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Upper Extremity Sling for Dynamic Rehabilitation of Traumatic Brachial Plexus Injury

Client: Karen A. Blaschke OTR/CHR UW Health

Advisor: John P. Puccinelli, PhD

Team Leader: Kelly Hanneken

Communicator: Anthony Schmitz

BSAC: Marie Greuel

BWIG: Colin Dunn

Department of Biomedical Engineering

2130 Engineering Centers Building, University of Wisconsin-Madison,1550 Engineering Drive, Madison, Wisconsin 53706

608/263-4660 Fax: 608/265-9239 Email: bme@engr.wisc.edu http://www.bme.wisc.edu

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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 lifestyle, mainly running. We aim to create a sling that would adapt to patients at differing levels of rehabilitation. Three designs for the arm portion and two designs for the body anchor were created and evaluated. An arm and anchor design were selected and integrated to create a sling that offered support and allowed proper movement of the arm while running.

Background

The brachial plexus is a network of nerves that provides 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 the Ulna.[2] The anatomy of the brachial plexus is shown in figure 1 below.

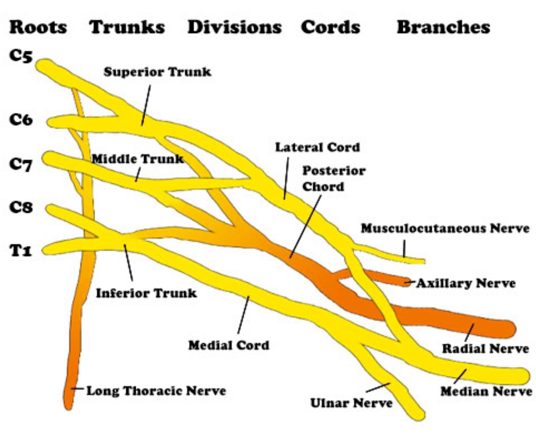

Figure 1: The anatomy of the Brachial Plexus[4]

An injury to the brachial plexus often results from trauma such as a sporting injury or a motor accident. Newborns can also sustain brachial plexus injuries during difficult childbirth and other conditions, such as inflammation or tumors may also injure the brachial plexus. Impact injuries result from a compression force is placed on the shoulder and head. These forces stretch the neck and thus the brachial plexus. The forces that result in overstretching are demonstrated in figure 2 below.[1] The severity of injury ranges widely. The nerve can be simply stretched or worse, completely torn. There are three main classes of nerve damage. The nerve root may be stretched, ruptured, or avulsed, where the nerve root is torn from the spinal group.[3] Rupture and avulsion almost always require surgery whereas a stretch injury may be successfully treated with therapy.[1] There are also different types of brachial plexus injury. Two main types of this injury are labeled open and closed. An open injury is often caused by a gunshot or blade wound. A closed injury is caused by traction or crushing. Common symptoms of a brachial plexus injury include paralysis, absent sensibility, and pain.[3]

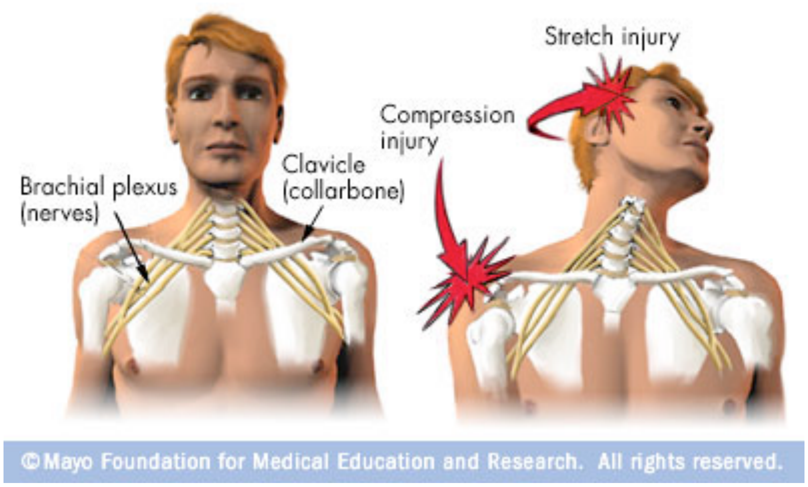

Figure 2: Image depicts a stretch injury. Compressive force to the head and shoulder.[1]

Several treatment options are available to treat the symptoms of brachial plexus injury. The nerve can either be repaired or reconstructed. A nerve graft is one of these options and is where the damaged part of the brachial plexus is removed and replaced with sections of nerves taken from other parts of the body. Similarly, a nerve transfer is done when avulsion has occurred. In a nerve transfer procedure the surgeon removes a less significant nerve that is still attached to the spinal cord and attach it to the nerve that has avulsed. Lastly if the arm muscle has deteriorated, a muscle transfer may be performed. In this procedure the surgeon removes a less significant muscle or tendon from another part the body and transfers it to the injured arm. Recovery of brachial plexus injury is variable.[1]

Problem Motivation

Currently, there are few dynamic slings on the market, and none that aid the motion of running. A dynamic sling that could support the shoulder during the motion of jogging would not only benefit individuals with brachial plexus injury but also other impact injuries that affect the shoulder such as rotator cuff injuries. We aim to design a sling that is comfortable and easy to use. We also hope to design a device that would be able to be modified for varying degrees of disability. Ideally, the design will be breathable, lightweight, and withstand washing. The design must encourage and allow proper running form.

Current Devices

There are various sling designs on the market to support patients of a brachial plexus injury. These current methods focus primarily on preventing subluxation of the affected shoulder and do not show a potential to be used in dynamic situations like during running or exercise.

Figure 3. Patient wearing the GivMohr sling. www.ncmedical.co3m

One device, the GivMohr sling, leads the field in its support of the affected shoulder.[5] This design consists of a figure-8 strap of webbing that loops around the anterior of the unaffected shoulder that focuses on correct anatomic alignment and emphasis of proper movement and function. Testing results have concluded that this device successfully reduces vertical subluxation without overcorrecting vertically or horizontally. Little horizontal support was identified through testing.[5] This device is recommended for static use only in late recovery periods of therapy, so this device lacks the dynamics support our team seeks. Also, the patient's hand is secured in a non-function position by holding onto a plastic handle. Even though this device properly supports the shoulder for static situations, a patient running while wearing the GivMohr sling will feel uncomfortable in this extended arm position. Specific aspects of this design can be replicated in our teams device including the locations of attachments and materials used.

Another device, the Rolyan humerus cuff, incorporates other design aspects to accommodate different anatomical support mechanisms. This device consists of an anterior and posterior strap connected from the humerus cuff to the uninjured shoulder straps. Through testing, this sling was successful at reducing vertical asymmetry of the injured shoulder, but was unsuccessful at reducing vertical subluxation and often led to restriction of circulation in the upper arm.[6] By observing this design, our team has sought after replicating the anchoring mechanism consisting of under-the-arm straps that connect in the back by an O-ring.

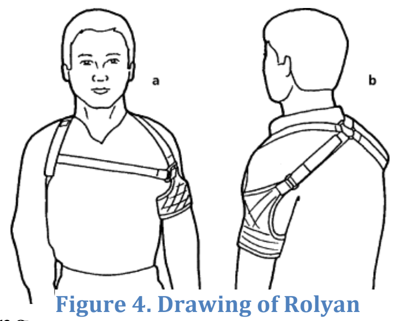

Figure 4. Drawing of Rolyan humerus cuff, posterior view.

Previous Design

In the fall semester, a dynamic sling to support brachial plexus injuries was first introduced. It consisted of several straps. The first is a 2 in wide strap that circling the chest connected by Velcro. The second strap goes from the chest of the uninjured shoulder, loops around a metal ring, and then crosses over the injured shoulder. Two Thera-bands of specific length and resistance were chosen to meet the necessities of the injury. One band ran from the injured elbow, up the posterior portion of the upper arm, and around the back to the uninjured shoulder. The other attached from the wrist to the strap hanging over the injured shoulder. Through testing, conclusions stated that this design successfully redistributed the weight from the injured to uninjured shoulder. Their design met the specifications they sought after, but modifications were easily

Figure 3. Visual of previous design team's device.. http://bmedesign.engr.wisc.edu/projects/file/?fid=2547

spotted. The sling proved to not be very breathable because of the tight and thick cuff mechanism in place. Also, the device was difficult to assemble and adjust due to the clipping method being implemented. Finally, the design was catered to one specific person and their body size. The team hopes to design a more universal sling for more uses than just running, to support multiple injuries, and have different attachment sites for personal modifications or preferences.

Design Specifications

The client has given our team specific guidelines to follow when developing our device. The main focus of the design will be to stabilize the shoulder in an anatomically correct position throughout the running motion. Proper arm movement and elbow angle and orientation are critical to mimic normal running. Anesthetically, the design must be visually appealing, breathable, washable, and not cause abrasions, chaffing, or restriction of blood flow. Recovery from a brachial plexus injury may take multiple years, so the device should last the entirety of the patient's therapy. The sling must be able to be worn with lightweight clothing and not weight down the user while running. Adjustments must be available to accommodate different body types and injuries. Easy of assembly is critical because the patient should be able to put on the sling by themselves and it must be simple enough that a list of assembly instructions in not necessary. Our design aims to produce one finished sling product while staying under a budget of $150.

Design Alternatives

Designs for Arm Section of the Sling

Sleeve

The first arm portion of the design considered was a full-length sleeve, with anchoring attachment points sewn on at designated areas. These attachment points will be placed at optimal positions to create the best arm stability and promote proper arm mechanics throughout the entire running motion. Yet, given the fact that these attachment points might tend to pull on

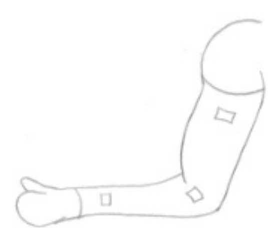

Figure 6. Illustration of the sleeve design.

the sleeve material when strapped to the anchoring system, their amount must be limited in order not to ruin the entire sleeve itself.

Cuffs

Multiple cuffs that incorporated attachment points to the anchoring system were explored as well. These cuffs would strap onto the patient at designated areas to promote proper arm alignment and arm swing mechanics while running. In addition, they would be made of Velcro, and could become easily adjustable upon desire. Overall, the cuffs allow for a greater amount of attachment points, and easy variability from one patient to the next.

Figure 7. Illustration of the cuff design.

Hybrid

Lastly, a cross between the cuff and sleeve design was considered. This design consists of a full-length sleeve that has a denser material running down its center. This denser portion of the sleeve would serve as a location for multiple attachment points to the anchoring system, thus promoting healthier arm mechanics throughout the running motion and eliminating the potential for tugging and tearing from the attachment points as seen in the plain sleeve design.

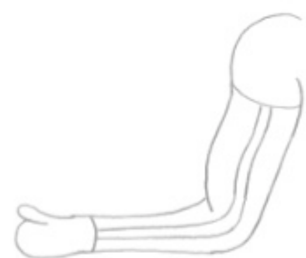

Figure 8. Illustration of the hybrid design.

Design Options for Anchoring Section of the Sling

Vest

The first anchoring system considered was a vest design. It's beginning appeal is that it works as a shoulder cuff, by securing to the injured shoulder and distributing its weight to the opposite side of the body through the strap that runs to the other side of the chest. In addition, its wide range of surface area makes it optimal for multiple attachment points that connect from the arm portion of the sling.

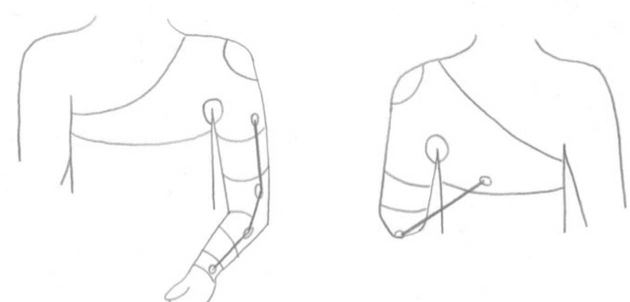

Figure 9. Illustration of the vest design.

The vest design could also be constructed out of two parts that connect through Velcro, a chest region and a back region. With these two regions separated, the sling can adapt to a wider range of sizes, be easy to put on, and can cater to multiple different body types.

Strap

The last option considered for the anchoring system of the design was a strap system. The straps will be sewn into a figure eight like approach, and the patient will place each arm inside either gap. Then, the mechanism can be tightened in order to pull the shoulders back, and the overall result will promote a healthier posture. Since this anchoring system is only made of straps, its surface area is greatly reduced, which limits the amount of attachment points that connect from the arm portion of the sling.

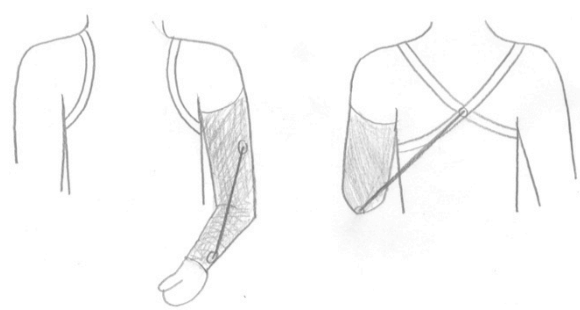

Figure 10. Illustration of the strap design.

Design Matrices

Both portions of the design were weighted based on the same criteria and scale. The mechanism category was given the highest weight, due to the fact that the slings overall purpose is to restore proper arm swing and running mechanics. Second, the ergonomics of the sling was given a high priority due to the fact that it must be comfortable and user friendly in order for the patients to actually want to run in it. Next, universality, ease of use, and ease of manufacturing all received a lower weight. Although it would be nice for the sling to meet the needs of multiple shoulder and arm injuries, be as simple as possible to assemble, and easy for the team to manufacture, all of those variables will not completely hinder the design as a whole if they cannot be not incorporated to the highest grade.

Arm Section Matrix

Category	**Weight**	**Full Sleeve**	**Cuffs**	**Hybrid**
Cost	10%	7	8	7
Ease of Manufacturing	15%	6	7	5
Ease of Use	15%	5	4	8
Universality	15%	4	7	8
Mechanics	25%	5	7	8
Ergonomics	20%	7	4	8
	Total Out of 10	5.6	6.05	7.3

As seen above, the hybrid design took the lead from in this design matrix. Its ability to incorporate many attachment points led to its high scores in mechanics and universality, while its sleeve portion gave it a higher ranking in terms of comfort and ease of use for the patient. However, it could become difficult to assemble when sewing the denser material into the sleeve for the attachment points, and its overall cost might be more than if the team were to have used cuffs.

The cuff design scored low in both the ease of use category, and the ergonomics category, because the team predicted that it could eventually cause chaffing and with multiple cuffs they could become easily confused when strapping to the arm. For the same reason as the hybrid, it scores high in both the mechanics and universality sections of the matrix.

Lastly, for the full sleeve design, the fact that it has a reduced ability for multiple attachment points gives it a low score in both the mechanics and universality categories. It also scores low in the ease of use section, because its sleeve structure could make it difficult to put on for people of larger arm sizes. This sleeve aspect does give the design higher scores in terms of ergonomics and comfort, and cost efficiency.

Anchoring Section Matrix

Category	**Weight**	**Strap**	**Vest**
Cost	10%	8	5
Ease of Manufacturing	15%	7	5
Ease of Use	15%	4	7
Universality	15%	6	8
Mechanics	25%	6	8
Ergonomics	20%	6	8
	Total Out of 10	6.05	7.1

From the final anchoring section matrix, the vest design won overall. Its large surface area permits for a variable amount of attachment points, and its shoulder cuff aspect gives it large scores in the large mechanics, ergonomics, and universality categories. In addition, since it will be made in two parts, the vest design will be easy to assemble onto the body for even a patient by themselves. But its complicated infrastructure, and contorted curves that allow it to fit comfortably around the body will make it difficult to manufacture, and possibly more expensive.

The vests competitor, the strap mechanism, came in second because it lacked the ability to provide as much mechanical, ergonomic, and universality. The mechanical and universality category suffered due to the fact that the limited amount of space it provides for attachment points could lead to a reduced ability to cater toward a wider range of disabilities, and a reduced capability to strengthen the arm swing mechanics during running. In addition, the figure eight strap structure could become easy to confuse and assemble onto the patient along with causing chaffing and abrasions to the skin. This strap structure does work in the designs favor, nevertheless, when considering the simplicity of its manufacturing and cost.

Final Design

The final design for the sling will incorporate a vest like chest anchoring system coupled with a hybrid sling and cuff system for the arm support. A representative sketch of the design is depicted in Figure 11.

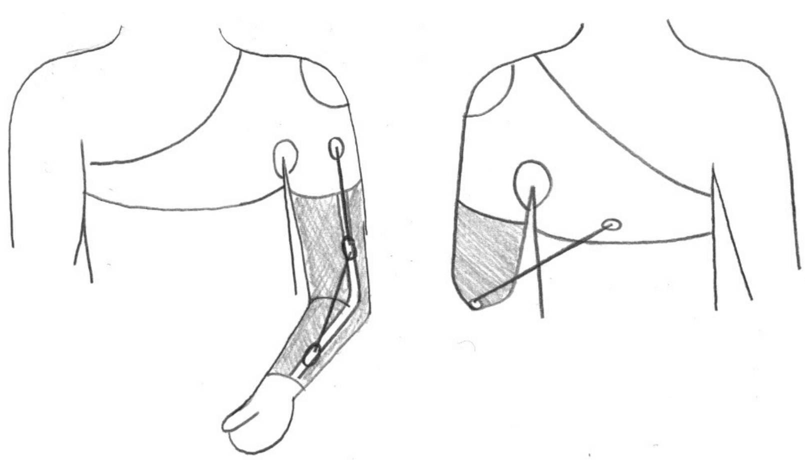

Figure 11. Shows a preliminary sketch of the final design.

The anchoring system will be made out of a slightly more rigid fabric such as neoprene to offer a strong supporting base for tensile support elements. This will allow for multiple connecting points on the anchor without a risk of material displacement that could result in a loss or decrease in functionality of the upper extremity support elements. The larger area also distributes loading across the material eliminating uncomfortable pressure points that could be apparent in other designs. The vest design also reduces the difficulty to put the device on for an injured patient because it is less confusing than a design containing multiple straps. Finally, this system also allows for a higher possible number of attachment points to vary the degree of support based on varying degrees of patient disability.

The arm support will be a sleeve made of a moisture wicking fabric technology with polyester anchoring elements incorporated into the fabric. This design enhances the ease of putting the device on because it is one continuous element, and the athletic material will also improve comfort during exercise. There are also multiple points for tensile support attachments that allow the user to vary the degree of support to their specific needs.

The goal of the tensile elements in this design will be to externally recreate the support generated by healthy muscle and connective tissues. There will be multiple detachable and variable strength supports that will act in the same way as the muscles of the affected extremity. This will allow for variability based on the size of the user, as well as catering to the specific muscles affected by the users injuries.

Testing

Currently, the design team has not reached the testing phase of the project. However, preliminary tests have been outlined for use later in the semester. The first testing that must be accomplished is a static and dynamic biomechanic analysis of the forces acting on the upper extremity. This will allow for determination of forces carried by different points on the arm during exercise and outline the required tensile forces needed to support the arm. The second aspect of testing the team hopes to accomplish after prototyping is analysis in the running lab using motion capture. This will allow for quantitative comparison between a healthy runner's arm, existing products, and the prototype. It will also allow for qualitative comparison of comfort between devices. These are only preliminary plans for testing and by no means exhaustive at this point. Other procedures may be determined and carried out later in the semester, as well a higher degree of specificity of testing protocol outlined above.

Future Work

The most pressing current matter is to conduct static and dynamic biomechanic analysis of forces acting on the arm to determine the load carried by each muscle group in the upper extremity. This will make material selection possible for the tensile elements. The next task will be determining the connection points based on our biomechanic analysis. The connection points will be an external representation of muscular force direction and orientation for each region of the arm and shoulder. After the anchoring locations are determined, sufficient material support must be analyzed at these points to ensure the material displacement and corresponding loss of function is minimized. The analysis will allow the team to determine materials with physical and mechanical properties necessary for success in the tensile system. Once this is completed, a prototype will be created and tested in the running lab. Motion capture will be done to determine the efficacy of the sling in supporting proper motion during dynamic movement. This will be compared to a healthy runner as well as existing slings. Comfort during this testing will also be qualitatively assessed to make ergonomic improvements to the design that is difficult to predict without testing.

Conclusion

Brachial plexus injuries cause a moderate to severe loss of function of the upper extremity in patients who have experienced a traumatic injury. Currently, full immobilizers are offered for patients who have recently suffered an injury or completed an operation. However, there are no slings that can offer support during the extremely important dynamic phase of rehabilitation. A preliminary design containing a vest and sleeve hybrid element has been proposed to offer comfort and support during this dynamic phase. Theoretical and physical testing must still be conducted to determine the efficacy of this design, but it will attempt of mimic the support offered by a healthy arm and shoulder through variable tensile support elements. This will allow for patients to enter a dynamic section of rehabilitation with the end goal of promoting healing to regain full active function of the upper extremity.

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Appendix

Product Design Specifications

Function:

The purpose of this design will be to create a shoulder sling to aid in rehabilitation and functionality of patients suffering from traumatic brachial plexus injuries. The device must have tensile support of major muscle groups throughout the upper extremity with the ability to vary the amount of support as well as types of support given due to the varying degrees of disability in patients with brachial plexus. In order to aid in the dynamic rehabilitation, the device must contain design elements that allow for a guided and supported natural running motion while having ergonomic specifications that keep the device comfortable during extended periods of exercise.

Client Requirements:

- A sling will be designed to give anterior and posterior support to the shoulder, especially in order to prevent slouching as to create proper body alignment while running.

- Adjustable for different body types and degrees of disability.
- Comfortable structure that does not cause abrasion or chaffing.
- Easy to assemble and secures properly to the body.
- Materials should be easy to clean and light in weight.
- If the user so chooses to exercise in the sling on average of four days a week, the sling should be able to last for three to five years.

Design Requirements:

1. Operational and Physical Characteristics

a. *Performance Requirements*: The support system should be focused on stabilizing the shoulder and keeping the arm in its proper place throughout the running motion. This includes keeping the arm directly at the side of the body, bending the elbow in a ninety degree angle, and creating arm movement from the shoulder.

b. *Safety*: The sling will be designed so that it will not restrict blood flow, cause abrasions, contain sharp parts, cause asphyxiation, or facilitate poor running mechanics.

c. *Reliability*: The sling should function properly throughout operation, and stay secured in its appropriate location.

d. *Life in Service*: The sling will be designed to last throughout a patient's recovery period. This varies depending on injury, but overall, this time span should be approximately three to five years, if the user so chooses to exercise in the sling about four times a week.

e. *Operating Environment*: The device should be able to withstand the outdoors while in use during exercising, including all types of weather conditions. In addition, the sling will be functional inside different indoor environments of the home, office, or gymnasium.

f. *Ergonomics*: The sling will not interfering with lightweight clothing, and will be adjustable and comfortable for patients of a medium to strong build (roughly 50 - 75 kg for women, and 70 to 100 kg for men). Also, the design will make it easy for patients to place properly on themselves without assistance.

g. *Size*: The size will be adjustable and made for adults of both sexes. This range covers chest circumferences of approximately 75 to 100 cm, and arm diameters of 22 to 40 cm.

h. *Weight*: The sling should not cause slouching or weigh down the arm due to an increased load. The target goal for the weight of the design is approximately 1.5 kg.

i. *Materials*: The material that makes up the design should be hypoallergenic, washable and easy to clean, and weather resistant. In addition, the sling should be relatively soft in places that it come into contact with the skin.

j. *Aesthetics, Appearance, and Finish*: The sling will be designed to look sleek and trim since patients will be wearing the device in public.

2. Production Characteristics

a. *Quantity:* There will be one finished sling product, that will have multiple replaceable components.

b. *Total Project Budget Cost*: The intended cost for the sling will range at approximately $150.

3. Miscellaneous

a. *Accessories*: The design of the sling will incorporate a utility pocket that will allow for the placement and security of mp3 players, keys, and or other small personal belongings.

b. *Market Approval:* If the sling is successful and reaches market potential, approval by the FDA is required.

c. *Competition:* The current design for a sling on the market that allows for a full arm swing throughout the running motion does not appear to exist.