Final Project Report

IPRO 332 Tournitech: Smart Clothing for
Sensing Muscle Development
Dec. 3, 2004

Project Team:
Instructor: Prof. Emmanuel Opara
Consultant: Ray Deboth
Team Members: Dan Latuszek, Hakan Ozmen, Alexis Dulinskas, Jotvinge Vaicekauskaite, Jonathan Beckmen, Craig Rohe, Jose Zamacona, Nate Godfrey, Wonsuk Chung

Introduction:
The original concept for this project came to IIT from Mr. James Adducci, he was exploring the potential for selectively promoting muscle development. As an experienced personal trainer he had been studying various research publications that focus on large muscle fiber development via arterial occultation. In this IPRO we focused on taking this concept into prototype development and the investigation of a target market.

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Project Background:
Most people exercise when their body is in a post absorbent state. In this state your body metabolizes carbohydrates and sugars through the process of glycolisis to produce energy in the form of ATP. An aerobic digestion of glucose will take place when oxygen is present; and anaerobic digestion will take place when oxygen is absent at the post absorbent state. While exercising, your body calls upon muscle fibers in an order of smallest to largest. There are two types of fibers within skeletal muscle. Slow twitch muscles, small muscle fibers that are used for high endurance activity, use an aerobic glycolisis process to form energy. When the oxygen supply is depleted in the muscles, your body will then call upon fast twitch muscle, large muscles that make an individual

stronger and faster with increased size, that are able to use stored muscle sugar through anaerobic glycolisis to produce energy.

Tournitech is a device that is applied to the proximal end of the arms and legs over the arteries. When activated, the device would apply a pressure between the systolic and diastolic blood pressure in order to restrict but not fully cut off the flow of blood. With this restriction of blood, less oxygen would be available locally. This means the slow twitch muscles would fatigue faster leaving the fast twitch muscle to work alone. Under anaerobic respiration, glucose is metabolized to lactic acid which causes pH to decrease. Decreased pH can cause fatigue and cramps over time.

Purpose:
This IPRO is the second of a two phase design project. Its objective is to continue the work of the summer 2004 IPRO 332 team, advancing from feasibility study and conceptual design to prototype development. Also a target market for this product will be investigated for which this product is both safe and effective.

Research Methodology:
Our IPRO team consisted of eight undergraduate students from diverse majors and back grounds. Four groups for the project were established in order to investigate what was determined to be the necessary areas of interest:

<u>Background/Research:</u>
Since there was limited knowledge of the physiology of muscle development a team was assembled in order to better understand the process that are occurring in the muscles. Also included in their investigation was the specific research that has been performed using blood restriction. The information gathered was provided to the design team and used to determine the appropriate consumer for the product.

<u>Monitoring Systems</u>
This group was to research the feasibility and state of current technology for monitoring pH levels in the muscles during the workout. Information gained from this investigation would be provided for further improvements to the prototype.

<u>Mechanical Prototype</u>
Using creative design ideas this group was to investigate how to produce a prototype that would produce a constant force from a mechanical device.

<u>Electrical Prototype</u>
Based on using an air bladder it was determined that the only way to safely and effectively applying a constant pressure was with a electrical device. This group was to develop and build such a device.

For communication the team met twice a week during the regular scheduled course times. Also yahoogroups was used for making files and information available to the entire team.

Assignments
Background and Safety- Jotvinge Vaicekauskaite, Alexis Dulinskas, Nate Godfrey
Prototype:
Mechanical- Jonathan Beckman, Hakan Ozmen
Electrical- Craig Rohe
Sensing- Jose Zamacona
Website- Dan Latuszek
Sketches- Wonsuk Chung

IPRO Project Team Tasks

<u>Research</u>

The information gathered from the scientific research papers is shown below and associated with the research article that it came from.

Effects of Resistance Exercise Combined with Moderate Vascular Occlusion on Muscular Function in Humans

Yudai Takarada, Haruo Takazawa, Yoshiaki Sato, Shigeo Takebayashi, Yasuhiro Tanaka, and Naokata Ishii

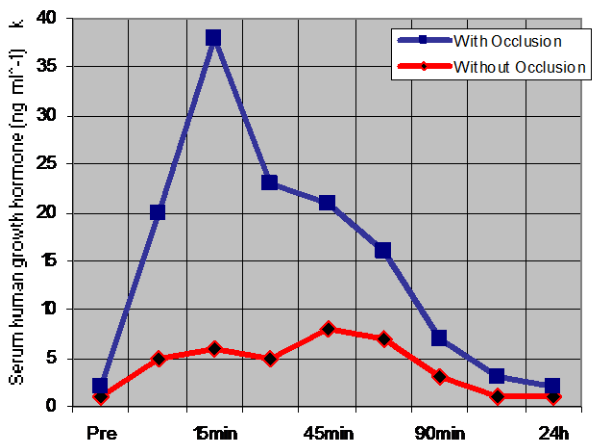
- Acute and long-term effects of resistance exercise combined with vascular occlusion on muscular function were investigated.
- The first investigation used 5 males between the ages 25-40 years old. The second investigation used 24 women between the ages of 47-67 years old.
- Arm occlusion pressure ranged from 0-100 mmHg.
- The occlusion cuff used had a width of 90mm and length of 700mm.
- It has been thought that the only way to gain muscle size was to use both high and medium intensity workout with a very short resting period between sets.
- During this study, the intensity used in the low-intensity occlusion exercise was as low as ~50% 1 RM (RM= repetition maximum), which is expected to be substantially effective. It was previously thought that intensity lower than 65% 1RM was not useful for gaining muscle strength and size.
- In spite of the low level of force generated, occlusion causes the activation of a sufficient number of fast-twitch fibers, which would be one of the requirements for gaining muscular size and strength.
- A combination of low-intensity resistance exercise and moderate vascular occlusion is potentially useful for accelerating the recovery of muscular strength in patients and aged people.
- However, further investigations need to be conducted to determine any harmful side effects. Micro damage to vascular walls and thrombosis are just two of the many effects being investigated.

Rapid Increase in Plasma Growth Hormone After Low-Intensity Resistance Exercise with Vascular Occlusion

Yudai Takarada, Yutaka Nakmura, Seiji Argua, Tetuya Onda, Seiji Miyazaki, and Naokata Ishii

- Hormonal and inflammatory responses to low-intensity resistance exercise with vascular occlusion were studied.
- The cuff used was 33mm in width and 800mm in length.
- During each set of exercises, the subjects performed the specific exercise until exhaustion.
- Growth hormone, norepinephrine, and lactate consistently showed marked, transient increases after the exercise with occlusion, but did not change a great deal after the exercise without occlusion.
- All of the concentrations dramatically increased after the exercise with occlusion, whereas they did not change a great deal after the exercise without occlusion done at the same intensity and volume as that with occlusion.
- The present exercise with occlusion may cause micro damage in vascular walls and or muscular tissues, this damage would be less serious than that caused by strenuous resistance exercise.
- These results suggest that extremely light resistance exercise combined with occlusion greatly stimulates the secretion of growth hormone through regional accumulation of metabolites without considerable tissue damage.

Growth Hormone vs. Time



(Graph 1) Graph representing the change in Growth Hormone with occlusion vs. without occlusion.

- Resistance exercise combined with vascular occlusion, even at an extremely low intensity, causes enhanced muscular electrical activity and endocrine responses.
- The peak concentration of Lactate after the exercise with occlusion was twice as large as that after the exercise without occlusion
- Although the possibility of serious tissue damage was excluded, further studies are required on fine micro damage in blood vessels and subtle changes in blood flow, both of which may stimulate thrombosis.

Low-load Resistance Muscular Training with Moderate Restriction of Blood Flow After Anterior Cruciate Ligament Reconstruction

- An increase in the strength and size of normal muscles, a load of more than 50-60% of one repetition maximum, has been considered necessary.
- Recent reports have indicated that if muscle training of a limb is done during moderate restriction of blood flow produced by an air tourniquet worn on the proximal portion of the limb, then even low-load resistance muscular training may induce the same increase and enlargement of the muscles as high-load muscular training.
- The air tourniquet was used on the proximal part of the thigh and a pressure of about 180 mmHg was used.
- Recovery of muscular strength after surgery is most important for an improvement in knee joint function and rehabilitation for performance in athletics.
- Takarada reported that low-load resistance muscular training performed with an appropriate restriction of blood flow induced the same muscular augmentation and enlargement as high-load muscular training.
- Significant recovery was seen 4 months after surgery. The effect is due to restriction of blood flow.
- Muscular training under a pressure of 180 mmHg exerted by a tourniquet was accompanied by slight discomfort and dull pain in the lower extremities during training.
- No other complications were seen to be caused by muscular training during blood flow restriction.
- Training during moderate restriction of blood flow is effective in rehabilitation after ACL reconstruction. This mode of training is not limited just to rehabilitation after ACL reconstruction, but also in training atrophied muscles in general.
- Problems still remain unsolved. Discomfort or pain during training due to the tourniquet and the possible effects on the circulation including thrombosis and edema still need to be investigated.

<u>Monitoring Systems</u>

Mechanical Prototype

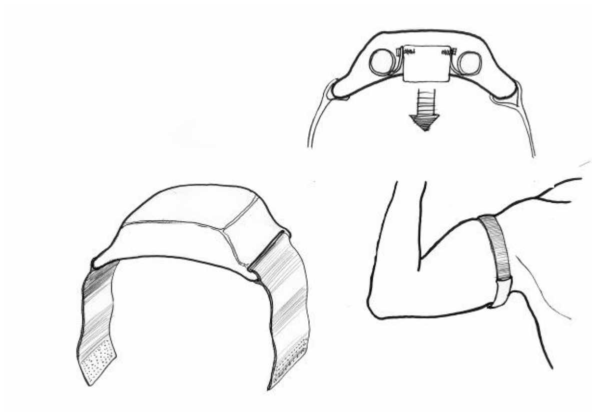


Figure 1: Schematic drawing of the mechanical prototype.

One idea for a prototype was a mechanical design, which used no electrical components, and therefore would be inexpensive and easy to produce. The mechanical design strips the concept down to its basics. We looked at a means of simply applying a force to the artery with no other gimmicks. The design helps one to understand what really happens with the tourniquet.

The idea was first brought up when the idea of a constant force spring was discovered. This is a spring that will always apply the same force at all times, as opposed to a traditional spring which has a varied force depending on how long it is stretched. A good example of a constant force spring is a tape measure. The force is applied where the tape bends, and no matter how far the end is extended, there is no change in the force needed to extend the tape. Our initial plan was to attach the spring directly to the strap. We realized, however, that to achieve a constant pressure, you must have a variable force for different strap sizes. So a conventional spring, with a certain *k* value, was our next idea. This plan was dropped because we realized that he strap could not be adjustable. Only the spring could stretch, and this was not a large enough adjustment to accommodate the large variations in arm diameters. Our final idea is a combination of these old ideas.

In the end, we went back to the idea of using a constant force spring. We attached two constant force springs to a block that would serve as the means for applying the force to the arm. The block is simply aligned over the correct part of the arm and the pressure will be applied to the artery. To design this, we took the known pressure requirements and designed the force of the spring and area of the block to match it. Since the area of the block is constant and the force of the spring is constant, the same pressure will be applied at all times. Flexing your arm or muscle growth over time will not change the pressure, which is what we were going for.

We then took block and spring structure and attached it to a strap as a basic prototype. In the final design, the block will be locked into place and the strap attached to the arm. The block can then be released by a switch, and begin applying pressure to the artery. At this point the workout is performed, and the strap can simply be removed when finished.

Again, this is a basic design. There still are many modifications and improvements that could be made. There are also factors that we did not incorporate into the design. However, the electrical design improved upon this idea and took the design a few steps further.

<u>Electrical Prototype</u> – Electronic Controlled Air Pressure Prototype:

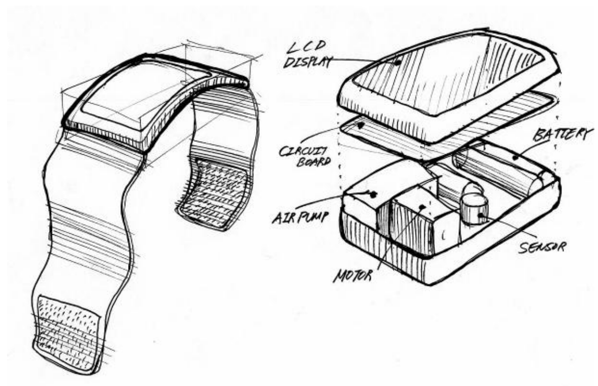


Figure 2: Schematic drawing of the electrical prototype.

One of the original concepts for the restriction device consisted of an air bladder that was pumped up to a predetermined pressure. This pressure would be held constant during a workout session to allow only a partial blood flow into the target muscle groups. A bladder setup was devised using only a small manual pump and some pressure release valves for protection. During some preliminary testing, however, we discovered that flexing and movement caused the pressure to fluctuate (higher than the initial pressure). We also found that certain inadequate bladders lost pressure over time. In all, there are three main problems with a manually controlled bladder:

1) An overpressure valve is required for safety, so that a user cannot over inflate the bladder and cut off all blood circulation. Because the pressure can increase for short periods of time during flexing, this valve would release air and render the device useless without constant inflation.
2) There is no way to alert a user to under pressure (short of a bulky pressure dial on the cuff). The bladder could easily fall below the desired pressure and become ineffective.
3) Restriction of blood flow can be a good muscle growth technique if used properly. However, extended periods of reduced blood flow can easily damage tissues and kill cells. With a manual device, the user is required to manage the time interval of use. It may be too easy to leave the device on long enough to cause damage.

These problems led us to use an electronically controlled pressure system, consisting of a control circuit, small electric air pump and solenoid release valve. A microcontroller constantly monitors the pressure in the bladder, and can make any adjustments necessary.

It initially pumps up the bladder, and can make any adjustments necessary. It initially pumps up the bladder to the desired level (around 100 mmHg.). Once done, the user can begin to exercise. During the workout, small spikes in pressure can be ignored and no air is released. If the bladder falls below pressure, the circuit can turn on the pump to keep it at an effective level. In addition, a microcontroller can measure the amount of time elapsed, and automatically release pressure in the bladder and end the workout before any dangerous conditions occur.

Other improvements to be considered in the future:

A) Two small sensors, spaced a distance apart on the armband, could be used to sense artery pulses and help the user place the bladder directly over the veins on the underside of the arm. Using this technique, the bladder size could be drastically reduced, and thus decrease the size of the air pump and battery pack. Allowing the control unit to be further miniaturized (pump and batter are the largest components in the design). The sensors for armband placement are feasible in production, but will not be included in the prototype simply due to size and complexity. A prototype is generally more bulky and constructed by hand and this addition would be too difficult with the resources and time available to our group.

B) Using a lactic acid or glucose (pH) sensor, actual conditions in the blood stream could be monitored, and the device could respond according to preprogrammed settings and excess acid or sugar levels. There are currently no economically fe3asible lactic acid/glucose sensors for such a device. These sensors may be available in the near future, and this idea should be revisited. Instead, the pressure level and duration of use will be determined based on research studies of lactic acid and glucose levels to ensure the dangerous concentrations are not reached.

C) A customization interface would also be a simple addition. In the form of an LCD and few buttons, the user could adjust settings such as pressure limits, duration of workouts, and possibly pH level limits for the device. This would allow any user to obtain a more effective workout by running the armband to their specific needs.

D) Gyroscopic generators are available today in commercial products such as watches and flashlights. These devices use motion to create an electrical current which usually charges a battery. Because the nature of our product is used during movement, it is possible to incorporate such a device to the armband. This generator would then either produce all the electricity needed for use, or (more likely) charge the battery at a slower rate than energy is being used. This would at the very least extend the lifespan of the battery and make the armband more cost effective to operate.

Microprocessors in applications such as these are now relatively inexpensive and offer many advantages. Even after the prototype is built, pressure levels, time intervals and safety measures can be adjusted simply by changing a few lines of code. Tweaking, testing and customizing of such a device would be easily accomplished. Microprocessors today are designed to run on battery power and have only minimal energy requirements. The bulk of the batter power will go to the air pump, which can be reduced using a smaller bladder and other conservation techniques. In turn, the size of the batter will also decrease substantially, and the entire control unit can be built in a very small, unobtrusive package suitable for strapping onto an arm or leg.

Figure 3: Final electrical prototype.

Barriers and Obstacles

In the beginning there were two major obstacles that prevented quick advancement of this project. First we lacked a student from the summer IPRO that could provide a smooth transition from the ideas and information collected to be incorporated into the advancement of this semester. Second we lacked a student from the Life Sciences department with more of an understanding of the basic physiological processes occurring.

However more related to this project we faced the issue of finding related scientifically based information. Occultation for muscle development is both relatively new and somewhat controversial. Furthermore the information that was found had to be analyzed and presented in such a way for our group who had little experience in the field of exercise physiology.

Results and Conclusions

Both prototype groups were able to come up with creative design solutions. These results could be compared to determine the best fit to this application. The sensing group was also able to discover a new solution for measuring muscle activity. It was determined that pH could be measured to determine when the muscle is within the optimal training zone. Finally the Safety and Background group was able to use research in determining an appropriate use for such a controversial product.

After reviewing the advantages of both the mechanical and electrical prototypes the electrical prototype was selected as the most effective solution. It was chosen because it could have more safety features incorporated in its final design. It was also determined that the effects of this product, with low intensity exercise, are similar to those of traditional high intensity exercise. The advantages that it does provide are with rehabilitation and those with limited ability to lift large amounts of weight. This will also allow for a group to be monitored for overall physical health. Certain side effects or long term effects of this product can be monitored and prevented.

Recommended Next Steps

The next step for this project is to miniaturize the overall design of the electrical prototype to a size more suitable for a marketable product. Continued research into the long term effect and optimal pH levels investigated. With pH levels defined the added safety feature could be included in the final design. Finally a new name for this product should be determined to get away from associating this product with a tourniquet that has been the cause of loss of limb.

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