OTHER COLLABORATING ORGANIZATIONS

- **What individuals have worked on the project?**

Name:	Kenton Kaufman, PhD, PE
Project Role:	Principal Investigator, Mayo Clinic
Nearest person month worked:	2
Contribution to Project:	Dr. Kaufman has held regular meetings with the study staff. He has led the design meetings. He has prepared materials for the Mayo IRB and HRPO. He has served as the liaison with the DOD and has provided the required quarterly and annual reports.
Funding Support:	

Name:	Sandesh Bhat, PhD
Project Role:	Post-doctoral Fellow, Mayo Clinic
Nearest person month worked:	12
Contribution to Project:	Dr. Bhat has served as an engineer for the project. He has work to test the mechanical design and implement the real-time control algorithm. He has attended regular meetings with the Co-Investigators.
Funding Support:	

Name:	Emily Miller, MS
Project Role:	Research Engineer, Mayo Clinic

Nearest person month worked:	3
Contribution to Project:	Ms. Miller has worked to develop the control algorithm. She attended regular meetings with the Co-Investigators.
Funding Support:	

Name:	Paul Kane, BS
Project Role:	Research Engineer, Mayo Clinic
Nearest person month worked:	1
Contribution to Project:	Mr. Kane has worked on the electrical design of the prototype He attended regular meetings with the Co-Investigators.
Funding Support:	

Name:	Thomas Sugar, PhD
Project Role:	Site Principal Investigator, Arizona State University
Nearest person month worked:	1
Contribution to Project:	Dr. Sugar is the ASU site principal investigator for the project. He attended all study meetings and coordinates the work being accomplished at ASU. The focus this year has been on the design of the prototype device.
Funding Support:	Sub award

Name:	Kevin Hollander, PhD
Project Role:	Consultant, Augspurger Komm Engineering, Inc.
Nearest person month worked:	3
Contribution to Project:	Lead mechanical designer. Dr. Hollander has twenty years of experience in designing orthoses, prostheses, and exoskeletons. He attends all study meetings
Funding Support:	Sub award

Name:	Bryan Carlton, MS Student
Project Role:	Graduate Research Assistant
Nearest person month worked:	1
Contribution to Project:	Design of the arm cuffs
Funding Support:	Not funded on the project

Name:	Claudio Vignola, PhD student
Project Role:	Graduate Research Assistant
Nearest person month worked:	50% GRA – 20 hours per week for two semesters
Contribution to Project:	Integrating the mechanical design with the microprocessor and electronics. Development of a phone application. He attends all study meetings
Funding Support:	Sub award

Name:	Alexander Boehler, PhD
Project Role:	Lead Electronics Specialist
Nearest person month worked:	1
Contribution to Project:	Mr. Alexander Boehler is an electronics expert in prosthetics and exoskeletons. He is developing commercial grade microprocessor units to control the motor and integrate the EMG signal
Funding Support:	Sub award

- **Has there been a change in the active other support of the PD/PI(s) or senior/key personnel since the last reporting period?**

No.

- **What other organizations were involved as partners?**

Nothing to report.

## **8. SPECIAL REPORTING REQUIREMENTS**

- **Collaborative Awards**

- **Quad Chart**

## **9. APPENDICES**